Consultancy Services for the Plant Audit in various Pump Stations and Reservoirs (OP18REFCS03)

Technical Report for R1P Pump Station

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GHD Ply Ltd.

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Author(s):
Nam Le (PhD), Peter Vasquez, and Drex D. Torre

Reviewer(s):
Nam Le/Paul Hansfold

Director(s):
Paul Hansfold

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Executive Summary

The station was received a major rehabilitation/upgrade in 2017, thus, there has not progressive deterioration and degradation observed to date. The study was based on preliminary assessment on historical corrective and preventive intervention records prior to 2017 together with the operational data.
Based on the results of testing and reliability analysis, GHD recommends to execute a set of preventive intervention program that involves periodic replacement of pump components and frequent inspection/testing to collect historical data sufficient to estimate the reliability of pumps and the system.
Furthermore, GHD recommends Maynilad that optimal time window to execute the intervention program shall take into consideration of network analysis which will enable Maynilad to set priorities to perform intervention program not only for Pagcor station but also for other stations. In addition, Maynilad might consider to combine intervention programs of a group of stations as it will be also optimal when preparing the bid.

Contents

Chapter 1

Introduction

1.1 General introduction

The station is located in Alabang Village, Muntinlupa City (refer to Figure 1.1). It has a total capacity of 45 MLD and delivers treated water to the discharge line serving the vicinity. Pump gallery is shown by Figure 1.2.

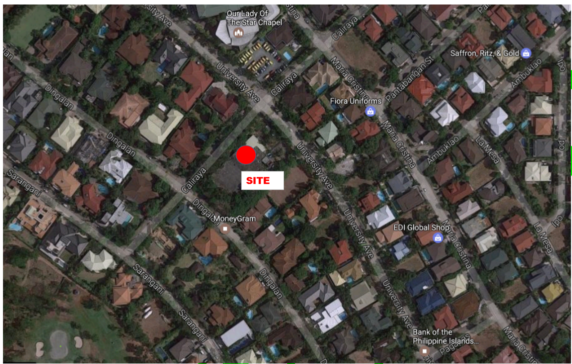


Figure 1.1: Location: Caliraya St. Corner University Avenue, Ayala Alabang, Muntinlupa City

Figure 1.2: Pump gallery

Recently rehabilitated in 2017, this PS has been included by the Client in the first cluster of pump stations for systems audit, benchmark establishment and asset management.

The Client has therefore awarded GHD and its sub-consultants (RB Sanchez and APSI) to conduct a plant audit project with an expectation to establish rigorous asset management framework based on reliability study and to determine optimal intervention program for the next five (5) years.

1.2 Objectives

The objectives of this work are as follows

- To evaluate the current operating condition of PS as compared to the original design intent and to provide recommendations for improving the operational efficiency and lowering operating cost;

- To be able to determine an optimal intervention program for the PS in the next 5 years with reference to the recommendations from the assessment and audit based on life cycle cost; and equipment efficiency study whether the equipment is subjected to replacement or repair. These equipment are:
  - Pumps;
  - Motors;
  - Generators;
  - Electrical System and Protective Device;
  - Substation (Transformer, Switchgears);
  - MCC (VFDs, Soft starters, Circuit Breakers, and Protective Devices);
  - Motorize Valves.

1.3 Scope of Work

Scope of Work (SOW) has been defined in the Contract Agreement and be in compliance with the GHD technical and financial proposal and the agreements made during a number of project meetings (refer to minutes of meeting of the project).

It is important to note that the electrical audit and analysis is not part of this report but will be included in the next revision.

1.4 Limitations

Results of the study with analysis, conclusion, and recommendations are only within the scope of work and agreements, and particularly under the following major constraints:

- Operational constraint: It was not possible to shutdown the entire PS for visual inspection of assets, particularly mechanical assets;
- Incomplete historical data: It was a matter of fact that Maynilad has not established an asset management system, thus data regarding historical intervention is limited and incomplete, leading to non-optimal reliability analysis;

1.5 Glossaries

Following glossaries are defined and used in the report:

Level of Services (LOS)

A Level of Services (LOS) is any value or expectation of asset managers and beneficiers regarding the functionality and serviability of an asset of a system of assets.

Intervention

Intervention is a generic and global term used to refer to non-physical and physical activities on assets. It encompasses do-nothing, or do somethings like repair, maintenance, rehabilitation, renewal, investment, and inspection and testing.

Corrective Intervention (CI)

A Corrective Intervention (CI) is an intervention executed without proper and systematic plan. An CI is often incurred by failure/breakdown of assets. In most of cases, it incurs significant negative impacts (e.g. cost to repair, disruption of service, loss in revenue).

Preventive Intervention (PI)

A Preventive Intervention (PI) is an intervention executed with proper and systematic plan. Note that an PI is executed on asset that is still working but not provide adequate level of services.

Intervention Type

An Intervention Type (IT) is a specific and well-defined type of work/task that can be executed on/for an asset (e.g. replacement of a bearing for a pump).

Intervention Strategy (IS)

An Intervention Strategy (IS) is a set/collection of intervention types.

Intervention Program (IP)

An Intervention Program (IP) is a set/collection of intervention strategies for one asset or more than one assets of the same system.

Work Program (WP)

A Work Program (WP) is an execution program consisting of Intervention Program and management program (e.g. project management, procurement) that shall be implemented in order to realize/actualize the Intervention Program.

Chapter 2

Preliminary Assessment and Data Gathering

GHD conducted preliminary assessment on a set of data provided by Maynilad. The data set includes a number of records on daily production and power consumption and intervention reports issued after Maynilad experienced failure/breakdown of assets.

The assessment provided a base for GHD to generate the Inspection Testing Plan (ITP) [6, 7] aiming to gather necessary data for conducting reliability study. The ITP has been reviewed by Maynilad, together with the Work Safety Permit (WSP), prior to execution of visual inspections and testings at the site.

2.1 Maynilad's data

Maynilad provided a set of data as shown in Table 2.1

Table 2.1: Data provided by Client.

No.	Data	Remarks
1	As-built drawings	Contains CAD drawings of recent rehabilitation
2	Monitoring Dashboard	From years 2015 to 2017
3	CI Records	Contains only one file dating back to 2016 when pump station not yet rehabilitated
4	Asset registry	Asset registry was incompleted as confirmed by the IAM team of Maynilad.

2.1.1 Intervention records

The current format and structure of the monitoring dashboard somehow presents difficulty in useful and consistent use of the dashboard. Entries are varied and input consistency is low. On which monitoring activity, test and on which part is not readily determined. There is a need browse the item individually. These show that the dashboards may not be really performing its function as a monitoring tool but rather simply is a log with varied maintenance with low consistency.

Particularly, the most important historical data concerning specific failure of components of pumps with elapsed time is missing. Thus, the provided information is not useful for detailed reliability study on frequent failure of assets at component level.

The problem with missing specific failure data was due to a matter of fact that Maynilad still has not come up with preventive maintenance program within the overall asset management framework. The IAM team has recently established with expectation to generate short-term, medium-term, and long-term preventive intervention program. In close discussion with Maynilad, GHD learns that Maynilad has a regular/frequent activities for check-up (e.g. monthly and quarterly), however, recorded data has not been digitalized and the data itself has not aligned well with the asset registry.

There is no significant data to be found on the monitoring dashboard relating to the pumps currently installed in the station since all logs date back before rehabilitation and the pumps were replaced during the rehabilitation.

2.1.2 Interview data

GHD conducted an interview session on 07/12/2018. Results of the interview are summarized in the minutes [4], with the following highlights.

- No further data is available aside from the provided set presented in earlier section;
- There is an existing regular check-up for assets but data is not digitalized and the information is only generic;
- Spare parts are not stocked for most of components, except for bearing. Regarding service delivery, the required discharge pressure remains the top priority in pump operation modulation and sequencing. Critical parts and components for VFD and bearing are usually stacked to have spared in case of emergency repair and replacements. The consumables on the other hand, are not stacked but ordered in advance for use in maintenance activities;
- No visual bank of assets;
- No standard testing regime that follows a regular scheme based on optimality;
- Pumps are operated based on pressure and not manual;
- No existing PI/CI procedure to be followed;
- No expansion plan is forecasted;physically impossible to add another pump in the existing pump room
- There is a problem with the inflow of incoming water, leading to lower level of reservoir chambers that has affected pump operations occasionally;
- no historical data on pump efficiency, which is a simple yet useful value in determining pump performance. The main impediment in the individual pump efficiency is the measurement of flow produced by each pump. The existing configuration of the pump-motor and piping system do not cater to conventional methods of flow determination;
- No intervention records for FDAS. It was revealed that different version on operation and functionality of the FDAS was reported by both guard and site operators.

2.1.3 Asset hierarchy

During the bidding phase, Maynilad did provide the first draft of the Asset Registry (AR) that describes a hierarchy of eight (8) levels. Figure 2.1 visualizes the hierarchy with brief description presented in Table 2.2.

GHD received the latest version of the AR with 101 assets for this PS. The full list of assets is given in the excel file provided by Maynilad in 2018. GHD has developed a MS Access program to convert the data in the excel file to a relational database structure. Per agreement with Maynilad, GHD will only verify level 7 of the AR with the actual site condition for the study [5].

2.2 Preliminary assessment

Assessment on the lastest provided intervention records reveals that the provided pertinent data is incomplete and cannot be used as representative data for a complete reliability study.

It is also confirmed from the provided data that the Client has done regularly check-up on GENSETs to ensure that it provides adequate level of services in case of emergency. To date, no failure records has been observed for the GENSET.

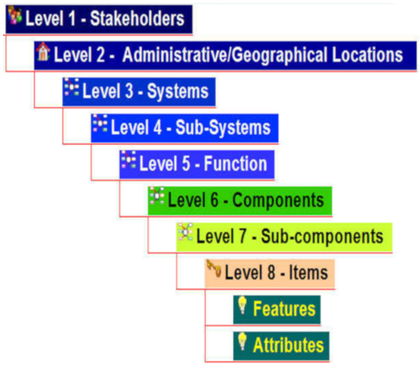


Figure 2.1: Asset Hierarchy

Table 2.2: Condition state definition - Multiple.

Asset hierarchy	Description
Level 1	Stakeholder level. For example, an pump station belongs to MWSI
Level 2	Geographical locations/ or administrative zone (e.g. a pump station belong to Quezon city or Makati)
Level 3	System (e.g. the entire pump stations and reservoir system)
Level 4	Sub-system (e.g. one specific pump station and reservoir such as the Lamesa PSR)
Level 5	Functional system (e.g. booster system or storage system)
Level 6	Component (e.g. Suction line, Reservoir line and Tank)
Level 7	Sub-component (e.g. Suction pipe and fittings, Concrete reservoir, pump)
Level 8	Items (e.g. valve, bearing, motor)

Further evaluations and tests have to be conducted to identify the areas for improvement of preventive measures in mitigating corrective measures and study the ways to strengthen preventive measures to improve operating conditions and life of pump components.

Improving the reliability of the pump stations for the next coming years require evaluation of the existing pump station conditions and maintenance practices, particularly assessment of the pump and its components. With that, areas for improvement of operation and maintenance be addressed through action items that come from the resulting recommendations.

In order to capture a relatively good picture on the reliability of the pump system and its associated assets, a number of tests shall be conducted.

2.3 Summary of the inspection test plan (ITP)

A complete write-up on testing shall be referred to the ITP [6, 7], which has been submitted, reviewed, and approved by the Client. This section only provides highlights to help readers keeping abread of the flow of the report.

2.3.1 Mechanical Audit

The Mechanical Tests to be conducted are enumerated and discussed hereunder including their background and applications, standards used if applicable, and the equipment to be used. During testing, the following are the assumptions and considerations:

- The operation of the pumps cannot be interrupted (at day time when demand is high).
- The valve settings then cannot be adjusted to produce different flow rates.

2.3.1.1 Structural Inspection for Pump Discharge and Suction Line

This activity measures the current thickness of the existing pipelines at the pump vicinity using ultrasonic thickness gauging. The flow regime especially around the elbow and possibly corrosion and scaling conditions are to be predicted from the measurements of this test.

Following procedures will be executed

Step 1: Locate and mark testing points

At a minimum of two (2) meters away from the pump intake/discharge flange, the test points shall be marked at 3, 6, 9 and 12 o'clock positions and at one (1) meter interval along the pipes, additional test sections with same set points shall be added as long as available beneath the immediate ground level (Figure 2.2 and Figure 2.3). Note that there will be no testing at sections indicated in the figure as it falls on the control valve. The next 1 meter away from the pump flange will be considered instead.

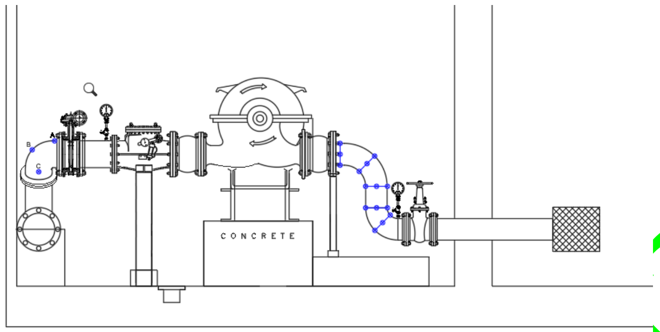


Figure 2.2: Tentative pump layout and testing points

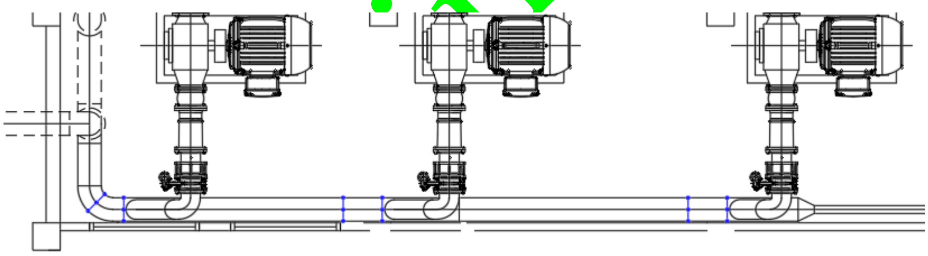


Figure 2.3: Tentative pump testing points

The test points shall also consider elbows on probable points of most thinning from turbulent water flow.

Step 2: Prepare test point surfaces

- Wipe the surface free of dirt (no need to remove paint)
- Using a chalkstone (erasable), mark x on the test point

Step 3: Apply sufficient couplant on test point surface

- Use petroleum jelly/Vaseline as couplant

a - 01

b -02

Figure 2.4: Reading pipe thickness on set points using UTG

Step 4: Set transducer probe on test point

Step 5: Read and record value as indicated on module display

(Figure 2.4 - 1 and Figure 2.4 - 2)

Step 6: Clean test point after reading

2.3.1.2 Unit Flow Measurement

The activity measures pump capacities. Pump efficiency is then calculated using the measured values.

Step 1: Locate Sensor Position Point Area and mark all points to be taken.

- Observe required offset distance from fittings/pump to consider the fully developed flow. At least 10 times the diameter distance away from the suction/discharge of the pump if applicable, otherwise consider at least 2D distance away from the fittings. This is to ensure the flow will be stable and fully developed for flow measurement accuracy (Figure 2.5 - a and Figure 2.7 - b).
- Otherwise, test at near turbulent zones and consider normalizing the flow.

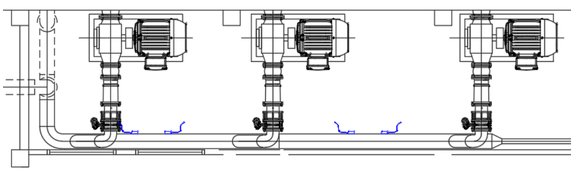


Figure 2.5: a - Set points

Figure 2.6: b - UFM probes

Figure 2.7: Flow measurement using UFM

Step 2: Pipe Specification Input on the Flow Meter.

- Identify nominal pipe size with equivalent parameters such as schedule designation, equivalent thickness, OD, and etc.

- Input outside diameter.
- Input pipe thickness.
- Input pipe material (carbon steel).
- Input pipe medium (water).

Step 3: Prepare test point surfaces

- Clean the surface of pipe with a sandpaper and steel brush or any suitable abrasive materials, exposing the base metal.

Step 4: Install transducers at set points

- Apply enough couplant that it covers transducers sensors to ensure an acoustically conductive connection to the pipe. Also apply couplant on the test point surface
- Clamp the transducers at the side of pipe using metal chains, straps or mounting rails Observing proper spacing and alignment. Note flow direction and install transducers at either 0 or 45 degrees, whichever would give more stable reading.
- Wait for the module to display "System Normal" before reading. Inspect set-up for any fault and properly reinstall if signal is poor/low (no reading)

Step 5: Data gathering

Read and record all necessary data measurement by the equipment, (i.e. flow, fluid velocity, sound velocity, Reynolds number, etc.)

Figure 2.8: UFM Measurement Display

Step 6: Remove transducers and restore paints

Remove the transducers and restore the surface of pipe after measurement.

2.3.1.3 Suction and Discharge Pressure Measurement

The activity measures each pump suction and discharge pressure. The pump efficiency is then calculated using the measured values.

Step 1: Disassembly of existing Pressure Gauge

- Inspect for any leaks or unusual noise before proceeding: If anything is detected, report immediately to the operator;
- Close gate valve located before the pressure gauge and wait for the pressure reading to drop;
- Remove the pressure gauge: (1) Hold the adapter steady with one wrench and the grip the stationary socket of the pressure gauge with another; (2) Loosen the pressure gauge then remove it.

Step 2: Installing the Pressure Gauge

- Prepare the connections: (1) Clean the connections before installing; (2) Put Teflon tape on the pressure connection of the gauge;
- Install the pressure gauge: (1) Mount the pressure gauge on the adapter then hand tighten the arrangement; (2) Further tighten the assembly using a pair of wrenches: hold the adapter steady with one wrench and the grip the stationary socket of the pressure gauge with another; (3) Tighten the assembly;
- Inspect the assembly again.

Step 3: Reading the pressure

- Slowly open the gate valve: Observe any leaks or unusual noise;
- Measurement: (1) Wait until reading is stable; (2) Record the pressure as indicated.

Step 4: Restoring the earlier gauge

- Inspect for any leaks or unusual noise before proceeding: If anything is detected, report immediately to the operator;
- Close gate valve located before the pressure gauge and wait for the pressure reading to drop;
- Remove the pressure gauge: (1) Hold the adapter steady with one wrench and the grip the stationary socket of the pressure gauge with another; (2) Loosen the pressure gauge then remove it;
- Prepare the connections: (1) Clean the connections before installing; (2) Put Teflon tape on the pressure connection of the gauge;
- Install the pressure gauge;
- Mount the pressure gauge on the adapter then hand tighten the arrangement;
- Further tighten the assembly using a pair of wrenches: hold the adapter steady with one wrench and the grip the stationary socket of the pressure gauge with another;
- Tighten the assembly.

2.3.1.4 Parameters

Parameters was recorded using visual inspection form, interview questionnaire, and testing results. Main parameters are listed, but not limited to, in the Table 2.3. Raw data is enclosed in the Appendix.

Table 2.3: Main parameters to be collected.

Parameters	Symbol	Remarks
Pipe thickness Gauge	t	mm
Pump Capacity	Q	Gpm/cmh
Suction Pressure	Ps	mH2O
Discharge Pressure	Pd	mH2O
Vibration Data	-	-
Head	H	mH2O
Efficiency	e	%

2.3.2 Vibration and structural assessment

This activity measures the vibrations of the pump and motor at the drive and non-drive ends. The data will be used to address pump vibration problems such as cavitation, pump flow pulsation, bent pump shaft, pump impeller imbalance, shaft misalignment and bearing problems.

Following procedures will be executed

Step 1: Test location identification

Locate the testing points on drive and non-drive ends of pump and motor

Step 2: Set transducer probe on test point. Observe HIRAC for access to elevated positions

Step 3: Read and record value as indicated on module display

2.3.3 Workplace environment management

GHD/RBSanchez conducted WEM tests at designated locations (Figure 2.9) to record values of parameters presented in Table 2.4.

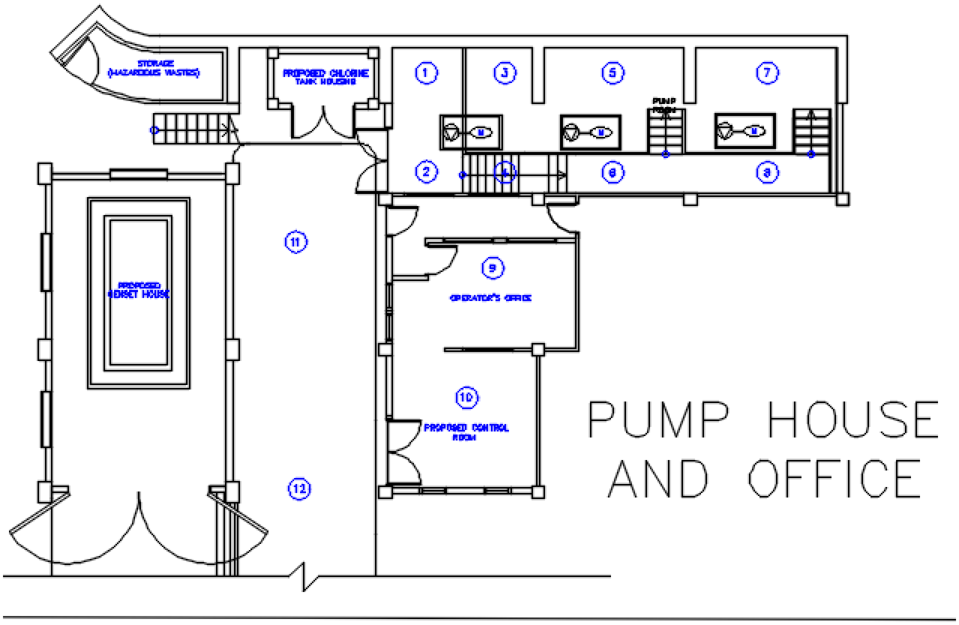


Figure 2.9: Testing locations

Table 2.4: WEM Parameters.

Parameters	Symbol	Units
Dry Bulb Temperature	tdb	oF/oC
Relative Humidity	RH	%
Sound Intensity	-	dB
PM 2.5 Count	PM2.5	ug/m^3
Visible useful light	-	Lux

2.4 Database

GHD developed an MS Access program that functions as a database used to record data collected from visual inspections and testings. The database has been developed using the concept of Relational Database Management System (RDMS), which is a must to record data systematically. The benefits of using the database are

- Eliminate redundancy and repetition of same data
- Eliminate incorrect data entry that is often found when working with excel files

- Provide linkages among asset hierarchy
- Provide ease for programing (e.g. reliability modeling and life cycle cost analysis)
- Support Maynilad AIM team to learn the benefits of using RDMS in developing an integrated Asset Management System for now and future
- Provide compatibility with any CMMS that is often using other RDMS such as Microsoft SQL Server, Oracle SQL server, or MySQL platform
- Provide ease for compilation of desire tables for further analysis using SQL (Structure Query Language)
- Provide ease for importing/exporting to different extension formats (e.g. flat, csv, xlsx)
- Provide a strong background for Maynilad team to migrate recording practices to Web-based that will be part of GHD's recommendation for future usage.

The MySQL database is then migrated into MySQL server, which is powerful database system that is used also to migrate, compile, and store all production and power consumption data into a single table. Main reasons behind the development of the MySQL server are for statistical computing with R and for faster compilation of queries.

GHD will provide these two sets of database as part of our deliverable and will provide training for Maynilad team to learn how to use the database in an efficient approach.

Chapter 3

Methodology

3.1 The Integrated Asset Management Approach (IAM)

We proposes an Integrated Asset Management (IAM) approach with its framework shown in Figure 3.1 for executing this project. The IAM approach will eventually be beneficial to Clients as it will lay a foundation to build up a systematic asset management plan for the future.

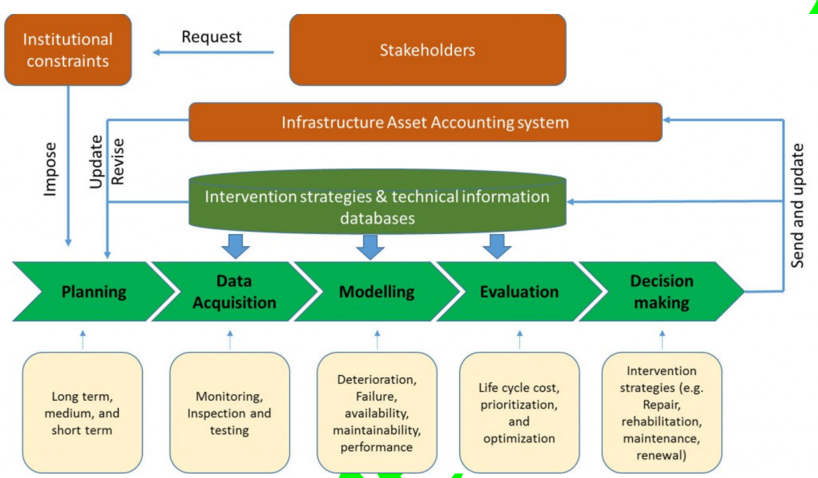


Figure 3.1: Integrated asset management approach (adopted from POM+ http://www.pomplus.vn)

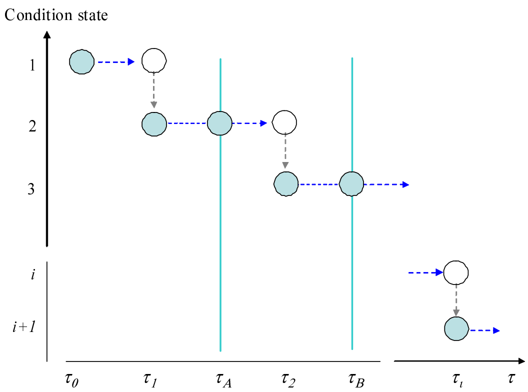
As can be seen in Figure 3.1, we sees the overall picture of works that should be executed in close connection to each other in order to make a full cycle of asset management effectively.

Works associated with auditing equipment and facilities of pump stations and reservoirs, coming up with a preventive maintenance program, tendering, and detailed design can be described explicitly using the framework in Figure 3.1. For example, various type of data concerning physical and operational condition and performance of equipment and facilities will be collected, filtered, and analyzed (Data Acquisition); the data will be further used for modeling purposes (e.g. prediction of failure rate, draw deterioration curve, reliability and efficiency); life cycle cost analysis will be then performed for each equipment and for its system. In this process, either prioritization or optimization technique can be used; finally a set of preventive maintenance intervention strategies will be generated for decision making purposes.

3.2 Deterioration process and rating index

In order to analyze and forecast the deterioration of assets, it is necessary to accumulate time series data on the CS of the assets. The historical deterioration process of an asset is described in Figure 3.2. This figure shows the deterioration progress of a component that has not been repaired. In reality, there exists uncertainty in the deterioration progress of the asset, and moreover, the CS at each point in the time axis is restricted by the time, at which, visual inspection is carried out.

In this figure, τ represents real calendar time (the expression "time" will be used instead throughout this paper). The deterioration of the asset starts immediately after it begins to operate at time τ_0. The CS of an asset is expressed by a rank J representing a state variable i $(i = 1, \cdots, J)$. For a component in the good or new situation, its condition state is given as $i = 1$, and increasing of CS i describes progressing deterioration. A value of $i = J$ indicates that an asset has reached its service limit. In Figure 3.2, for each discrete time τ_i $(i = 1, \cdots, J-1)$ on the time-axis, the corresponding CS has increased from i to $i+1$. Hereinafter τ_i is referred to the time a transition from a CS i to $i+1$ occurs.



Note) In this example, the deterioration process of a infrastructure component if expressed in terms of calendar time $\tau_1, \tau_2, ..., \tau_i$, and condition state of the section is increased in unitary units.

Figure 3.2: Transition Time of Condition State (adopted from [14]).

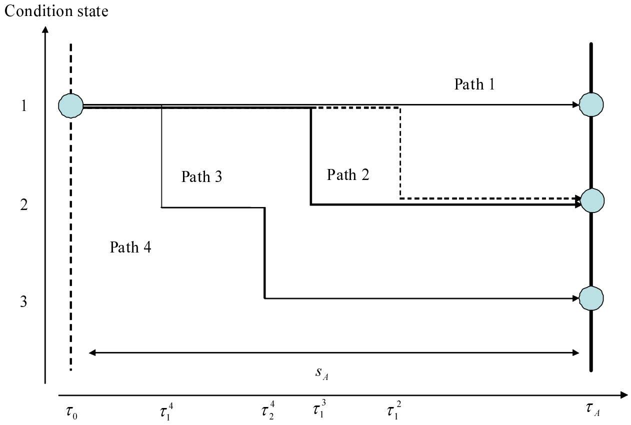
Information regarding the deterioration process of an asset can be acquired through periodical visual inspections. However, information on the CS based on continuous visual inspection is difficult to obtain. In this case, the initial inspections is carried out at times τ_A on the time-axis. It is supposed that at time τ_A the CS observed by inspection is i $(i = 1, \cdots, J-1)$. The deterioration progress in future times is uncertain. Among the infinite set of possible scenarios describing the deterioration process only one path is finally realized.

Figure 3.3 shows four possible sample paths. Path 1 shows no transition in the CS 1 from initial time τ_0 to first inspection time τ_A. In paths 2 and 3, CS has advanced to one upper CS at the calendar times τ_1^2 and τ_1^3 respectively. The CS of these two paths observed at time τ_A become 2. In a periodical inspection scheme, the point times τ_1^2 and τ_1^3 in which the CS has changed from 1 to 2 are not determined. In addition, path 4 shows transitions in the CS at times τ_i^4 and τ_{i+1}^4 during the inspection interval. The CS observed at time τ_A becomes 3. That is, in spite of the transitions in the CS are observable at the time of periodical inspection, it is not possible to obtain information about the times in which those transitions occur.

Figure 3.4 further describes the deterioration process inferring the inspection approach and how the CS is assumed. In this figure, it is assumed that the CS at the calendar time τ_{i-1} has changed from $i-1$ to i. The calendar time τ_{i-1} is assumed to be equivalent to $y_i = 0$. The time represented by the sample time-axis is referred from now on as a "time point", and differs from "time" on the calendar time axis. The times τ_A and τ_B correspond to the time points y_A and y_B on the sample axis. It can be seen that $y_A = \tau_A - \tau_{i-1}$, $y_B = \tau_B - \tau_{i-1}$.

Information on the CS i at the beginning of the calendar time τ_{i-1} cannot be obtained in a periodical inspection scheme. Therefore, time points y_A and y_B on the sample time-axis cannot be correctly obtained either. For convenience of description, it is assumed that the information at the time a point is known in order to develop the model, despite this assumption is not necessarily essential. The following paragraph discusses that even without information at time points y_A and y_B an exponential hazard model can be estimated.

In the case the CS of an asset at time τ_i (time point y_C) is assumed to change from i to $i+1$, the period length in which the CS has remained at i (referred as the life expectancy of a CS i) is represented by $\zeta_i = \tau_i - \tau_{i-1} = y_C$. The life expectancy of a CS i is assumed to be a stochastic

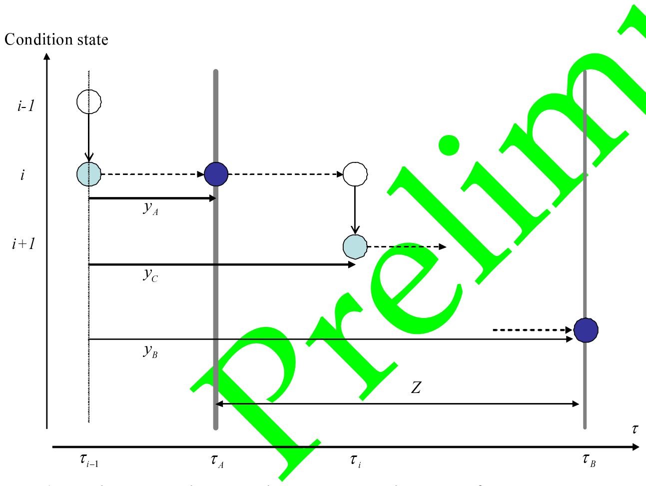


Note) In this example, the deterioration process of an asset is expressed in terms of four different sample paths. In paths 2 and 3 the CS has advanced to one upper CS at the calendar times τ_1^2 and τ_1^3 respectively. In path 4, the CS has increased one state at each time τ_1^4 and τ_2^4. However, in the case of a periodical inspection carried out at times τ_A the CS at any point in time between inspections cannot be observed.

Figure 3.3: Transition Pattern of Condition State.

variable ζ_i with probability density function $f_i(\zeta_i)$ and distribution function $F_i(\zeta_i)$. Random variable ζ_i is defined in the domain $[0, \infty]$. The distribution function is defined as

$$F_i(y_i) = \int_0^{y_i} f_i(\zeta_i) d\zeta_i. \tag{3.1}$$



Note) In the case the condition state changes from $i-1$ to i at the calendar time τ_{i-1} the inspections carried out at times τ_A and τ_B will also correspond to the points in time y_A and y_B when using τ_{i-1} as the time origin. The figure shows a sample deterioration path in which the condition state has advanced in one unit to y_c in the interval time $\tau_{i-1} - y_C$. However, observations at time τ_{i-1} are not possible in a periodical inspection scheme, so there is no way to obtain observation at y_A, y_B and y_C. Nevertheless, it is possible to use the information contained in $z = y_C - y_A \in [0, Z]$.

Figure 3.4: Model of Deterioration Process.

The distribution function $F_i(y_i)$ represents the cumulative probability of the transition in the CS from i to $i+1$. CS i is assumed to be observed at initial time $y_i = 0$(time τ_A). The time interval measured along the sample time-axis until the time point y_i is $\tau_{i-1} + y_i$. Therefore, using the cumulative probability $F_i(y_i)$, the probability $\tilde{F}_i(y_i)$ of a transition in the CS i during the time points interval $y_i = 0$ to $y_i \in [0, \infty]$ is defined by $\tilde{F}_i(y_i)$:

$$\text{Prob}\{\zeta_i \geq y_i\} = \tilde{F}_i(y_i) = 1 - F_i(y_i). \tag{3.2}$$

The conditional probability that the CS of an asset at time y_i advances from i to $i+1$ during the time interval $[y_i, y_i + \Delta y_i]$ is defined as

$$\lambda_i(y_i)\Delta y_i = \frac{f_i(y_i)\Delta y_i}{\tilde{F}_i(y_i)}, \tag{3.3}$$

where the probability density $\lambda_i(y_i)$ is referred as the hazard function.

3.3 Condition State (CS) definition

Condition of an asset can be described either by a range of discrete condition state (CS) or by continuous values of one or more than one parameters such as cracking, thickness, and corrosion. In asset management practice, discrete range of CS is often for the following reasons:

- It can be converted/mapped from continuous value of monitoring data;
- It is convenient for non-technical persons and managers;
- It is suitable for determination of intervention strategy and thus for life cycle cost modeling.

Assets in pump stations are different in category and functionality, thus it is not easy to define a universal range of CSs. However, it is possible that a generic range of CSs can be used to map appropriately different type of assets. In this project, following definitions are used for multiple CSs (Table 3.1) and binary state (Table 3.2) systems.

Table 3.1: Condition state definition - Multiple.

CS i	Definition	Require Intervention	Remarks
1	New/likely new and provide adequate LOS	No	Good (None/Insignificant)
2	Install <=5 years, provide adequate LOS	No	Acceptable (Minor)
3	Moderate aging, not provide adequate LOS, observed moderate breakdown	Yes	Damaged (Significant)
4	Moderate aging, not provide adequate LOS, require frequent CI and PI	Yes	Poor (Extensive)
5	Aging and not provide adequate LOS	Yes	Safety is endangered

Table 3.2: Condition state definition - Binary.

CS i	Definition	Require Intervention	Remarks
0	Not provide adequate LOS	No	
1	Provide adequate LOS	Yes	

3.4 Technical efficiency

Technical efficiency is a coefficient measured as the ratio of actual parameter value and expected/design parameter value. In case of PSs, TE is often discussed around the value of pump efficiency (η), which is a factor that accounts for the kinetic energy lost during the operation [8]. The PE is a product of the followings:

- Hydraulic efficiency (primarily, disk friction against the liquid with impeller shrouds). This efficiency is contributed by the speed and impeller geometry. Shock losses during rapid changes in direction along the impeller and volute can also resulted in additional shock losses;
- Volumetric efficiency (recirculation losses at wear rings, interstage bushes and other);
- Mechanical efficiency (friction at seals or gland packing and bearings)

Hydraulic efficiency and volumetric efficiency are used at the design stage of PS when there is a need to determine suitable pump or group of pumps that satisfies the designed LOS. Whilst, mechanical efficiency is used to determine operational efficiency once pumps are in used.

The mechanical efficiency (η_m) is estimated based on the equation 3.4

$$\eta_p = \frac{P_W}{P_B} \tag{3.4}$$

Where P_W and P_B are water power and brake power, respectively.

Following equations are used to calculated the P_W and P_B:

$$P_{W(kW)} = \gamma \times H \times Q \tag{3.5}$$

$$P_{B(kW)} = P_E \times e_m \tag{3.6}$$

where

P_W	*Water power (kW);*
P_B	*Brake power (kW);*
P_E	*Electric power (kW);*
Q	*Water flow rate (m^3/s);*
H	*Head produced by pump (m_{H_2O});*
η_e	*Motor efficiency (%);*
γ	*specific weight of fluid (water) (kN/m^3).*

3.5 Reliability

3.5.1 Qualitative and Operational Analysis

3.5.1.1 Failure Mode and Effects Analysis (FMEA)

An FMEA is often the first step of a system reliability study. It involves reviewing as many components, assemblies, and subsystems as possible to identify failure modes, and their causes and effects. FMEA is an inductive reasoning (forward logic) single point of failure analysis and is a core task in reliability engineering, safety engineering and quality engineering.

A successful FMEA activity helps identify potential failure modes based on experience with similar products and processes—or based on common physics of failure logic. It is widely used in development and manufacturing industries in various phases of the product life cycle.

Functional analyses are needed as an input to determine correct failure modes, at all system levels. The FMEA is in principle a full inductive (forward logic) analysis, however the failure probability can only be estimated or reduced by understanding the failure mechanism. Hence, FMEA may include information on causes of failure (deductive analysis) to reduce the possibility of occurrence by eliminating identified (root) causes.

3.5.1.2 Reliability Centered Maintenance (RCM)

Reliability-centered maintenance (RCM) is a process to ensure that systems continue to do what their user require in their present operating context. It is generally used to achieve improvements in fields such as the establishment of safe minimum levels of maintenance. Successful implementation of RCM will lead to increase in cost effectiveness, reliability, machine uptime, and a greater understanding of the level of risk that the organization is managing. It is defined by the technical standard SAE JA1011, Evaluation Criteria for RCM Processes.

Reliability centered maintenance is an engineering framework that enables the definition of a complete maintenance regimen. It regards maintenance as the means to maintain the functions a user may require of machinery in a defined operating context. As a discipline it enables machinery stakeholders to monitor, assess, predict and generally understand the working of their physical assets. This is embodied in the initial part of the RCM process which is to identify the operating context of the machinery, and write a Failure Mode Effects Analysis (FMEA). The second part of the analysis is to apply the "RCM logic", which helps determine the appropriate maintenance tasks for the identified failure modes in the FMEA. Once the logic is complete for all elements in the FMEA, the resulting list of maintenance is "packaged", so that the periodicities of the tasks are rationalised to be called up in work packages; it is important not to destroy the applicability of maintenance in this phase. Lastly, RCM is kept live throughout the "in-service" life of machinery, where the effectiveness of the maintenance is kept under constant review and adjusted in light of the experience gained.

RCM can be used to create a cost-effective maintenance strategy to address dominant causes of equipment failure. It is a systematic approach to defining a routine maintenance program composed of cost-effective tasks that preserve important functions.

3.5.2 Weibull model

In hazard analysis, the deterioration of element is subjected to follow a stochastic process [13]. For binary state system, two condition level $0, 1$ are often used. When receiving a PI or CI, the CS from 1 must be changed into 0. In reliability study, this process is often regarded as renewal process. The renewal is carried out at alternative time t_k $(k = 0, 1, 2, ...)$. In this way, the next renewal time is denoted as $t = t_0 + \tau$, where τ indicating the elapsed time. The life span of an asset is expressed by a random variable ζ. The probability distribution and probability density function of the failure occurrence are $F(\zeta)$ and $f(\zeta)$ respectively. The domain of the random variable ζ is $[0, \infty]$. The living probability (hereafter named as survival probability) expressed by survival function $\tilde{F}(\tau)$ can be defined according to the value of failure probability $F(\tau)$ in the following equation:

$$\tilde{F}(\tau) = 1 - F(\tau). \tag{3.7}$$

The probability, at which the asset performs in good shape until time τ and break down for the first time during an interval of $\tau + \Delta\tau$ can be regarded as hazard rate and expressed in the following equation:

$$\lambda_i(\tau)\Delta\tau = \frac{f(\tau)\Delta\tau}{\tilde{F}(\tau)}, \tag{3.8}$$

where $\lambda(\tau)$ is the hazard function of the asset. In reality, the breakdown probability depends largely on the elapsed time of the asset since its beginning of operation. Thus, the hazard function should take into account the working duration of the asset (time-dependent). In another word, the memory of the system should be inherited. Weibull hazard function is satisfied in addressing the deterioration process [2, 12]:

$$\lambda(\tau) = \frac{1}{\eta}\beta\tau^{\beta-1}, \tag{3.9}$$

where η is the scale parameter expressing the arrival density of the asset, and β is the acceleration or shape parameter. The probability density function $f(\tau)$ and survival function $\tilde{F}(\tau)$ in the form of Weibull hazard function can be further expressed in equation (3.10) and (3.11):

$$f(\tau) = \frac{1}{\eta}\beta\tau^{\beta-1}\exp(-\alpha\tau)^{\beta}, \tag{3.10}$$

$$\tilde{F}(\tau) = \exp(-\frac{1}{\eta}\tau)^{\beta}. \tag{3.11}$$

Estimation for Weibull's parameter is often with Maximum Likelihood Estimation (MLE) approach on historical data. Thus, the model's parameter is sensitive to how data behaves. We recommend to use this model only when there is sufficient data to be used.

An example of source code for education purpose is given in Github site of Nam Le [1]. The complete program is a copyright of Nam Le.

3.5.3 Markov model

The transition process among the condition states of an infrastructure component is uncertain. Therefore, future condition states cannot be forecasted deterministically. In this situation, Markov transition probability is employed to represent the uncertain transition pattern of the condition states during two time points. Markov transition probabilities can be defined for arbitrary time intervals.

For simplification, Markov transition probabilities can be defined and used to forecast the deterioration of a infrastructure component based on the information from periodical inspection scheme shown in Figure 3.4. The observed condition state of the component at time τ_A is expressed by using the state variable $h(\tau_A)$. If the condition state observed at time τ_A is i, then the state variable $h(\tau_A) = i$. A Markov transition probability, given a condition state $h(\tau_A) = i$ observed at time τ_A, defines the probability that the condition state at a future time (τ_B for example) will change to $h(\tau_B) = j$:

$$\text{Prob}[h(\tau_B) = j | h(\tau_A) = i] = \pi_{ij}. \tag{3.12}$$

The Markov transition probability matrix can be defined and rearranged by using the transition probabilities between each pair of condition states (i, j) as

$$\mathbf{\Pi} = \begin{pmatrix} \pi_{11} & \cdots & \pi_{1J} \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \pi_{JJ} \end{pmatrix}. \tag{3.13}$$

The Markov transition probability (3.12) shows the transition probability between the condition states at two given times τ_A and τ_B, therefore, it is straightforward that the values of a transition probability will differ for different time intervals. Since deterioration continues as long as no repair is carried out $\pi_{ij} = 0$ $(i > j)$. From the definition of transition probability $\sum_{j=1}^{J} \pi_{ij} = 1$. Following conditions must be satisfied:

$$\left.\begin{array}{l} \pi_{ij} \geq 0 \\ \pi_{ij} = 0 \ \ (\text{when } \ i > j) \\ \sum_{j=1}^{J} \pi_{ij} = 1 \end{array}\right\}. \tag{3.14}$$

The worse level of deterioration is expressed by the condition state J, which remains as an absorbing state in the Markov chain as long as no repair is carried out. In this case $\pi_{JJ} = 1$.

Markov transition probabilities are defined independently from the deterioration history. As shown in Figure 3.4, the condition state at the inspection time τ_A is i, however, the time, at which, condition state changed from $i-1$ to i is unobservable. In a Markov chain model, it is assumed that the transition probability between the inspection times τ_A and τ_B is only dependent on the condition state at time τ_A.

The Markov chain model is operative and widely applied in management of infrastructure system. Particularly, at management of network level, Markov chain model is used to define the average transition probability of the entire system, or a group of infrastructure components given two periodical inspection data.

Estimation for the Markov transition probability can be done by the MLE approach [13, 14] or Bayesian Estimation approach [9, 11] based on historical data. One advance of using the Markov model is that one time monitoring data can be used. A generic formula to estimate the transition probability is given in following Equations:

[1] https://github.com/namkyodai/Models

$$\pi_{ii} = \exp(-\theta_i Z), \tag{3.15-a}$$

$$\pi_{ii+1} = \frac{\theta_i}{\theta_i - \theta_{i+1}}\{-\exp(-\theta_i Z) + \exp(-\theta_{i+1} Z)\}, \tag{3.15-b}$$

$$\pi_{ij} = \sum_{k=i}^{j} \prod_{m=i}^{k-1} \frac{\theta_m}{\theta_m - \theta_k} \prod_{m=k}^{j-1} \frac{\theta_m}{\theta_{m+1} - \theta_k} \exp(-\theta_k Z), \tag{3.15-c}$$

$$\pi_{iJ} = 1 - \sum_{j=i}^{J-1} \pi_{ij}, \tag{3.15-d}$$

$$(i = 1, \cdots, J-1) \quad (j = i, \cdots, J).$$

An example of source code for education purpose is given in Github site of Nam Le [2]. The complete program is a copyright of Nam Le.

3.6 Intervention Strategy (IS)

Intervention Strategy (IS) is at asset level (level 7). It is a collection of intervention type for component level (level 8). A collection of ISs will form an Intervention Program for (IP) the station. A collection of IPs will form a Work Program (WP) for network level intervention (e.g. a bid awarded for a designer/contractor can be a WP that consists of intervention program for one or more than one pump stations). Following generic IS is defined to guide the selection of IPs that will be details in the later part of the report.

Table 3.3: Generic intervention strategy (IS).

IS	Definition	Remarks
1	Do Nothing	
2	Minor repair	Require minimal effort and can be done only for certain asset type
3	Major repair	Require extensive efforts to return the asset to likely new condition
4	Replacement/Renewal	Replacing assets or components of asset with identical one or with new model

For each type of asset, IS will be selected based on reliability study and consideration of cost. Further more, Employers inputs and requirements are also taken into account.

3.7 Determination of optimal intervention strategy

Following subsections briefly describe the model that can be used to determine optimal intervention strategy.

3.7.1 Block Replacement Model

It is assumed that a PI is executed after a pre-defined time $n \cdot T$ $(n = 0, 1, 2, \cdots, N)$. Once the PI is executed, the functionality and serviceability of the asset could be the same or different from that of the asset before the intervention. In between the time Δt $([0 \leq \Delta t \leq T])$, hazards could occur and cause the asset in worse CSs (hereafter denoted as i $(i = 1, \cdots, I)$), in which the asset is no longer providing an adequate level of services (LOS). In both cases, when the PI or CI is executed, there are impacts incurred by stakeholders s (e.g. the owner, the users, the public).

Following notations are used to describe the formulation of the model.

[2] https://github.com/namkyodai/Models

$\theta(\Delta t|t)$ Conditional failure rate i ($i = 1, \cdots, I$) when the asset has been in service in an interval t after the PI

$\Psi(\cdot|t)$ Any conditional function Ψ given that a PI is executed by a unit of age t, where t is a random variable

$F(t)$ Cumulative distribution function (cdf) of age t of a unit for a PI at execution time

$w_p^s(t)$ Impacts incurred by stakeholder s due to the execution of PI

$w_c^s(t)$ Impacts incurred by stakeholder s due to the execution of CI

$w_o^s(\Delta t|t)$ Conditional impacts incurred by stakeholder s when the structure is remains in normal operation (*i.e.* providing an adequate LOS) during time interval Δt after a PI has been carried out and the asset has not entered failure state

ρ discount factor

$p_l^k(t)$ probability of failure at time t of the affecting other assets k

$C_c^{s,k}$ Impacts incurred by stakeholder s due to the execution of an CI on other assets k

T interval between the PIs

$T^\star$ Optimal interval time between PIs, which is the variable of the model

$\Omega_p(T,t)$ minimum expected total discounted impact for an infinite time span when the asset has been in service during an interval t after the execution of the PI and the asset has not entered failure state

$\Omega_c(T,t)$ minimum expected total discounted impact for an infinite time span when a CI has been executed, of the asset that has been in service during a time interval t after the execution of the PI and the asset has entered failure state

In the model, it is assumed that at each damage level i, there exists a corresponding well defined CI. Within an increment of time Δt, after the asset has been under the PI after time t, the total expected impacts due to the execution of CIs are:

$$v_c(\Delta t|t) = \sum_{s=1}^{S} \left[w_c^s(\Delta t) + \sum_{k=1}^{K} p_l^k \cdot C_c^{s,k} \right] \cdot \theta(\Delta t|t). \tag{3.16}$$

The total impacts due to the execution of PIs and the total impacts incurred by stakeholders during the service time of the asset are defined in Eq. (3.17) and Eq. (3.18), respectively.

$$v_p(t) = \sum_{s=1}^{S} w_p^s(t). \tag{3.17}$$

$$v_o(t) = \sum_{s=1}^{S} w_o^s(t). \tag{3.18}$$

According to the principle of optimality, which is described in [1, p. 15], the minimum expected total discounted impact $\Omega_c(T,t)$ for infinite time is formulated in following equation.

$$\Omega_c(T,t) = \int_0^\infty \left[v_c(\Delta t|t) + \Omega_p(T, \Delta t|t) \right] dF(t). \tag{3.19}$$

The minimum expected total discounted impact $\Omega_p(T, \Delta t|t)$, which appears inside Eq. (3.16), is obtained as follows

$$\Omega_p(T, \Delta t) = min \Gamma(\Delta t). \tag{3.20}$$

where $\Gamma(\Delta t)$ is defined as

$$\begin{aligned} \Gamma(\Delta t) = \int_0^\infty \Bigg[v_o \int_0^{dt} exp(-\rho\tau)d\tau + \{1 - \theta(\Delta t|t)dt\} \cdot \Omega_p(T, \Delta t + dt|t) exp(-\rho dt) \\ + \theta(\Delta t|t)dt \cdot \Omega_c(T, \Delta t + dt|t) exp(-\rho dt) \Bigg] dF(t). \end{aligned} \tag{3.21}$$

According to [10], Eq. (3.21) is rewritten in following form

$$\begin{aligned} \Gamma(\Delta t) = \Omega_p(T, \Delta t) + \left[-\rho \Omega_p(T, \Delta t) + d\Omega_p(T, \Delta t)/dt \right] dt \\ + \int_0^\infty \left[v_o + v_c(\Delta t|t) \right] dF(t) dt. \end{aligned} \tag{3.22}$$

Thus, from $\Omega_p(T,\Delta t) = \Gamma(\Delta t)$ (Eq. (3.20)), the following equation can be derived:

$$\Omega_p(T,\Delta t) = exp(\rho\Delta t)\left[\Omega_p(T,0) - \int_0^\infty \int_0^t exp(-\rho\tau)\left\{v_o + v_c(\tau|t)\right\}\right] d\tau dF(t). \quad (3.23)$$

where,

$$\Omega_p(T,0) = \{1 - exp(-\rho T)\}^{-1}\int_0^\infty \left[exp(-\rho T)\left\{v_p(T,t)\right\} + \int_0^T exp(-\rho\Delta t)\left\{v_o(\Delta t|t) + v_c(\Delta t|t)\right\} dt\right] dF(t). \quad (3.24)$$

when T tends to infinity $T \to \infty$, Eq. (3.24) becomes

$$\Omega_p(\infty,0) = \int_0^\infty \int_0^\infty exp(-\rho t)\left[v_o + v_c(\Delta t|t)\right] dt dF(t). \quad (3.25)$$

Eqs. (3.24) and (3.25) are the explicit forms of the expected total discounted impact in infinite time horizon. This is the classical optimization problem. By differentiating the expected total discounted impact $\Omega_p(T,0)$ and $\Omega_p(\infty,0)$ and setting it equal to zero, the optimal time $T^\star$ can be obtained. The optimal time $T^\star$ for PI is the solution of the following system of equations:

$$\begin{cases} T^\star = \arg\min_{T^\star\in[0,T]} \Theta_p(T,0) \\ T^\star = \arg\min_{T^\star\in[0,\infty]} \Theta_p(\infty,0) \end{cases} \quad (3.26)$$

in which the differentiates of $\Theta_p(T,0)$ and $\Theta_p(\infty,0)$ are respectively:

$$\begin{aligned}\Theta_p(T,0) &= \frac{\delta(\Omega_p(T,0))}{\delta T} \\ &= [1 - exp(-\rho T)]\int_0^\infty \Big[-\rho v_p(T,t) \\ &\quad + d(v_p(T,t))/dT + v_o(T,t) + v_p(T,t)\Big] dF(t) \\ &\quad -\rho\int_0^\infty \Big[exp(-\rho T)\left\{v_p(T,t)\right\} \\ &\quad + \int_0^T exp(-\rho\Delta t)\left\{v_o(\Delta t|t) + v_c(\Delta t|t)\right\} dt\Big] dF(t). \end{aligned} \quad (3.27)$$

and

$$\begin{aligned}\Theta_p(\infty,0) &= \frac{\delta(\Omega_p(\infty,0))}{\delta T} \\ &= \int_0^\infty \Big[-\rho\left\{v_p(\infty|t) + \int_0^\infty exp(-\rho t)\left\{v_o(\Delta t|t) + v_p(\Delta t|t)\right\}\right\} \\ &\quad + \lim_{T\to\infty} d(v_p(T,t))/dT + v_o(\infty|t) + v_p(\infty|t)\Big] dF(t) \end{aligned} \quad (3.28)$$

3.7.2 Time-dependent replacement model

Time-dependent replacement model (or Age replacement model) are the ones where the following conditions apply:

- the asset starts operating at $t = 0$, i.e. it is newly built or newly restored to a like new condition following an intervention;
- the probability of failure is described with $f(t)$ and $F(t)$, i.e. the lifetime density and the lifetime;
- if the asset fails on the interval $(0, T]$ a CI is executed;

- if the object does not fail on the interval $(0, T]$ the object is replaced at T, i.e. the PI replacement is executed, regardless if the object has failed and been restored in the time interval $(0, T]$;
- the execution of a PI restores the object to a like new condition;
- the execution of a CI restores the object to a like new condition.

3.7.2.1 Minimize impact

If an age replacement IS is followed the time to the first intervention, Z, is the minimum amount of the time to failure of the length of the renewal period:

$$Z = min(\tau, T) \tag{3.29}$$

The expected, or mean, time to the first intervention is then determined by

$$E[Z = \int_0^T (1 - F(x))dx] \tag{3.30}$$

The mean impact in one renewal period then equals the probability of failure on T multiplied by the impacts associated with the CI plus the probability that no failure occurs on T multiplied by the impacts associated with the PI:

$$F(T) \times I^{CI} + (1 - F(T)) \times I^{PI} \tag{3.31}$$

The mean impacts per unit time, therefore, equal the mean cost in one renewal period divided by the length of the renewal period, i.e. the time to the first intervention.

$$\eta_{AC} = \frac{F(T) \times I^{CI} + (1 - F(T)) \times I^{PI}}{\int_0^T (1 - F(x))dx]} \tag{3.32}$$

3.7.2.2 Maximize availability

If it is desired to determine the age replacement IS that maximizes availability the following is often assumed, additionally that:

- the PI replacement takes t^{PI};
- the PI takes t^{CI};

If the asset fails before T then the length of the renewal period will, therefore, be $X = t + t^{CI}$, which has the probability $f(t)dt$ of occurring, and if the object does not fail before T then the length of the renewal period will be $X = t + t^{PI}$, which has the probability $1 - F(T)$ of occurring.

In this case, the expected, or mean, renewal period length is:

$$E[X] = \int_0^T (1 - F(x))dx + t^{CI}F(T) + t^{PI}(1 - F(T)) \tag{3.33}$$

As the asset is operational on average $\int_0^T (1 - F(x))dx$ then the availability is given by:

$$\eta_{AA} = \frac{\int_0^T (1 - F(x))dx}{\int_0^T (1 - F(x))dx + t^{CI}F(T) + t^{PI}(1 - F(T))} \tag{3.34}$$

Chapter 4

Data and Analysis

4.1 Qualitative and Operational Analysis

4.1.1 Facts and Data

Summary of facts and data concerning operational and overall plan reliability is presented in this subsection.

4.1.1.1 Operation Scenario

At present the station follows the operation schedules as shown in Table 4.1

Time	Set Pressure (psi)	No. of Pumps running
4am - 7am	35	2
7am - 11am	38	2
11am - 12nn	35	2
1pm - 9pm	30	1
9pm - 10 pm	25	1
10pm - 4am	20	1

Table 4.1: Plant Operation Schedule

4.1.1.2 Spares Policy

- 1 or 2 booster switch every 24 hours (in operation for full 24 hours then switch)
- 3 booster switch every weekday operational from 6AM – 1PM
- 3 booster switch on weekends operational from 6AM – 2PM

4.1.1.3 Emergency Situation (loss of electrical power from Meralco)

- Auto start of pumps

4.1.1.4 Maintenance

- For operational problems, operator will call Control Center to report problem. CC to send contractor within 1-2 hours. CC supervisor (Gilbert).
- For non-operational maintenance, operator will call Mark Pascual for action.

4.1.1.5 Current Problems

- Continuous presence of water at sump area of booster pumps. Sump pump operation is done manually because if it is auto-start, the pump frequently breaks down. When the water level rises to about 7 inches, the operator manually starts the sump pump. This happens every 3-4 hours daily. There is a spare sump pump on standby ready to replace the damaged unit. The in-line pump sump areas also have water ingress especially during the rainy season. This results in frequent start of the sump pump. Unfortunately, the sump pump fails about 4 times per year. The operator suspects the sump pump is of poor quality.

4.1.2 Recommendations

In order to ensure the PS to provide adequate level of services around the clock, it is important to establish a good operational scheme that allows optimization of use of pumps to reduce breakdown and to conserve energy. A summary of major recommendations to be considered are

- This facility is does not allow for the installation of an additional pump in case the demand increases because there is no more available space in the underground facility to cater for another pump. The design could be acceptable if there will be no significant increase in demand for the foreseeable future – assuming that the customers will only be limited to Ayala Alabang Village.
- Consider a dedicated duty and a dedicated spare set-up for the pumps. If this is not acceptable, then consider doing a much longer switch of the storage pumps. Currently, it is being switched daily. This allows for almost an equal rate of deterioration between the two pumps and if one pump fails due to age-related component failure, the other one is close to a similar failure which may occur before the first pump is fully repaired or replaced. It is suggested that the switch happen once a month or even every 3 months.
- In place of the longer switching cycle (e.g. every 3 months), there should be a corresponding maintenance program for the standby pump for both booster and storage.
- Know what maintenance activities are done weekly and how the contractors/Maynilad use the information gathered to predict equipment failures.
- Develop a more structured discipline in applying routine maintenance work process to ensure that maintenance tasks are given the proper priority in terms of mitigation measures and avoid unplanned shutdown of critical pumps in operation.

Aside from the above recommendations, we also generate a list of recommendations based on the RCM methodology. This is presented at at the end of the document on A. The list shall be considered as a living program, which requires continuously improvement as part of the total quality management system (refer to Deming cycle presented in GHD's technical proposal).

4.2 Pump discharge and suction pipe - thickness

4.2.1 Data and measurement

Thickness data on discharge and suction pipes of pumps is presented in Table 4.2.

In the table, the positions and the distances for the Ultrasonic Thickness Gauging (UTG) are referred to Figure 4.1 and Figure 4.2.

4.2.2 Analysis

This section provides analysis/discussion on estimation of minimum allowable thickness of pipes and statistics around the measured data collected during inspection and testings.

Table 4.2: Thickness data - Booster Pumps (mm).

Asset	Position	Distance								
		Suction						Discharge		
		0.3 m	0.5 m	Elbow 1	1.0 m	Elbow 2	1.4m	Elbow	1.5 m	2.0 m
BP1	12	7.17	-	7.56	6.66	7.76	7.65	6.46	4.47	4.35
	3	7.79	-	7.62	6.57	7.52	7.4	5.19	5.48	4.27
	6	7.74	-	6.89	6.1	7.37	7.13	5.82	5.48	4.18
	9	7.55	-	6.62	6.73	7.71	7.59	-	4.21	4.37
BP2	12	6.48	-	5.81	5.91	6.94	6.99	6.18	6.46	4.41
	3	6.5	-	6.31	6.67	6.81	6.91	6.35	5.72	4.2
	6	6.75	-	5.92	6.31	6.17	7.16	6.34	5.17	4.18
	9	6.55	-	6.19	6.17	6.15	6.9	-	5.92	4.09
BP3	12	6.32	7.26	7.58	6.25	7.69	-	6.65	4.49	9.93
	3	6.55	7.57	7.65	6.32	7.71	-	6.62	4.9	10.02
	6	6.33	7.58	7.36	6.02	7.4	-	7.17	4.67	10.01
	9	6.8	7.46	7.44	-	7.69	-	-	4.92	10.23

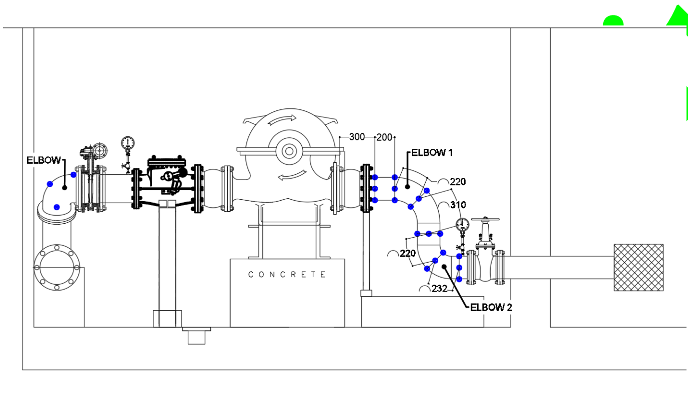


Figure 4.1: Test points and distances of UTG – Booster Pumps Suction and Discharge Side

BP1

- Suction Piping System-The 1.0 m section is a spool connecting the bends and is observed to have the thinnest part overall at the suction side, especially the 6 o'clock section. As observed, bends are situated before and after this spool which might affect its thinning rate due to the momentum of water over the course of operation.
- Discharge Piping System- It is observed that this pump has the thinnest section at its 6 o'clock position at the 2.0 m section which happens to be a bend, and at the 9 o'clock position at 1.5 m section. These are the sections where the water mixes with the water from the other pumps, thus increasing the velocity and momentum of the water with contributes to the increase of the thinning rate of the pipe wall. It is also observed that the thinnest component is at the bend where in it takes all momentum and change in direction over time, thus subjected to high shearing forces and results to higher thinning rates.

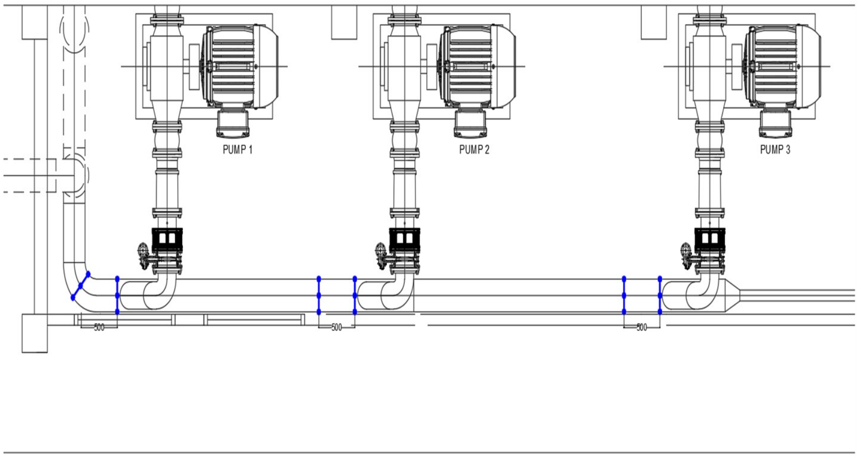


Figure 4.2: Test points and distances of UTG – Storage Pumps Discharge Side

BP2

- Suction Piping System-It is observed that the thinning occurs at the 12 o'clock position of the 1.0 m section of the spool. This might indicate that the water starts to flow swirling from the 6 o'clock past to the 9 o'clock and through the 12 o'clock. Then it continues to the extrados area of the bend at the 0.7 m section with a possibility of creating a vacuum or eddy zone at the intrados area (6 o'clock), thus having the localized thinning zones at the 12 and 6 o'clock positions. It continues the pattern of swirling from 12 o'clock to the 3 o'clock before entering the pump. This pattern is different than of the pump1 and has thinner localized wall at 0.7 m, that may be caused by higher flow rate (thus higher velocity) of water.
- Discharge Piping System-It is observed that the 6 o'clock position at the 1.5 m section is 0.65 mm thinner than the average in that section. This is due to the discharged water entering the header line which the flow might be directed toward the bottom part of the header. Moreover, due to the turbulency and disturbance made by the entering water from the discharge line, the 3-6-9 o'clock positions of the pipe at the 2 m section experience localized thinning.

BP3

- Suction Piping System-The thinnest part is the spool at the 1.0m section, especially at the 6 o'clock position which is in coherence with the other suction pipe.
- Discharge Piping System-The thinnest part of the discharge side is at the 1.5 m section at the 12 o'clock position which might be due to the eddies formed by the disturbance made by the water entering the header pipe. The extrados and crown of the first bend are observed to have a difference in thickness of 0.55 mm. It is evident that the component with the thinnest part is the 1.5 m section which might due to the eddies and the high velocity coming from the pump. On the contrary, the 2.0 m section of the header pipe has the thickest part overall.

.

4.2.2.1 Assumptions

Following assumptions are used in calculating the required thickness of pipe

- Maximum Working Head – based on the design drawings and pump nameplate;

- Pipe Material – assume pipe material is ASTM A570 Grade 33 (market available material for spiral welded pipe);
- Design Guide – basis used for the simulated calculation is AWWA Manual M11 – Steel Pipe, A Guide for Design and Installation, 4th Edition. Statement for corrosion allowance is located at Chapter 4, which states *"At one time, it was a general practice to add a fixed, rule-of-thumb thickness to the pipe wall as a corrosion allowance. This was not an applicable solution in the water work field, where standard for coating and lining materials and procedures exists. The design shall be made for the required wall-thickness pipe as determined by the loads imposed, then linings, coatings, and cathodic protection selected to provide the necessary corrosion protection"*;
- Thickness calculation will be based on the internal pressure. External pressure will not be considered because much of the discharge line is not buried.
- Surge Pressure was not considered since there are surge protection along the line.
- This document will only consider the calculation of the minimum thickness along the discharge line since this is the part of the system where maximum pressure is experience.

4.2.2.2 Limitations

As confirmed by Maynilad, there is no available data regarding the design report. Design assumptions herein may be different from what was used by the designer/contractor of this station.

This document will not be able to provide the corrosion/degradation factor of the pipe since there is no available historical data on the thickness of the pipe.

4.2.2.3 Parameter values for thickness estimation

In order to estimate the minimum allowance thickness for pipes in straight line considering material handling (t_{mh}) and maximum internal pressure based on AWWA M11 (t_{sph}), following equations are used, respectively:

$$t_{mh} = \frac{\Phi}{\delta} \tag{4.1}$$

$$t_{sp} = \frac{\epsilon \times P_{max} \times \Phi}{2 \times S_e} \tag{4.2}$$

where P_{max} is maximum internal pressure

$$P_{max} = \frac{\rho_{H_2O} \times g \times H_{max}}{1000} \tag{4.3}$$

In order to estimate the minimum allowance thickness for pipes at elbows (Miter Bend), only maximum internal pressure is considered:

$$t_{mb} = \frac{P_{max} \times \Phi}{2 \times S_e} \times \left[1 + \frac{\Phi}{(3 \times R) - (1.5 \times \Phi_d)}\right] \times \epsilon \tag{4.4}$$

Paramater values used for computation are given in Table 4.3

4.2.2.4 Recommendations

Given the current thickness of pipe the lack of design information, it is advisable to

- Not perform any major intervention on the pipes;

Table 4.3: Parameter values for thickness estimation.

Parameters	Symbol	Unit	Pumps Booster	Remarks
Discharge diameter	Φ	mm	250	
Max flow rate	Q_{max}	m^3/s	0.174	
Max pump head	H_{max}	m	35	based on name plate
Yield strength of material	S_y	MPa	227.5	ASTM A570 Grade 33, spiral welded pipe based on AWWA C200
Allowable stress	S_e	MPa	113.75	
Density of water	ρ_{H_2O}	kg/m^3	1000	
Gravity constant	g	m/s^2	9.81	
Safety factor	ϵ		2	
Bulk modulus of compressibility of liquid	k	Pa	2.1E+09	
Young's modulus of elasticity of pipe wall	E	Pa	2.1E+11	
Radius of Elbow	R	mm	375	
Empirical constant	δ		288	

Table 4.4: Minimum thickness allowance.

Pumps	Internal pressure (Mpa)	Minimum allowable thickness (mm)		
	P_{max}	t_{mh}	t_{sp}	t_{mb}
Booster	0.343	0.868	0.754	1.005

- Keep regular testing on exact locations using the same type of UTG device. It is important for Maynilad to establish a testing regime for obtaining thickness at exact same location over time (e.g. every year). Information obtained from testing will be then used to compute deterioration rate based on thickness value;
- Establish an approach to inspect/test the thickness of underground pipe, which is considered to be more vulnerable to leakage and corrosion on external wall;
- The elbows in the suction and the discharge piping systems must be monitored regularly;
- It is recommended to have a profiling of the piping systems above and below the ground in order to have a baseline in the analysis of the Maynilad Piping System. In order to have a profiling of pipe thickness at differential time T, additional measurement at similar locations shall be conducted periodically, behavior can then be monitored;
- Perform coating regularly of the pipe to prevent possible corrosion/errosion and damage that cause by external factors and surrounding condition;

4.3 Visual Inspection on Pipe, valves, fittings, supports, expansions, and appurtenances

4.3.1 Highlights

Visual inspection data on pipes, valves, fittings, supports, expansions, and appurtenances is highlighted in Table 4.5.

Visual inspections are supported with the photos taken at particular locations/positions in question.

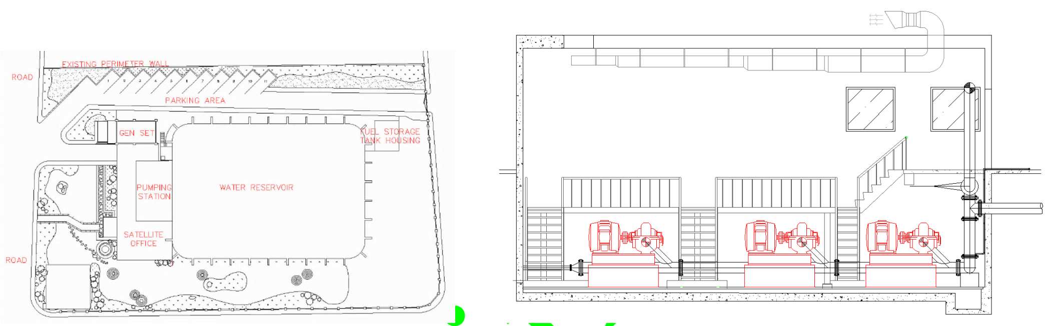
Relative to the station's desired capacity and reservoir size, the area allotted for the pump system is rather very limited (Figure 4.3 - a and Figure 4.4). 3 HSC pumps each with its motor, valves and pipes and fittings were fitted inside the limited space resulting to a compact arrangement. This led to a few compromises regarding pipe design.

To increase suction head, the pumps are installed at lower elevation close to bottom level of reservoir. The pump system was recently rehabilitated and new pumps were installed along

Table 4.5: Highlights of visual inspection

No.	Items	Remarks
1	Suction pipe design	May promote turbulent flow profile which is not beneficial to long term pump operation
2	Water velocity	Velocity of water pipes exceed recommended maximum fluid velocity and will shorten pipe life.
3	As-built changes	Few modifications and major omissions (air valve and STC) from the design was observed. Some need to be address to improve performance and life of both pump and pipes
4	Discharge pipe	Excessive local deterioration via corrosion which is a potential source of leak in the future. PRV Lever experiences excessive galvanic corrosion and is very unaesthetic. Old pipes have deteriorated contrasted to the younger pipes. Corrosion is very noticeable
5	Air valve	No air valve installed on either discharge or suction side of pump
6	Discharge isolation valve near ceiling	Has no handle and maybe useless due to inacessibility
7	Machine foundation and available space	Old foundation block remains, new foundation block raises pump centerline with purpose of increasing available space to fit valves and special connections

with its auxillaries. Corresponding foundation blocks were also built beside the old foundations (Figure 4.3 - b).



a - plant layout (01) b - pump layout (02)

Figure 4.3: PSR layouts

Figure 4.4: Pump system

Figure 4.5: Pump discharge

The distance of the main discharge header and the pump discharge flange was small and so the design opted for higher pump centerline elevation to allow space for the placement of check valve. As a consequence of increasing the pump centerline elevation, existing pipe connecting the reservoir and the old pump had to reach the new pump centerline and so a series of two elbows was used. (Figure 4.5)

The water leaves the reservoir and passes thru two successive elbows finally a rubber bellow-type flexible coupling before it enters the pump intake. High turbulence of entering water is expected. Further inconsistency in flow profile may be expected and vacuum spots may occur within the suction piping. (Figures 4.6 - a, 4.6 - b, 4.6 - c)

a - double elbow suction (01) b - double elbow suction (02) c - double elbow suction (03)

Figure 4.6: suction pipe design

This is not desired as it will reduce performance and life of pump when flow profile of water entering pump is not relatively developed. Basic simulation of flow predicts show flow profile. Ideally, a fully developed flow entering pump intake is desired to avoid problems in suction by following good suction pipe design practice. Elbow should never be bolted directly to the pumps suction nozzle. This will result to noisy operation loss in efficiency and capacity and heavy end thrust.

The abrupt connection between the short 200 mm short pipe (just after the elbow) and the 250 mm bellow-type flexible coupling is unideal and will promote turbulence near the pump inlet and further reduce pump performance and life.(Figure 4.7)

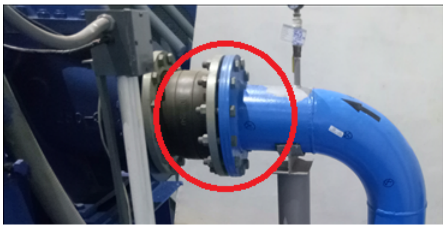


Figure 4.7: Abrupt connection

It can be said that such a minor details in the pipe suction design will prove to be a great factor in pump performance and longevity. Pumps, and especially centrifugal pumps, work most efficiently when the fluid is delivered in a surge-free, smooth, laminar flow. Any form of turbulence reduces efficiency and increases wear and tear on the pump's bearings, seals and other components. There should be at least 5 pipe diameters' worth of straight piping connecting to the pump. Never connect an elbow, reducer, valve, or strainer within this final run of pipework. If an elbow is directly connected to the pump flange, the fluid is effectively centrifuged towards the outer curve of the elbow and not directed into the centre of the impeller. This creates stress on the pump's bearings and seals which could lead to wear and premature failure.

The rehabilitation did not entirely replace all pipes and retain a portion of the discharge line and the pipe connecting reservoir to pump suction. These pipes displayed comparable deterioration with the new pipes and might be attributed to ageing. Pipe deterioration is evident as the protective paint has become brittle and the stripped areas reveal the serious corrosion occurring on the pipe surface. Where the pipe penetrates the wall, substantial corrosion also has occurred and may become a source of leak soon. Furthermore, the handle for the pressure control valve has experienced serious galvanic corrosion which resulted to its unaesthetic deterioration (refer to Figure 4.8).

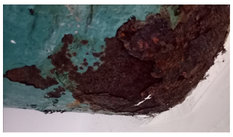
Although the pipes can withstand a remarkable amount of corrosion before failure, this should not be allowed to simply continue. As part of reliability and good upkeep, all pipes should generally be protected and preserved as much as possible.

A note on one discharge gate valve located above ground: this placement of valve should be avoided as it is not easily accessible to operator to adjust if needed (refer to Figure 4.9).

On a positive note, the pump system incorporates vibration meters which are valuable monitoring tools of the condition of the system (refer to Figure 4.10 and Figure 4.11).

A discrepancy in unit is observed between the flow meter and the control panel. This is just a minor error and should be corrected by the operator.




a - pipe (01) b - old suction (08) c - pipe (03) d - pipe (04) e - pipe (05)




f - pipe (06) g - suction pipe (07) h - pipe (02) i - corroded handle (09)

Figure 4.8: Examples of deterioration on pipes and connections

Figure 4.9: Inaccessible gate valve

Figure 4.10: Pump/motor DE vibration probe-01

Figure 4.11: Pump/motor DE vibration probe-02

Other minor observations are listed below:

- There is discrepancy of units between flow meter and control panel is observed. Use the correct units m3/hr and change the unit for the control panel to avoid further confusion.
- Insert pressure tapping for pressure gauge near pump flange for more accurate measurement of head.
- Suction pipe should have ascending inclination toward pump suction nozzle (preferably 1/100 sloping gradient)
- Hydraulic design considerations for pump suction piping would recommend at least 5 to 10 diameters of straight pipe leading to the pump intake to minimize swirls or turbulent flow and facilitate better pumping action. This is to be followed should suction piping be reconfigured.

4.3.2 Visual inspection data

Visual inspection data on assets are summarized in tables of this section.

4.3.3 Recommendations

- The rehabilitation was concerned with the major components of the mechanical system, namely the pumps. However, little changes were made to the pipe design and this could make the flow in the system not conducive for long term pump operation.

Table 4.6: Visual inspection data - P1

No.	Item	CS	Remarks
1	Double elbow	3	Design may promote turbulent flow profile which is not benefitial to long term pump operation
2	Suction FC	1	Connection is serving its purpose to accommodate minor displacements however connection to adjacent pipe need to be replaced with a diffuser to minimize hydraulic losses
3	Discharge FC	1	Connection is serving its purpose to accommodate minor displacements
4	Check valve	1	Check valve is relatively new, no leaks or signs of corrosion, no malfunction observed
5	Discharge BV	1	No malfunction observed
6	Machine foundation	1	Damping capacity of foundation based on rule of thumb is adequate, raises machine inertia due to height
7	Vibration probes	1	Probes are working properly

Table 4.7: Visual inspection data - P2

No.	Items	CS	Remarks
1	Double elbow	3	Design may promote turbulent flow profile which is not benefitial to long term pump operation
2	Suction FC	1	Connection is serving its purpose to accommodate minor displacements however connection to adjacent pipe need to be replaced with a diffuser to minimize hydraulic losses
3	Discharge FC	1	Connection is serving its purpose to accommodate minor displacements
4	Check valve	1	Check valve is relatively new, no leaks or signs of corrosion, no malfunction observed
5	Discharge BV	1	No malfunction observed
6	Machine foundation	1	Damping capacity of foundation based on rule of thumb is adequate, raises machine inertia due to height
7	Vibration probes	1	Probes are working properly

Table 4.8: Visual inspection data - P3

No.	Items	CS	Remarks
1	Double elbow suction 1	3	Design may promote turbulent flow profile which is not benefitial to long term pump operation
2	Suction 2	1	Use of existing pipe line might not be benefitial as it promotes turbulence due to design and is not desired for pump operation
3	Suction FC	1	Connection is serving its purpose to accommodate minor displacements however connection to adjacent pipe need to be replaced with a diffuser to minimize hydraulic losses
4	Discharge FC	1	Connection is serving its purpose to accommodate minor displacements
5	Check valve	1	Check valve is relatively new, no leaks or signs of corrosion, no malfunction observed
6	Discharge BV	1	No malfunction observed
7	Machine foundation	1	Damping capacity of foundation based on rule of thumb is adequate, raises machine inertia due to height
8	Vibration probes	1	Probes are working properly

Recommendations

✓ Modifications need to made to correct these sitaution. Refer to conceptual design for further details.

- The old pipes are experiencing corrosion which might need to be replaced to if water quality is desired to be maintained as well as avoiding leaks that could prompt dangerous situations.

Recommendations

✓ Schedule replacement or restoration corroded pipes.

- There are some notable discrepancy between the as-built and the as-found, namely, air valves and STCs were not installed. The air valve is important to rid of air pockets that could prove harmful to pump during operation.

Recommendations

✓ Modify the pump discharge side piping configuration to correct these situation. Refer to conceptual design for further details.

- A quick check between recommended flow velocity of water pipe versus the pipe diameter would show that the velocity induced provided that the pump operate at rated capacity is over the recommended values. This can also shorten both pipe and pump life considerably if velocity is too fast.

Recommendations

✓ Check the velocity of pipe along suction if it exceeds minimum pipe velocity. Install larger pipe diameters for the discharge side.

4.4 Vibration and structural assessment

4.4.1 Measurement and spectrum reading

Rotating equipment generate vibration waveforms that are mathematical functions of machine dynamics, such as speed, alignment, and rotor balance, among others. Vibration analysis entails measurement and analysis of the amplitude of vibration at certain frequencies to gather useful information relating to the accuracy of shaft alignment and balance, the physical condition of bearings, and the possible effects of structural issues; in the case of Maynilad, the problem of impeller possible cavitation is an added and serious concern.

Three main parameters are measured to determine the severity or amplitude of vibration; namely: displacement, velocity and acceleration. Along with temperature, the vibration level is a primary indicator of the physical condition of a machine. As a generally rule, higher vibration levels indicate greater defects.

Rotating speeds below 600 rpm (10 Hz) generate minimal acceleration, moderate velocity, but relatively high displacement. Hence, shaft displacement is a critical parameter for slow speed rotors, such as steam turbines. Between 600 – 60000 rpm (10 - 1000 Hz) velocity and acceleration levels provide useful indications of the severity of defects. While velocity as a parameter may indicate the presence or relative magnitude of a problem, it makes no distinction as to the source or cause. This is where an FFT vibration analyzer comes in. A fast Fourier transform algorithm converts acceleration waveforms into functions of frequency in a way suitable-trained humans can distinguish the component sources or causes of the vibration.

By means of a OneProd Falcon high-resolution FFT analyzer equipped with tri-axial accelerometer with a linear frequency range of 2Hz-30kHz, vibration spectral readings were taken from four bearing locations in each motor-pump unit. Analysis and results are summarized as follows:

4.4.2 Data and analysis

Raw data of vibration measurement is provided in separately digital format. The raw data of each pump is used to generate a set of graphs provided in Appendix B. Analytical results on vibration are also included.

A summary of grading for each pump is given in Table 4.9.

It is noted that the CS 2, and 3 shown in Table 4.9 infers good and fair, respectively [1].

4.4.3 Recommendations

Recommendations are shown in Table 4.10

[1] The CS is slightly different from that defines in Table 3.1

Table 4.9: Pump vibration condition state.

Assets	Operational issues detected	Condition	
		Motor	Pump
P1	Health is good for a long time service without restrictions Vibrations are within acceptable levels	1	1
P2	Health is good for a long time service without restrictions Vibrations are within acceptable levels	1	1
P3	Health is good for a long time service without restrictions Vibrations are within acceptable levels	1	1

Table 4.10: Recommendation to reduce vibration.

Assets	Condition		Recommendations	IT
	Motor	Pump		
P1	1	1	Continue to monitor vibrations periodically	1
P2	1	1	Continue to monitor vibrations periodically	1
P3	1	1	Continue to monitor vibrations periodically	1

4.5 Energy management audit

4.5.1 Production and power data

Production data for this station has been recorded in excel files. Each file represents a month with 24 hours of daily records. Maynilad provided this set of data from 2015 to 2018 per GHD' request. Initial verification on this set was conducted with following conclusions

- Data of 2015 and 2016 are excluded as the set belongs to the past prior to major rehabilitation, thus probabilistically, not representing the recent trend in power consumption vs production;
- Data of 2017 and 2018 contain a vast number that might not be correct (extremely small or extremely large);
- The structure of data is not homogeneous with numerical errors. This problem is due to the fact that excel file is not suitable for recording a large volume of data, particularly cells are not set up to reject string and value outside the lower and upper bounds. content.

In order to compile such a huge data set, it is not possible with manual inputting, instead, GHD has developed a hybrid program consisting of Visual Basic (VBA) Code and MySQL code for fast compilation. VBA code is used to add header, fill up missing information in excel file, and ignore rows and columns that should not exist with regard to database structure. MySQL codes are used to eliminate measurement errors and bring together all individual files to one file that allows statistical analysis with R.

4.5.2 Measurement errors

Following measurement errors are with the provided excel files

- String/text values are found numerous in columns that shall be only numerical values;
- Extreme values are found numerous;
- Negative values are found in many places that shall only be positive

4.5.3 Data compilation for analysis

Out of all recorded attributes, useful attributes that can be used for energy audit are total production per hour and total power consumption per hour. There is no record on production and power consumption for individual pump.

4.5.4 Analysis

As a matter of fact, power consumption of a PS is mostly contributed by the operation of pumps. Thus, the audit has been centralized on

- Analyzing given production and power consumption data to understand the trend and establish a benchmark ratio of production vs power for future audit and management;
- Evaluating other part of the audit such as pump efficiency and reliability in order to derive better intervention program that will eventually beneficial to the Client to maintain a benchmark level of power consumption against the production.

Figure 4.12 shows the statistical correlation between production and power. It can be seen from the correlation graph and correlation value that there is very weak correlation among these two values (coefficient is 0.118). A careful inspection on data reveals that data has been recorded inappropriately. It could be possible that the meters were not provide adequate level of services.

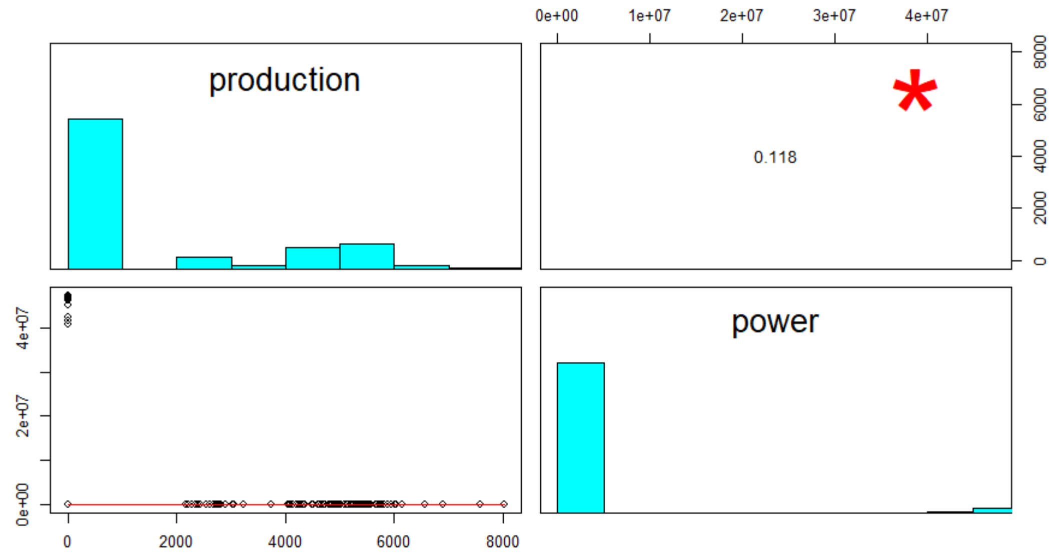


Figure 4.12: Correlation between production and power consumption

Figure 4.13 shows a trend in time series production since 2017. It can be seen from the graph that the production was recorded abnormally. In the first quarter of 2017, the production in ML was observed to be averagely less than 0.5 ML. However, abruptly, there was a period in the middle of 2017 to the first quarter of 2018, the production became averagely 5 ML, which was almost 10 times than that observed previously. Then production level has dropped to less than 0.5 ML again in the 3rd and 4th quarters of 2018.

Figure 4.14 shows a trend in time series power consumption since 2017. It can be seen from the graph that the power has been abnormally recorded.

Figure 4.15 shows time of ratio between power and production. If investing only the period of 1st quarter of 2017, the value of ratio kept decreasing on average, indicating more efficiency in saving energy. This trends could be also observed in 3rd and 4th of 2018. This could be due to the fact that the plant was renovated and thus able to operate more efficient.

Interpretation from these graphs can be summarized as follows

- There is almost no correlation between the production and power, which has been contributed by abnormal recording which might due to the failure of reading devices;
- There are too much outliers on the recorded data. THis data set is not reliable for a complete energy audit;

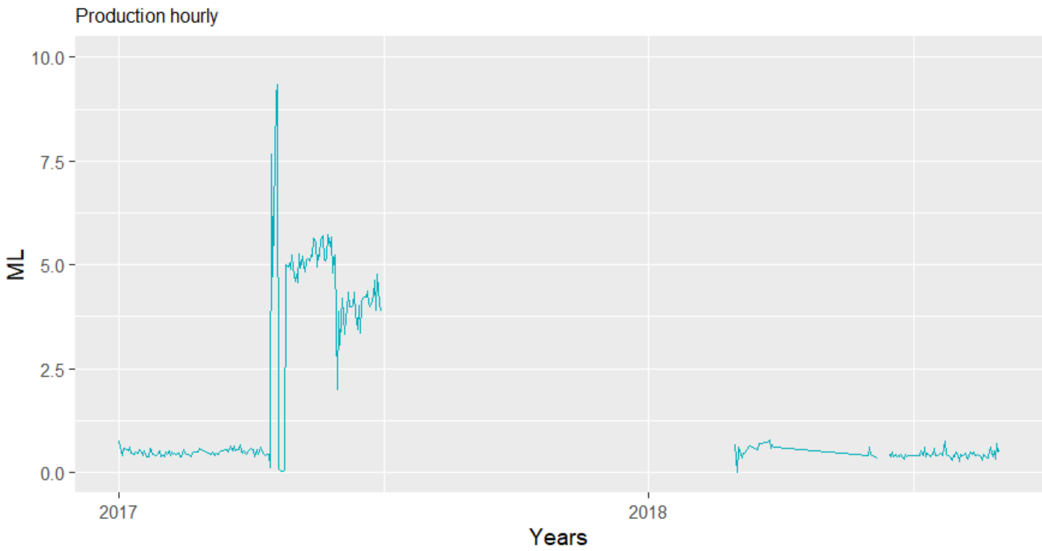


Figure 4.13: Time series production/hour

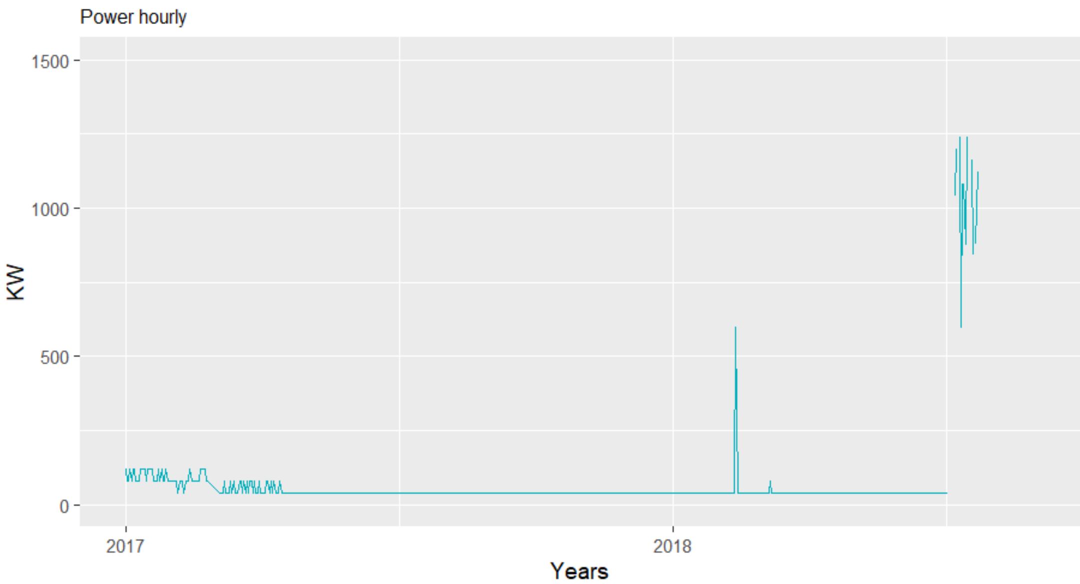


Figure 4.14: Time series power/hour

4.5.5 Recommendation

In order to operate the PS in a manner that is energy efficient, it is advisable to

- Establish an optimal operation scheme;
- Establish a benchmark energy efficiency ratio for continuous monitoring and reporting. This ratio shall become a Key Performance Indicator (KPI) used for managerial purpose. GHD suggests to first fix the issue of data recording and compilation for getting reliable set of data. This can be done from now to the end of 2019 for another round of energy audit.

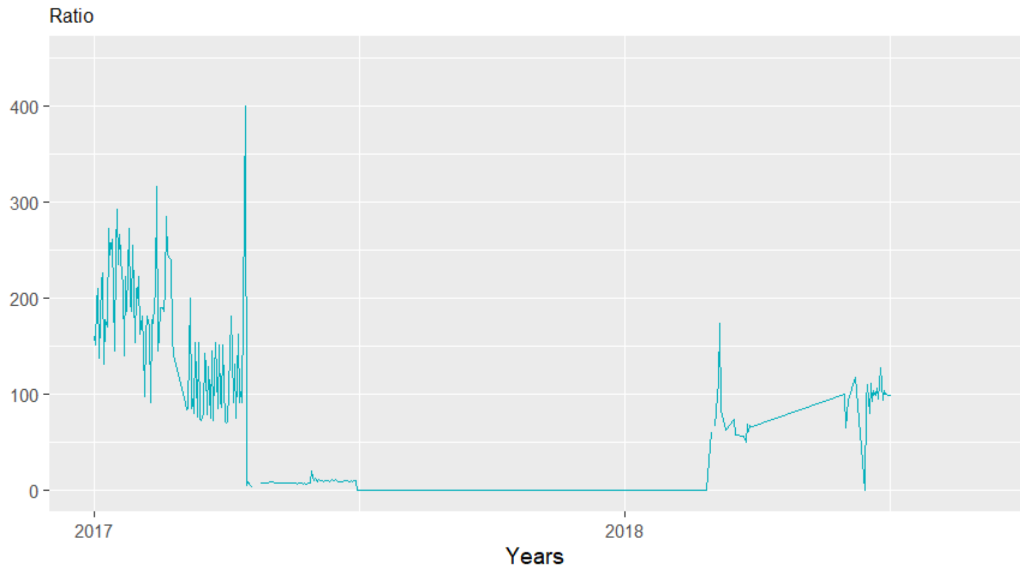


Figure 4.15: Time series ratio between production and power

4.6 Workplace environment management

4.6.1 Temperature and relative humidity

4.6.1.1 Data

Data concerning the temperature and relative humidity is presented in Table 4.11. Data was measured at targeted points shown in Figure 2.9. Raw data is with the site inspection reports, which will be provided to the Client separately. Prsuant to ASHRAE standard, the recommended ranges for temperature and humidity are [72 - 80 $^{\circ}F$] and [45 - 60 %], respectively.

4.6.1.2 Data and Analysis

Inside office registered a reading of approximately 73 F. This falls on the lower end of the recommended range. The RH, on the other hand, is about 64 % and is already outside the recommended range. Although this has minimal impact on comfort of operator staying inside the room, it is best to approach the recommended values to be safe. Note that the Air Conditioning System is installed inside the Office thus the temperature can still be vary based on the thermal comfort needed by the Operators.

From Table 4.11, the temperatures inside the pump house at every measurement points are significant higher than the maximum value of the recommended range (80 F). The average value is around 87 F. High values of temperature compared to the range have also been observed for points outside the pump house. The same is observed for the values of RH.

As a matter of fact, temperature and humidity is highly correlated and as per ASHRAE standard 55 under summer comfort zone, the recommended combination of temperature and humidity shall be within the comfortable zone as shown in Figure 4.16.

4.6.1.3 Recommendations

In order to reduce the negative impacts from high temperature, particularly inside the pump house, the Client shall consider

- Establishing a good daily monitoring, exercise, and management considering ergonomic and health and occupational activities (e.g. appropriate time window for break in designated resting area);

Table 4.11: Temperature and Relative Humidity

Points	Description of points	Temperature (F)		Humidity (%)	
		Actual	Range	Actual	Range
	A.				
1	Pump 1 (near storage)	85.2	72-80	69.9	45-60
2	Pump 1 (near door)	86	72-80	61.8	45-60
3	Pump 2 (near storage)	86.7	72-80	63.9	45-60
4	Pump 2 (near door)	87.4	72-80	65.1	45-60
5	Pump 3 (near storage)	87.8	72-80	64.8	45-60
6	Pump 3 (below)	87.9	72-80	64.6	45-60
7	Between pump 1 and 2 (below)	86.5	72-80	65.8	45-60
8	Between pump 1 and 2 (near storage)	86	72-80	65	45-60
	Average	86.69		65.11	
	B.				
9	Office	72.9	72-80	63.9	45-60
10	Electrical room	73	72-80	63.3	45-60
	Average	72.95		63.6	
	C.				
11	Parking lobby access (between generator and electrical room)	83.3	72-80	66.4	45-60
12	Payment center outside area	84.3	72-80	65.2	45-60
13	Payment center outside area (left side)	84.3	72-80	63	45-60
14	Reservoir left side corner	84.2	72-80	63.8	45-60
15	Reservoir right side corner (near day tank)	87.9	72-80	58.1	45-60
16	Reservoir right side corner (near parking lot)	84.5	72-80	63.1	45-60
17	Outer area near pump room	85.2	72-80	64	45-60
	Average	84.81		63.37	

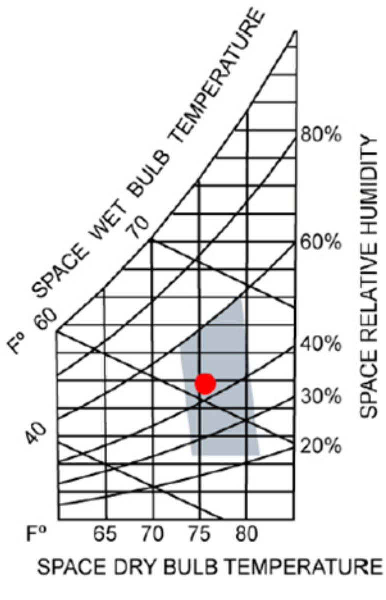


Figure 4.16: ASHRAE standard 55 : Summer Comfort Zone

4.6.2 Air quality

4.6.2.1 Data and analysis

Data concerning the air quality is presented in 4.12 with value of PM2.5 measured in ppm. Data was measured at targeted points shown in 2.9. Raw data is with the site inspection reports, which will be provided to the Client separately. Pursuant to currently applied standard, the recommended safe range for PM2.5 is in [0-35].

Table 4.12: Air Quality - PM2.5

Point	Description of the Point Location	PM2.5
	A.	
1	Pump 1 (near storage)	14
2	Pump 1 (near door)	14
3	Pump 2 (near storage)	15
4	Pump 2 (near door)	15
5	Pump 3 (near storage)	15
6	Pump 3 (below)	15
7	Between pump 1 and 2 (below)	14
8	Between pump 1 and 2 (near storage)	14
	Average	14.5
	B.	
9	Office	12
10	Electrical room	13
	Average	12.5
	C.	
11	Parking lobby access (between generator and electrical room)	13
12	Payment center outside area	13
13	Payment center outside area (left side)	14
14	Reservoir left side corner	14
15	Reservoir right side corner (near day tank)	13
16	Reservoir right side corner (near parking lot)	14
17	Outer area near pump room	13
	Average	13.4

The average reading inside and outside the vicinity of the Pump Stations and Reservoir as well as the Office is from 12.5 to 14.5 and falls under the Excellent Air Quality Level Range. Values of PM2.5 are all within the range of acceptance, inferring no issue with the quality of air.

4.6.2.2 Recommendations

Though there is no issue with the air quality, it is anticipated that future problem can incur with a certain low probability, a better management approach is to ensure that all activities/tasks to be executed within the premise of the PS to follow strictly safety and environmental regulation. For example, all employees and staff to wear appropriate dust-proofed masks when working with activities that potentially incurs dusts or other harmful particles.

4.6.3 Illumination

4.6.3.1 Data and analysis

Data concerning the illumination is presented in Table 4.13 with the LUX value. Data was measured at targeted points shown in Figure 2.9. Raw data is with the site inspection reports, which will be provided to the Client separately. Persuant to RULE 1075.4 of DOLE-OSH standard [3], the recommended minimum for LUX is in 100.

The average illumination of the pump room, office and vicinity is well above the standard minimum. Illumination of the pump room comes from the interior lighting. There is also additional illumination When the access door is open.

4.6.3.2 Recommendations

- Use artificial lighting equipment when accessing and conducting activities requiring detailed output at darker specific areas especially those under the overhang.

Table 4.13: Illumination

Point	Description of the Point Location	Illumination
	A.	
1	Pump 1 (near storage)	18
2	Pump 1 (near door)	106
3	Pump 2 (near storage)	280
4	Pump 2 (near door)	18
5	Pump 3 (near storage)	82
6	Pump 3 (below)	16
7	Between pump 1 and 2 (below)	18
8	Between pump 1 and 2 (near storage)	250
	Average	94.3
	B.	
9	Office	340
10	Electrical room	320
	Average	330
	C.	
11	Parking lobby access (between generator and electrical room)	6900
12	Payment center outside area	4200
13	Payment center outside area (left side)	7500
14	Reservoir left side corner	1800
15	Reservoir right side corner (near day tank)	106000
16	Reservoir right side corner (near parking lot)	7400
17	Outer area near pump room	2400
	Average	19457

4.6.4 Industrial ventilation

4.6.4.1 Data and analysis

Natural ventilation through the access door is not sufficient to attain the minimum Air Changes requirement of the Pump House and so Mechanical Ventilation is utilized most of the time.

4.6.4.2 Recommendations

-

4.6.5 Housekeeping

4.6.5.1 Documentation

Following problems are the facts:

- Current documentation practice is heavily dominated with paper based system, which follows the current practice in Maynilad. There is a large amount/collection of papers that recorded past activities but is of no use and beneficial if data cannot be transformed into digital format for time series analysis, which is an essential part of asset management practice;
- No proper filing/library system with standardized coding rule that will provide convenience for operators/users to timely find appropriate documents;
- Daily operation data is crucial information for future analysis but it is recorded in excel based file without relational tables, which makes it from hard to impossible for data compilation, filtering, and mining. Many past data has been recorded with outliers and incorrect data types.

Table 4.14: Housekeeping.

Description	Status	CS	IT	Remarks
- Sufficient waste segregation assets	yes	1	1	
- waste segregation policy	yes	1	1	
- Signage	yes	1	1	
- Genset emission control	yes		1	

4.6.5.2 Waste management and environmental control

There is no issue with regard to waste management and environmental control as confirmed by the checklist shown in Table 4.14

4.6.5.3 Office arrangement and ergonomic

Table 4.15 shows the data concerning parameters associated with office arrangement and ergonomic considerations.

4.6.5.4 Recommendations

Followings are recommendations

- Development of a web-based database management system, with appropriate set of relational data tables to record operational data, power consumption data, and intervention data;
- Development of documentation code and naming for appropriate filing and library/referencing;
- Applying best practices with regard to ergonomic in combination with interior design and arrangement of office space.

4.6.6 Noise

4.6.6.1 Data and analysis

Data concerning the noise is presented in 4.16.Data was measured at targeted points shown in Figure 2.18. Raw data is with the site inspection reports, which will be provided to the Client separately.

Regular operation at 2 pumps running was considered during the sound level measurement and so the reading closely represents the normal daily noise level inside the plant. The average sound level inside the Pump room is at 94.3 dBA.

The sound level at pump station vicinity and inside the office are within safe values below 70dBA.

A high pitch sound is heard when the exhaust fan is operated.

4.6.6.2 Recommendations

- Use protective hearing equipment when working inside the Pump House and have a scheduled break/rest at designated location. Shall not be exposed at such noise beyond 5 hours in a day.
- Designate location inside the Plant with the minimum noise level - can be the Office, Inside Pump Station and Reservoir, and Outside the Vicinity of Pump Station, if below is not possible.
- Install Sound Attenuation Device (such as sound-absorbing wall panels and door seals) at the Office to reduce the current 69 dBA to ideal Office level of 50-55 dBA.
- Investigate source of high pitch sound heard when the exhaust fan is operated.
- Purchase a sufficient numbers of electronic noise canceling earphones.

Table 4.15: Ergonomics.

Parameters	Sub-parameters	Status	Remarks
Posture	Head	1	Ceiling height is high enough to cause head injury while sitting or when standing.
	Neck	1	Neck posture is in good ergonomic condition. Consider having an interval for fit-break to avoid neck muscles stiffening.
	Back	1	Back posture while sitting is in good posture. Consider standing and doing fit-break exercises to relax spine.
	Hands/Wrist	0	Proper hand positioning in the keyboard is not observed. Wrist bending is seldom.
	Feet	1	Feet position is in good posture. Good clearance below worktables.
	Eyes	0	The computer monitor is on eyelevel in a certain operator only. Consider adjusting the monitor level comfortable to every operator. Look away into distance in order to rest the eyes for every 10 minutes or so.
Equipment / Tool			
	Computer display	0	Not adjusted and the operator get used to its current setting. Display brightness must be adjustable in the comfort of the operator-in-charge. Consider the use of anti-glare and blue light to reduce the possibility of eyestrain.
	Keyboard	1	Keyboard position causes poor hand posture that can lead to injury at long exposure.
	Mouse	1	Mouse usage is average due to monitoring. Prolong usage may cause reduced blood flow leading to muscular injury.
	Chair	0	Consider using ergonomic chair that is capable of back support, height, armrest adjustments.
	Table	0	Consider use of ergonomic tables to adjust the height of the table in desired position easily without exerting much effort to adjust manually.
	Files	1	Hard copy file system and location is well observed. Too high or too low file location may require a person to bend his body or force his hand to grip a file in an awkward posture. Frequent situation may lead to MSD.
Operations / Maintenance	Illumination	0	According to the maintenance team, the motion-activated light is not bright enough to complete their task efficiently at night. Moreover, the light has short on-off delay operation that means that the team must move more often to avoid the light to dim. Consider having a manual switch option to by-pass the motion sensors and le the light on while doing maintenance.
	Noise Exposure	1	Noise emitted by the machines in the pump station is high. Consider the use of proper ear protections to reduce the sound intensity. In offices, the sound intensity is acceptable.
	Temperature	1	Temperature in the pump station is not acceptable at long exposure. Consider cooling down the body temperature at the designated area (i.e. outside, office).
Facility / General Workplace	Layout	1	Layout of the pump station is well observed. Distance between pumps is acceptable for well maintenance movement.
	Height clearances	1	Height clearances from ceiling to head is very high. Chance of getting head injury is very low.

Table 4.16: Sound Levels.

Point	Description of the Point Location	Sound level
	A.	
1	Pump 1 (near storage)	95.8
2	Pump 1 (near door)	93.8
3	Pump 2 (near storage)	93.2
4	Pump 2 (near door)	94.2
5	Pump 3 (near storage)	90.5
6	Pump 3 (below)	94.2
7	Between pump 1 and 2 (below)	96.9
8	Between pump 1 and 2 (near storage)	95.7
	Average	94.3
	B.	
9	Office	69.5
10	Electrical room	70.0
	Average	69.8
	C.	
11	Parking lobby access (between generator and electrical room)	68.0
12	Payment center outside area	65.4
13	Payment center outside area (left side)	70.9
14	Reservoir left side corner	51.7
15	Reservoir right side corner (near day tank)	59.0
16	Reservoir right side corner (near parking lot)	69.9
17	Outer area near pump room	87.6
	Average	67.5

Chapter 5

Conceptual Design and Reliability Study

5.1 Basis of Design

5.1.1 As-built drawings

A collection of as-built drawings are given in A3 print out with electronic files saved both in PDF and CAD formats.

5.1.2 Mechanical design

As set of conceptual drawings is given in Appendix

5.2 Bill of Materials

Based on the recommendations and conceptual design, a high level Bill of Quantity (BOQ) can be generated . The BOQ table includes the condition states and intervention types respectively.

5.3 Determination of optimal intervention strategies

This section focuses on determination of intervention strategies for pumps or components of pumps in the station. Other assets such as electrical assets and other assets belong to FDAS system are not part of the analysis because they are utmost critical assets that require to provide adequate level of services at all time. Intervention strategies for electrical assets and FDAS assets are suggested to follow replacement schedule defined by the manufacturers.

5.3.1 Reliability

With the historical data given, it is not possible to precisely quantify the reliability for each pump or even each components of pumps. Thus, In order to more or less estimate the reliability, obtaining knowledge and experience of the end-users becomes important.

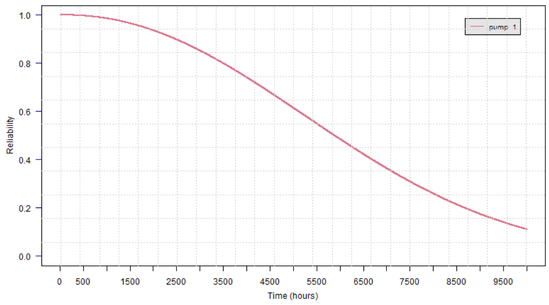
We assume reliability of an asset to follow a Weibull function. The Weibull function is suitable function to be used in survival/reliability analysis since it considers the memory of assets, i.e. past failure probability will be considered with duration of failure (refer to subsection 3.5.2 for further description on Weibull model).

Table 5.1 shows the assumed values used for model's parameters.

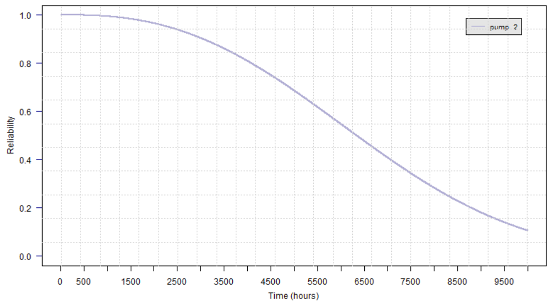
Using the parameter values in Table 5.1, reliability curves for respective pumps can be drawn (Figure 5.1.

Table 5.1: Weibull parameters.

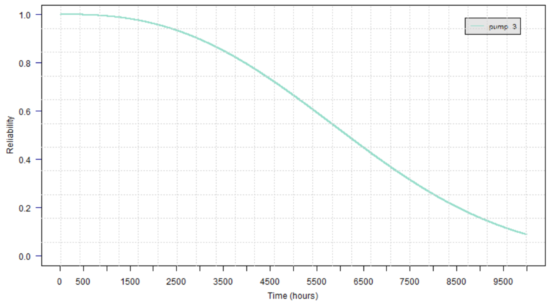
Assets	Weibull parameters		Remarks
	α	β	
BP1	6,966	2.174	
BP2	7,308	2.576	
BP3	7,092	2.573	



a - BP#1



b - BP#2



c - BP#3

Figure 5.1: Reliability

5.3.2 Impacts

Impacts are costs or loss of benefits incurred to the Client and users. Impacts are incurred by execution of PI or CI and by disruption to the operation of the PS.

Impacts incurred by execution of PI can be estimated based on, for example, conceptual design with the ballpark estimate. However, impacts incurred by execution of a CI is not easy to obtain due to lack of historical data. This is similar to the estimation of impacts such as loss in revenue, reputation, and regulatory.

Fortunately, from mathematical view point, the optimization model presented in subsection 3.7.1 will be only dependent on the ratio between CI and PI. This means that we can make assumption on the ratio between PI and CI based on holistic approach. For example, if the PI is 10 millions PHP and CI is 20 million, the ratio would be PI/CI =0.5, and the model will determine the optimal time window (T) to execute the PI. This time window T will not change as long as the ratio between CI/PI is the same.

Table 5.2 shows the assumption on impacts incurred by execution of PI and CI as well the the impacts incurred considering the 3Rs (revenue, reputation, and regulatory).

Values of revenues incurred by execution on respective pumps shall be calculated based on assumption on maintainability (e.g. duration of CI execution to fix the pump). Reputation and regulatory are not straightforward to estimate in monetary units, however, they can be assumed to be measured by "Willingness to Pay".

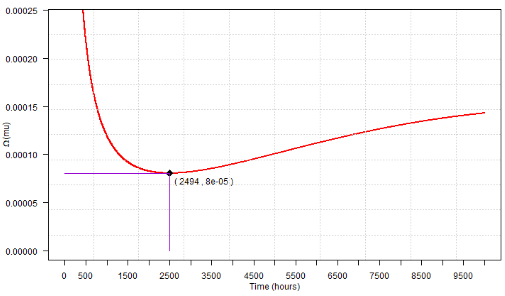
Table 5.2: Impact values (mus).

Assets	Weibull parameters		Impacts	Discount (%)	Remarks
	α	β	PI/CI	ρ	
BP1	6,966	2.174	0.1072	8.5	
BP2	7,308	2.576	0.4244	8.5	
BP3	7,092	2.573	0.2583	8.5	
BP4	7,710	2.987	0.3061	8.5	
SP1	6,458	2.983	0.3086	8.5	
SP2	6,048	2.636	0.2031	8.5	

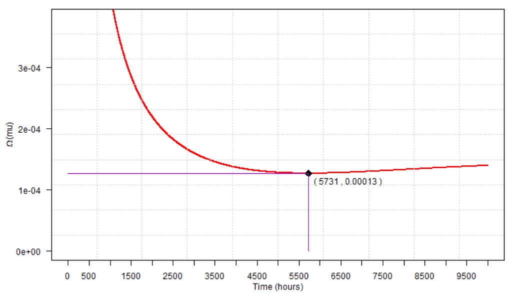
Note: R1, R2, R3 are revenue, reputation and regulatory, respectively.

5.3.3 Optimal Time Window and Impacts

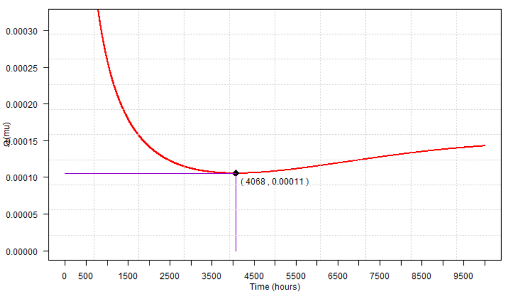
Figure 5.2 presents a collection of curves representing Optimal Time Window (OTW) and impacts incurred by executing PIs on respective pumps.



a - BP#1



b - BP#2



c - BP#3

Figure 5.2: Impact curves

The curves are with parabolic shapes, with a minimal point representing the optimal point obtained by the model. Shapes of the curves prove following important conclusions

- If a PI is executed too often, the failure probability will be decreased, however, at the same time, more money is to spend on intervention activities. It will be a waste of resources to follow a program that triggers PIs;
- The impact will decrease as the OTW increases to the optimal point and then go upward indicating that if a PI is executed beyond a certain reliability threshold, failure probability will increase, leading to more sudden failures that require to execute CIs and higher loss (e.g. the 3 Rs).

Table 5.3: Impact values (mus).

Assets	OTW (hours)	Minimum Impact (mus)
BP1	2,494	8.04E-05
BP2	5,731	1.27E-04
BP3	4,068	1.06E-04
BP4	4,785	9.66E-05
SP1	4,014	1.17E-04
SP2	3,052	1.08E-04

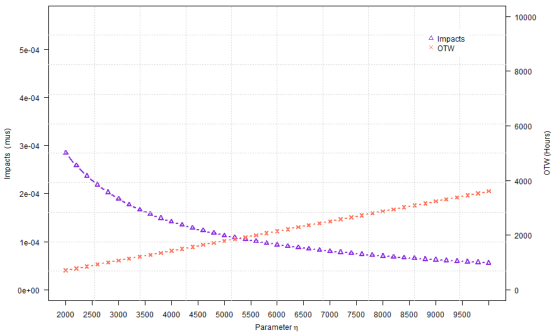
Note: OTW stands for Optimal Time Window to execute an PI.

5.3.4 Sensitivity analysis

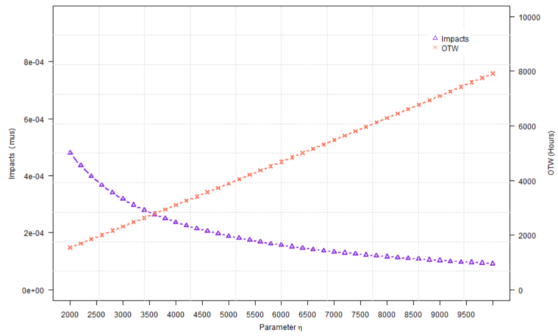
As a matter of fact, results of the optimization model are subjected to uncertainties with model's parameters and variables. Model's parameters are deterioration parameters η and β and impacts that should be obtained from historical data.

This subsection provides results of sensitivity analysis (SA) conducted on Weibull parameters η and β and the ratio between CI and PI. A SA was conducted by running the targeted parameter in a pre-defined range while keeping other parameters constant.

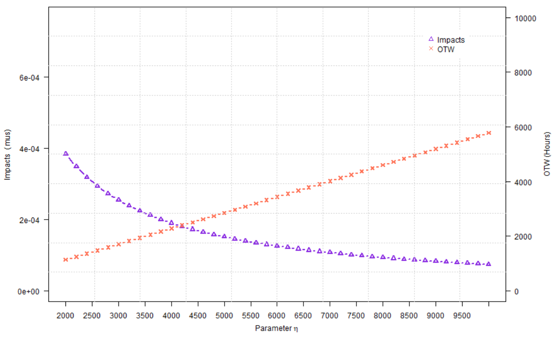
Results of the SA on parameter η are shown in Figure 5.3, with following discussion points.



a - BP#1



b - BP#2

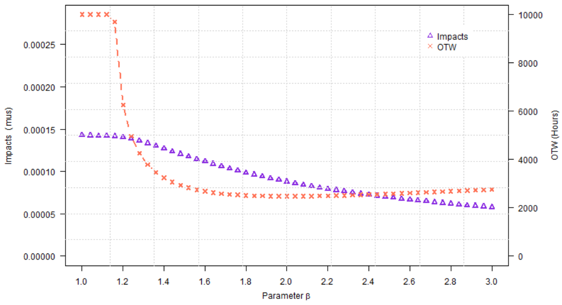


c - BP#3

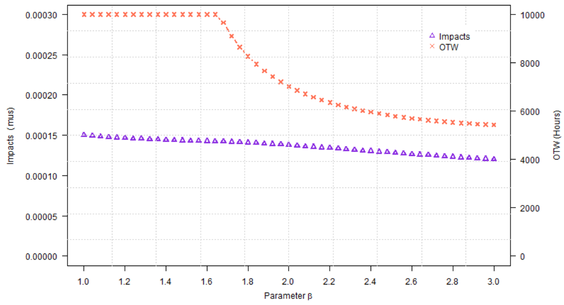
Figure 5.3: Sensitivity Analysis (η)

- Values of OTW follow either exponential function or log-normal function with decreasing trend and be converged to a minimum year. This is logic as the smaller value of α is, the less failure probability, and therefore the OTW will be deferred longer;
- Values of impact follow a monotonic increasing function. This is also logic as the higher failure probability infers more CIs to be executed.

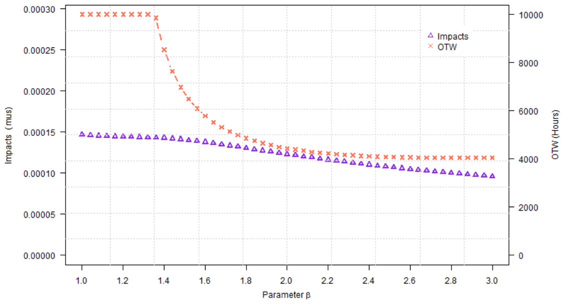
Results of the SA on parameter β are shown in Figure 5.4, with following discussion points.



a - BP#1



b - BP#2



c - BP#3

Figure 5.4: Sensitivity Analysis (β)

- Values of OTW follow an exponential function function with decreasing trend and be converged to a minimum year. This is logic as the smaller value of β is, the less failure probability, and therefore the OTW will be deferred longer;
- Values of impact follow a monotonic increasing function. This is also logic as the higher failure probability infers more CIs to be executed.

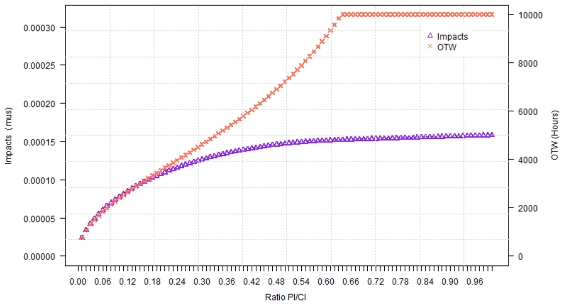
Results of the SA on the ratio PI/CI are shown in Figure 5.5, with following discussion points.

- Values of OTW follow an exponential function function with decreasing trend and be converged to a minimum year. This is logic as if the value of CI is not much different from PI, there is no need to perform PI often, the operators can just execute a CI when pumps fail. However, if the ratio is high, it means it will be very costly to let the system fails, hence it is advisable to shorten the time window to execute PIs to prevent possible failures from happening;
- Values of impact follow a monotonic increasing function. This is also logic as the higher ratio of CI/PI, the more impacts will be incurred with CI and therefore the annual cost will increase.

5.4 Return on Investment

It is important to note that in asset management context, the Return on Investment (ROI) is understood different from the ROI used for CAPEX projects. In CAPEX project, ROI is a ratio between the Net Present Value (NPV) of benefits (e.g. positive sum of cash flow) incurred over a pre-defined life cycle of a project (e.g. 20 or 30 years), at which there is a salvage value of the facility.

In asset management context, the ROI encompasses the ROI used in CAPEX project. This can be obviously seen in the impact curves shown in Figure 5.2. If the owner follows the optimal time



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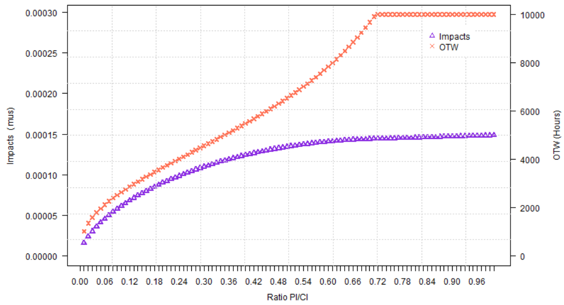
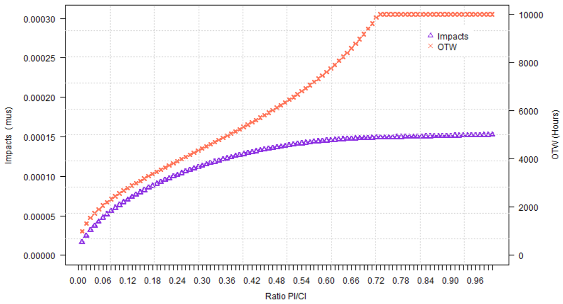


b - BP#2



c - BP#3

Figure 5.5: Sensitivity Analysis (PI/CI)

window defined to execute a PI on any individual pump, the return on investment compared to other strategy that follow different time window is the difference of the impacts.

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Appendix A

Recommended Maintenance Program

Maintenance Program

Code	Name	Station ID	Asset Description	Component	Failure Mode	Criticality	Failure Pattern	Task	Frequency	Done by	Comments
For dedicated spare pumps & motors only	**Pump**	**R1P**	**Horizontal pump between bearings**	**Bearings**	**bearing failure caused by false brinelling**	**High**	**Age-related**	**Rotate pump shaft 2-1/4 times**	**Every shift**	**Operator**	**Ensure that pump is isolated from power source**
For dedicated spare pumps & motors only	**Pump**	**R1P**	**Horizontal pump between bearings**	**Bearings**	**Bearing failure caused by contaminated oil**	**High**	**Random**	**Inspect oil for water contamination Regrease as necessary**	**Weekly**	**Maintenance contractor**	
For dedicated spare pumps & motors only	**Motor**	**R1P**	**Horizontal pump between bearings**	**Starter; Auto start system**	**Fail to start**	**High**	**Random**	**Start pump and run for at least 2 hours. Check all functionalities.**	**Monthly**	**Operator**	**Do this during visit by maintenance contractor.**
WSO-AR1PR-0014	Air Valve SP1	R1P	Air valve	Actuator	Fail Open/Fail Close	Medium	Random	Overhaul pneumatic actuaor & clean internals	Annually	Maintenance contractor	Assign task to OEM contractor.
WSO-AR1PR-0024	Air Valve SP2	R1P	Air valve	Actuator	Fail Open/Fail Close	Medium	Random	Overhaul pneumatic actuaor & clean internals	Annually	Maintenance contractor	Assign task to OEM contractor.
WSO-AR1PR-0034	Air Valve SP3	R1P	Air valve	Actuator	Fail Open/Fail Close	Medium	Random	Overhaul pneumatic actuaor & clean internals	Annually	Maintenance contractor	Assign task to OEM contractor.
WSO-AR1PR-0042	Bypass Valve	R1P	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-AR1PR-0013	Check Valve SP1	R1P	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-AR1PR-0023	Check Valve SP2	R1P	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-AR1PR-0033	Check Valve SP3	R1P	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-AR1PR-0038	Discharge Pipe and Fittings	R1P	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-AR1PR-0012	Discharge Pressure Gauge SP1	R1P	Pressure Measuring	Bourdon tube	Pressure gauge reading is wrong due to wear	Low	Age-related	Replace pressure gauge	Annually	Maintenance contractor	Replace with calibrated pressure gauge. Mark with acceptable operating range. Criticality is low if the online pressure sensors are still functioning properly.
WSO-AR1PR-0022	Discharge Pressure Gauge SP2	R1P	Pressure Measuring	Bourdon tube	Pressure gauge reading is wrong due to wear	Low	Age-related	Replace pressure gauge	Annually	Maintenance contractor	Replace with calibrated pressure gauge. Mark with acceptable operating range. Criticality is low if the online pressure sensors are still functioning properly.
WSO-AR1PR-0032	Discharge Pressure Gauge SP3	R1P	Pressure Measuring	Bourdon tube	Pressure gauge reading is wrong due to wear	Low	Age-related	Replace pressure gauge	Annually	Maintenance contractor	Replace with calibrated pressure gauge. Mark with acceptable operating range. Criticality is low if the online pressure sensors are still functioning properly.
WSO-AR1PR-0041	Downstream SAV1 BV	R1P	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-AR1PR-0071	Fuel Day Tank	R1P	Tank	Tank wall & bottom	Leaks due to corrosion	High	Age-related	Inspect tank for leaks	Daily	Operator	Anytime during day shift.
WSO-AR1PR-0071	Fuel Day Tank	R1P	Tank	Tank wall & bottom	Leaks due to corrosion	High	Age-related	Clean tank & inspect bottom plates for corrosion	Every 2 years	Maintenance contractor	Use qualified maintenance contractor.

WSO-AR1PR-0070	Fuel Storage Tank	R1P	Tank	Tank wall & bottom	Leaks due to corrosion	High	Age-related	Inspect tank for leaks	Daily	Operator	Anytime during day shift.
WSO-AR1PR-0070	Fuel Storage Tank	R1P	Tank	Tank wall & bottom	Leaks due to corrosion	High	Age-related	Clean tank & inspect bottom plates for corrosion	Every 2 years	Maintenance contractor	Use qualified maintenance contractor.
WSO-AR1PR-0003	Motorized Actuator BV1	R1P	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-AR1PR-0005	Motorized Actuator BV2	R1P	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-AR1PR-0016	Motorized Actuator SP1	R1P	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-AR1PR-0026	Motorized Actuator SP2	R1P	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-AR1PR-0036	Motorized Actuator SP3	R1P	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-AR1PR-0002	Motorized Discharge Valve BV1	R1P	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-AR1PR-0004	Motorized Discharge Valve BV2	R1P	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-AR1PR-0015	Motorized Discharge Valve SP1	R1P	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-AR1PR-0025	Motorized Discharge Valve SP2	R1P	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-AR1PR-0035	Motorized Discharge Valve SP3	R1P	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-AR1PR-0073	Overhead Travelling Crane	R1P	Lifting	Chain & gear mechanism	Failure of manual chain hoist due to wear & tear	High	Age-related	Inspect manual chain hoist for wear	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-AR1PR-0073	Overhead Travelling Crane	R1P	Lifting	Motor drive	Motor burns due to failure of winding insulation	High	Random	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-AR1PR-0072	Pipes and Fittings for Fuel	R1P	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-AR1PR-0007	Reservoir Blow-off Butterfly Valve	R1P	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-AR1PR-0010	Storage Pump 1	R1P	Pumping	Bearings	Loss of lubrication	High	Age-related	Scheduled greasing	Weekly	Maintenance contractor	Avoid overgreasing. Use correct grease as stipulated by bearing manufacturer.

WSO-AR1PR-0010	Storage Pump 1	R1P	Pumping	Bearings	High vibration due to cavitation	High	Random	Monitor suction pressure not to go below **xx** head.	Every hour	Operator	Refer to pump specifications on minimum NPSH requirements. Follow company policy in dealing with cavitation issues (e.g. call MCC to increase suction pressure and/or shutdown pumps)
WSO-AR1PR-0010	Storage Pump 1	R1P	Pumping	Bearings	High vibration due to bearing failure (e.g. foreign materials in lubrication)	High	Random	Vibration monitoring	2-weekly (every 2 weeks)	Maintenance contractor	Use trained contractor for the appropriate vibration monitoring device. Report findings every month.
WSO-AR1PR-0010	Storage Pump 1	R1P	Pumping	Packing	Excessive leaks	Medium	Age-related	Tighten packing bolts	2-weekly (every 2 weeks)	Maintenance contractor	Avoid overtightening of packing bolts.
WSO-AR1PR-0010	Storage Pump 1	R1P	Pumping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-AR1PR-0010	Storage Pump 1	R1P	Pumping	Vibration dampers	Leaks due to deteriorated materials caused by fatigue	Medium	Age-related	Replace vibration dampers based on recommended life	Every 10 years	Maintenance contractor	Refer to recommended life of dampers by manufacturer. Otherwise, purchase spare damper before its recommended life to ensure availability when needed.
WSO-AR1PR-0010	Storage Pump 1	R1P	Pumping	System	General system leaks	Low	Random	Inspect system for leaks	Shift	Operator	Report excessive leaks for scheduled repairs.
WSO-AR1PR-0010	Storage Pump 1	R1P	Pumping	Impeller	Impeller wear	Low	Age-related	-Replace impeller -Inspect and measure clearances	-10 years -Annually	Maintenance contractor	Inspect during annual overhauls.
WSO-AR1PR-0010	Storage Pump 1	R1P	Pumping	Suction strainer	Blockage	Medium	Age-related	Clean strainer	Annually	Maintenance contractor	During annual overhauls.
WSO-AR1PR-0020	Storage Pump 2	R1P	Pumping	Bearings	Loss of lubrication	High	Age-related	Scheduled greasing	Weekly	Maintenance contractor	Avoid overgreasing. Use correct grease as stipulated by bearing manufacturer.
WSO-AR1PR-0020	Storage Pump 2	R1P	Pumping	Bearings	High vibration due to cavitation	High	Random	Monitor suction pressure not to go below **xx** head.	Every hour	Operator	Refer to pump specifications on minimum NPSH requirements. Follow company policy in dealing with cavitation issues (e.g. call MCC to increase suction pressure and/or shutdown pumps)
WSO-AR1PR-0020	Storage Pump 2	R1P	Pumping	Bearings	High vibration due to bearing failure (e.g. foreign materials in lubrication)	High	Random	Vibration monitoring	2-weekly (every 2 weeks)	Maintenance contractor	Use trained contractor for the appropriate vibration monitoring device. Report findings every month.
WSO-AR1PR-0020	Storage Pump 2	R1P	Pumping	Packing	Excessive leaks	Medium	Age-related	Tighten packing bolts	2-weekly (every 2 weeks)	Maintenance contractor	Avoid overtightening of packing bolts.
WSO-AR1PR-0020	Storage Pump 2	R1P	Pumping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-AR1PR-0020	Storage Pump 2	R1P	Pumping	Vibration dampers	Leaks due to deteriorated materials caused by fatigue	Medium	Age-related	Replace vibration dampers based on recommended life	Every 10 years	Maintenance contractor	Refer to recommended life of dampers by manufacturer. Otherwise, purchase spare damper before its recommended life to ensure availability when needed.
WSO-AR1PR-0020	Storage Pump 2	R1P	Pumping	System	General system leaks	Low	Random	Inspect system for leaks	Shift	Operator	Report excessive leaks for scheduled repairs.

WSO-AR1PR-0020	Storage Pump 2	R1P	Pumping	Impeller	Impeller wear	Low	Age-related	-Replace impeller -Inspect and measure clearances	-10 years -Annually	Maintenance contractor	Inspect during annual overhauls.
WSO-AR1PR-0020	Storage Pump 2	R1P	Pumping	Suction strainer	Blockage	Medium	Age-related	Clean strainer	Annually	Maintenance contractor	During annual overhauls.
WSO-AR1PR-0030	Storage Pump 3	R1P	Pumping	Bearings	Loss of lubrication	High	Age-related	Scheduled greasing	Weekly	Maintenance contractor	Avoid overgreasing. Use correct grease as stipulated by bearing manufacturer.
WSO-AR1PR-0030	Storage Pump 3	R1P	Pumping	Bearings	High vibration due to cavitation	High	Random	Monitor suction pressure not to go below **xx** head.	Every hour	Operator	Refer to pump specifications on minimum NPSH requirements. Follow company policy in dealing with cavitation issues (e.g. call MCC to increase suction pressure and/or shutdown pumps)
WSO-AR1PR-0030	Storage Pump 3	R1P	Pumping	Bearings	High vibration due to bearings failure (e.g. foreign material in lubrication)	High	Random	Vibration monitoring	2-weekly (every 2 weeks)	Maintenance contractor	Use trained contractor for the appropriate vibration monitoring device. Report findings every month.
WSO-AR1PR-0030	Storage Pump 3	R1P	Pumping	Packing	Excessive leaks	Medium	Age-related	Tighten packing bolts	2-weekly (every 2 weeks)	Maintenance contractor	Avoid overtightening of packing bolts.
WSO-AR1PR-0030	Storage Pump 3	R1P	Pumping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-AR1PR-0030	Storage Pump 3	R1P	Pumping	Vibration dampers	Leaks due to deteriorated materials caused by fatigue	Medium	Age-related	Replace vibration dampers based on recommended life	Every 10 years	Maintenance contractor	Refer to recommended life of dampers by manufacturer. Otherwise, purchase spare damper before its recommended life to ensure availability when needed.
WSO-AR1PR-0030	Storage Pump 3	R1P	Pumping	System	General system leaks	Low	Random	Inspect system for leaks	Shift	Operator	Report excessive leaks for scheduled repairs.
WSO-AR1PR-0030	Storage Pump 3	R1P	Pumping	Impeller	Impeller wear	Low	Age-related	-Replace impeller -Inspect and measure clearances	-10 years -Annually	Maintenance contractor	Inspect during annual overhauls.
WSO-AR1PR-0030	Storage Pump 3	R1P	Pumping	Suction strainer	Blockage	Medium	Age-related	Clean strainer	Annually	Maintenance contractor	During annual overhauls.
WSO-AR1PR-0017	Storage Pump Motor SP1	R1P	Motor	Motor winding	Motor trip due to overloading	High	Random	Motor (skin) temperature measurement	Every hour	Operator	Refer to motor specifications on maximum allowable surface temperature.
WSO-AR1PR-0017	Storage Pump Motor SP1	R1P	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-AR1PR-0027	Storage Pump Motor SP2	R1P	Motor	Motor winding	Motor trip due to overloading	High	Random	Motor (skin) temperature measurement	Every hour	Operator	Refer to motor specifications on maximum allowable surface temperature.
WSO-AR1PR-0027	Storage Pump Motor SP2	R1P	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.
WSO-AR1PR-0037	Storage Pump Motor SP3	R1P	Motor	Motor winding	Motor trip due to overloading	High	Random	Motor (skin) temperature measurement	Every hour	Operator	Refer to motor specifications on maximum allowable surface temperature.
WSO-AR1PR-0037	Storage Pump Motor SP3	R1P	Motor	Motor winding	Motor burns due to failure of winding insulation	Low	Age-related	Inspect motor winding insulation	Annually	Maintenance contractor	Use qualified maintenance contractor.

WSO-AR1PR-0009	Suction Butterfly Valve SP1	R1P	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-AR1PR-0019	Suction Butterfly Valve SP2	R1P	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-AR1PR-0029	Suction Butterfly Valve SP3	R1P	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-AR1PR-0001	Suction Pipes and Fittings	R1P	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-AR1PR-0008	Suction Pipes and Fittings SP1	R1P	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-AR1PR-0018	Suction Pipes and Fittings SP2	R1P	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-AR1PR-0028	Suction Pipes and Fittings SP3	R1P	Piping	Flange	Leaks due to loose bolts and/or gasket failure	Medium	Age-related	Re-tighten bolts using specified torque values	Annually	Maintenance contractor	Use proper bolt tightening methods (e.g. manual, hydraulic, pneumatic, tensioning, etc.) Apply required bolt torque values.
WSO-AR1PR-0011	Suction Pressure Gauge SP1	R1P	Pressure Measuring	Bourdon tube	Pressure gauge reading is wrong due to wear	Low	Age-related	Replace pressure gauge	Annually	Maintenance contractor	Replace with calibrated pressure gauge. Mark with acceptable operating range. Criticality is low if the online pressure sensors are still functioning properly.
WSO-AR1PR-0021	Suction Pressure Gauge SP2	R1P	Pressure Measuring	Bourdon tube	Pressure gauge reading is wrong due to wear	Low	Age-related	Replace pressure gauge	Annually	Maintenance contractor	Replace with calibrated pressure gauge. Mark with acceptable operating range. Criticality is low if the online pressure sensors are still functioning properly.
WSO-AR1PR-0031	Suction Pressure Gauge SP3	R1P	Pressure Measuring	Bourdon tube	Pressure gauge reading is wrong due to wear	Low	Age-related	Replace pressure gauge	Annually	Maintenance contractor	Replace with calibrated pressure gauge. Mark with acceptable operating range. Criticality is low if the online pressure sensors are still functioning properly.
WSO-AR1PR-0040	Surge Anticipating Valve 1 (SAV1)	R1P	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.
WSO-AR1PR-0039	Upstream SAV1 BV	R1P	Valve	Valve disc & seat	Valve passing (leaks)	Medium	Age-related	Test valve integrity	Annually	Maintenance contractor	Use qualified maintenance contractor. Failure of this valve may cause problems during maintenance of pump/motor.

Appendix B

Vibration Data

DOCUMENT TITLE

AYALA ALABANG PUMP STATION MOTOR & PUMP UNITS VA STATUS REPORT AS OF FEB 2019

COMMENT

AYALA ALABANG PUMPING STATION

VISA

Written by	Approved by	State	Date
ENGR. JAY DIMALIBOT	ENGR. PETER VASQUEZ	PHI	25/03/2019 09:22:18

Table of contents

Synthesis Report

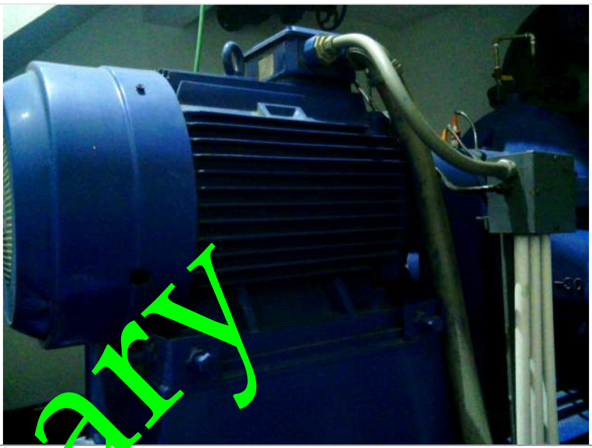
Filter: Equipment name (+) \ Tree order (+)

Location	Equipment	Diagnosis				Recommendations
		Previous Date		Current Date		
AYALA ALABANG\	BOOSTER PUMP UNIT 1			GOOD		Continue monitor vibrations periodically
				14/02/2019 11:38:36		
		Oper.		Oper.	DfCnd	
		Vibrations are within acceptable levels				
AYALA ALABANG\	BOOSTER PUMP UNIT 2			GOOD		No action required
				14/02/2019 11:57:25		
		Oper.		Oper.	DfCnd	
		Vibrations are within acceptable levels				
AYALA ALABANG\	BOOSTER PUMP UNIT 3			GOOD		No action required
				14/02/2019 11:43:11		
		Oper.		Oper.	DfCnd	
		Vibrations are within acceptable levels				

Expertise Report

Filter: Equipment name (+) \ Tree order (+)

Location	AYALA ALABANG\	Fixed speed
Designation	Ayala Alabang R1 Pump Station	
Equipment	BOOSTER PUMP UNIT 1	
Designation		
Abbreviation	BP#1	
Serial No		
Model		
Periodicity (d)	*Normal* 60 *Alarm* 15	



Previous Advice	*Condition*	*Rotation Speed*

Date 14/02/2019 11:38:36	GOOD	*Speed* 22.4 Hz / 1343 rpm
	Health is good for a long time service without restriction	*Author* u1
		System - Serial FALCON - 11407
Condition DfCnd		*Sensor*
		Connector

Diagnosis & Recommendation

Parameters sheet

Diagnosis

Vibrations are within acceptable levels

Good overall state for component 'Electric motor'.
Overall state still acceptable for the component 'Pump'.

Recommendations

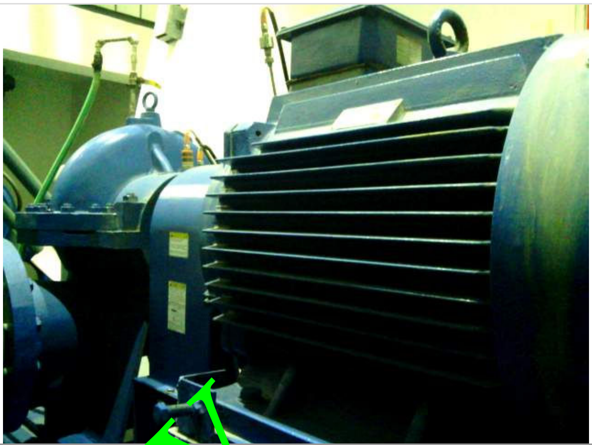
Continue monitor vibrations periodically

Continue monitor vibrations periodically

IP1.jpg


THREE PHASE INDUCTION MOTOR
TERAL
OUTPUT
kW
POLES
TYPE
VOLTAGE
V
FRAME NO.
FREQUENCY
Hz
BEARING NO.
DE
NDE
CURRENT
SPEED
min-1
DUTY TYPE
SERIAL NO.
IP
THERMAL CLASS
REMARKS
MASS
TERAL INC.

Location	AYALA ALABANG\	Fixed speed
Designation	Ayala Alabang R1 Pump Station	
Equipment	BOOSTER PUMP UNIT 2	
Designation		
Abbreviation	BP#2	
Serial No		
Model		
Periodicity (d)	*Normal* 60 *Alarm* 15	



Previous Advice	*Condition*	*Rotation Speed*

Date 14/02/2019 11:57:25 *Condition* DfCnd	GOOD *Health is good for a long time service without restriction.*	*Speed* [illegible] Hz / 1194 rpm *Author* u1 *System - Serial* FALCON - 11407 *Sensor* *Connector*

Diagnosis & Recommendation

Parameters sheet

Diagnosis

Vibrations are within acceptable levels

Good overall state for component 'Electric motor'.
Good overall state for component 'Pump'.

Recommendations

No action required

No action required

IP2.jpg

IP4.jpg

dusty

Location	AYALA ALABANG\	Fixed speed
Designation	Ayala Alabang R1 Pump Station	
Equipment	BOOSTER PUMP UNIT 3	
Designation		
Abbreviation	BP#3	
Serial No		
Model		
Periodicity (d)	*Normal* 60 *Alarm* 15	

Previous Advice	*Condition*	*Rotation Speed*

Date 14/02/2019 11:43:11	GOOD *Health is good for a long time service without restriction.*	*Speed*	29.8 Hz / 1787 rpm
Condition DfCnd		*Author*	u1
		System - Serial	FALCON - 11407
		Sensor	
		Connector	

Diagnosis & Recommendation

Parameters sheet

Diagnosis

Vibrations are within acceptable levels

Good overall state for component 'Electric motor'.

Good overall state for component 'Pump'.

Recommendations

No action required

No action required

IP3.jpg

Analysis Report

Filter: Equipment name (+) \ Tree order (+) Alarm type: Danger \ Alarm \ Pre-Alarm \ Error \ Ok \ Undefined \ Inhibited

AYALA ALABANG\ BOOSTER PUMP UNIT 1

Selected Date	14/02/2019 11:38:36	Speed	22.4 Hz / 1343 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

Operating param.	1	H/S	Last Date	Value	Unit	T-1	Ref.	Avg									
Ovrl:Rotation speed	Rot Spd	Hard	14/02/2019 11:38:36	1343	rpm		1343										
1-MT-Ax	**9**	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:38:36	1.65	mm/s		1.65		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:38:36	0.190	g		0.190		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:38:36	2.35	DEF		2.35		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:38:36	0.157	mm/s		0.157		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:38:36	0.0787	mm/s		0.0787		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:38:36	0.232	mm/s		0.232		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:38:36	0.110	g		0.110		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:38:36	0.129	g		0.129		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:38:36	0.105	g		0.105		DfCnd	High	0	0	0	0	2	4	0
1-MT-RH	**9**	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:38:36	1.20	mm/s		1.20		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:38:36	0.576	g		0.576		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:38:36	2.28	DEF		2.28		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:38:36	0.272	mm/s		0.272		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:38:36	0.183	mm/s		0.183		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:38:36	0.162	mm/s		0.162		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:38:36	0.0522	g		0.0522		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:38:36	0.548	g		0.548		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:38:36	0.129	g		0.129		DfCnd	High	0	0	0	0	2	4	0
1-MT-RV	**9**	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:38:36	1.36	mm/s		1.36		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:38:36	0.258	g		0.258		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:38:36	2.36	DEF		2.36		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:38:36	0.164	mm/s		0.164		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:38:36	0.0820	mm/s		0.0820		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:38:36	0.206	mm/s		0.206		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:38:36	0.0792	g		0.0792		DfCnd	High	0	0	0	0	.15	.3	0

AYALA ALABANG\
BOOSTER PUMP UNIT 1

Selected Date	14/02/2019 11:38:36	Speed	22.4 Hz / 1343 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

		H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
En-MF	En-MF	Soft	14/02/2019 11:38:36	0.0712	g		0.0712		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:38:36	0.246	g		0.246		DfCnd	High	0	0	0	0	2	4	0
2-MT-Ax	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:38:36	2.25	mm/s		2.25		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:38:36	0.323	g		0.323		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:38:36	2.64	DEF		2.64		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:38:36	0.244	mm/s		0.244		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:38:36	0.172	mm/s		0.172		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:38:36	0.0774	mm/s		0.0774		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:38:36	0.104	g		0.104		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:38:36	0.134	g		0.134		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:38:36	0.277	g		0.277		DfCnd	High	0	0	0	0	2	4	0
2-MT-RH	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:38:36	1.29	mm/s		1.29		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:38:36	0.655	g		0.655		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:38:36	2.78	DEF		2.78		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:38:36	0.478	mm/s		0.478		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:38:36	0.227	mm/s		0.227		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:38:36	0.123	mm/s		0.123		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:38:36	0.0566	g		0.0566		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:38:36	0.435	g		0.435		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:38:36	0.483	g		0.483		DfCnd	High	0	0	0	0	2	4	0
2-MT-RV	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:38:36	2.95	mm/s		2.95		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:38:36	0.430	g		0.430		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:38:36	2.54	DEF		2.54		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:38:36	0.299	mm/s		0.299		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:38:36	0.256	mm/s		0.256		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:38:36	0.424	mm/s		0.424		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:38:36	0.111	g		0.111		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:38:36	0.246	g		0.246		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:38:36	0.363	g		0.363		DfCnd	High	0	0	0	0	2	4	0

AYALA ALABANG\ BOOSTER PUMP UNIT 1

Selected Date	14/02/2019 11:38:36	Speed	22.4 Hz / 1343 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

3-PP-Ax	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:38:36	1.13	mm/s		1.13		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:38:36	0.379	g		0.379		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:38:36	2.98	DEF		2.98		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:38:36	0.228	mm/s		0.228		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:38:36	0.0585	mm/s		0.0585		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:38:36	0.0681	mm/s		0.0681		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:38:36	0.0808	g		0.0808		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:38:36	0.330	g		0.330		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:38:36	0.143	g		0.143		DfCnd	High	0	0	0	0	2	4	0

3-PP-RH	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:38:36	2.04	mm/s		2.04		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:38:36	0.753	g		0.753		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:38:36	3.00	DEF		3.00		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:38:36	0.516	mm/s		0.516		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:38:36	0.170	mm/s		0.170		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:38:36	0.185	mm/s		0.185		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:38:36	0.144	g		0.144		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:38:36	0.635	g		0.635		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:38:36	0.290	g		0.290		DfCnd	High	0	0	0	0	2	4	0

3-PP-RV	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:38:36	0.810	mm/s		0.810		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:38:36	0.433	g		0.433		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:38:36	2.69	DEF		2.69		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:38:36	0.0558	mm/s		0.0558		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:38:36	0.0674	mm/s		0.0674		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:38:36	0.0374	mm/s		0.0374		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:38:36	0.0589	g		0.0589		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:38:36	0.373	g		0.373		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:38:36	0.137	g		0.137		DfCnd	High	0	0	0	0	2	4	0

4-PP-Ax	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:38:36	1.49	mm/s		1.49		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:38:36	0.416	g		0.416		DfCnd	None							

AYALA ALABANG\ BOOSTER PUMP UNIT 1

Selected Date	14/02/2019 11:38:36	Speed	22.4 Hz / 1343 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

Defect factor	IND-0003	Hard	14/02/2019 11:38:36	3.11	DEF		3.11		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:38:36	0.0782	mm/s		0.0782		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:38:36	0.0350	mm/s		0.0350		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:38:36	0.0701	mm/s		0.0701		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:38:36	0.120	g		0.120		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:38:36	0.341	g		0.341		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:38:36	0.193	g		0.193		DfCnd	High	0	0	0	0	2	4	0
4-PP-RH	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:38:36	2.35	mm/s		2.35		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:38:36	0.681	g		0.681		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:38:36	3.18	DEF		3.18		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:38:36	0.107	mm/s		0.107		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:38:36	0.0757	mm/s		0.0757		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:38:36	0.0966	mm/s		0.0966		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:38:36	0.184	g		0.184		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:38:36	0.495	g		0.495		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:38:36	0.371	g		0.371		DfCnd	High	0	0	0	0	2	4	0
4-PP-RV	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:38:36	1.95	mm/s		1.95		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:38:36	0.435	g		0.435		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:38:36	3.05	DEF		3.05		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:38:36	0.104	mm/s		0.104		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:38:36	0.0759	mm/s		0.0759		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:38:36	0.119	mm/s		0.119		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:38:36	0.152	g		0.152		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:38:36	0.354	g		0.354		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:38:36	0.191	g		0.191		DfCnd	High	0	0	0	0	2	4	0

AYALA ALABANG\ BOOSTER PUMP UNIT 2

Selected Date	14/02/2019 11:57:25	Speed	19.9 Hz / 1194 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

AYALA ALABANG\ BOOSTER PUMP UNIT 2

Selected Date	14/02/2019 11:57:25	Speed	19.9 Hz / 1194 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

Operating param.	1	H/S	Last Date	Value	Unit	T-1	Ref.	Avg									
Ovrl:Rotation speed	Rot Spd	Hard	14/02/2019 11:57:25	1194	rpm		1194										
1-MT-Ax	9	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:57:25	0.884	mm/s		0.884		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:57:25	0.164	g		0.164		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:57:25	2.43	DEF		2.43		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:57:25	0.0427	mm/s		0.0427		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:57:25	0.162	mm/s		0.162		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:57:25	0.0639	mm/s		0.0639		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:57:25	0.0828	g		0.0828		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:57:25	0.135	g		0.135		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:57:25	0.0467	g		0.0467		DfCnd	High	0	0	0	0	2	4	0
1-MT-RH	9	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:57:25	1.19	mm/s		1.19		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:57:25	0.704	g		0.704		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:57:25	2.39	DEF		2.39		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:57:25	0.0491	mm/s		0.0491		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:57:25	0.0839	mm/s		0.0839		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:57:25	0.133	mm/s		0.133		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:57:25	0.0430	g		0.0430		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:57:25	0.703	g		0.703		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:57:25	0.0967	g		0.0967		DfCnd	High	0	0	0	0	2	4	0
1-MT-RV	9	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:57:25	0.455	mm/s		0.455		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:57:25	0.200	g		0.200		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:57:25	2.44	DEF		2.44		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:57:25	0.0278	mm/s		0.0278		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:57:25	0.0291	mm/s		0.0291		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:57:25	0.0529	mm/s		0.0529		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:57:25	0.0290	g		0.0290		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:57:25	0.109	g		0.109		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:57:25	0.171	g		0.171		DfCnd	High	0	0	0	0	2	4	0
2-MT-Ax	9	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*

AYALA ALABANG\ BOOSTER PUMP UNIT 2

Selected Date	14/02/2019 11:57:25	Speed	19.9 Hz / 1194 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

Point	Code	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:57:25	0.626	mm/s		0.626		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:57:25	0.232	g		0.232		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:57:25	2.34	DEF		2.34		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:57:25	0.0088	mm/s		0.0088		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:57:25	0.179	mm/s		0.179		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:57:25	0.0636	mm/s		0.0636		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:57:25	0.0428	g		0.0428		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:57:25	0.202	g		0.202		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:57:25	0.100	g		0.100		DfCnd	High	0	0	0	0	2	4	0
2-MT-RH	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:57:25	0.828	mm/s		0.828		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:57:25	0.433	g		0.433		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:57:25	2.50	DEF		2.50		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:57:25	0.0864	mm/s		0.0864		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:57:25	0.163	mm/s		0.163		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:57:25	0.129	mm/s		0.129		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:57:25	0.0321	g		0.0321		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:57:25	0.398	g		0.398		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:57:25	0.155	g		0.155		DfCnd	High	0	0	0	0	2	4	0
2-MT-RV	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:57:25	0.511	mm/s		0.511		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:57:25	0.333	g		0.333		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:57:25	2.43	DEF		2.43		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:57:25	0.0983	mm/s		0.0983		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:57:25	0.0712	mm/s		0.0712		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:57:25	0.0433	mm/s		0.0433		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:57:25	0.0288	g		0.0288		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:57:25	0.320	g		0.320		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:57:25	0.0807	g		0.0807		DfCnd	High	0	0	0	0	2	4	0
3-PP-Ax	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:57:25	0.727	mm/s		0.727		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:57:25	0.332	g		0.332		DfCnd	None							

AYALA ALABANG\

BOOSTER PUMP UNIT 2

Selected Date	14/02/2019 11:57:25	Speed	19.9 Hz / 1194 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

Defect factor	IND-0003	Hard	14/02/2019 11:57:25	2.91	DEF		2.91		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:57:25	0.0223	mm/s		0.0223		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:57:25	0.0604	mm/s		0.0604		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:57:25	0.0599	mm/s		0.0599		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:57:25	0.0408	g		0.0408		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:57:25	0.241	g		0.241		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:57:25	0.213	g		0.213		DfCnd	High	0	0	0	0	2	4	0

3-PP-RH	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:57:25	1.15	mm/s		1.15		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:57:25	0.564	g		0.564		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:57:25	3.09	DEF		3.09		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:57:25	0.126	mm/s		0.126		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:57:25	0.116	mm/s		0.116		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:57:25	0.0545	mm/s		0.0545		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:57:25	0.0649	g		0.0649		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:57:25	0.403	g		0.403		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:57:25	0.348	g		0.348		DfCnd	High	0	0	0	0	2	4	0

3-PP-RV	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:57:25	0.645	mm/s		0.645		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:57:25	0.322	g		0.322		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:57:25	2.98	DEF		2.98		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:57:25	0.0151	mm/s		0.0151		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:57:25	0.0253	mm/s		0.0253		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:57:25	0.0284	mm/s		0.0284		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:57:25	0.0380	g		0.0380		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:57:25	0.208	g		0.208		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:57:25	0.232	g		0.232		DfCnd	High	0	0	0	0	2	4	0

4-PP-Ax	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:57:25	0.523	mm/s		0.523		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:57:25	0.329	g		0.329		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:57:25	2.85	DEF		2.85		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:57:25	0.0150	mm/s		0.0150		DfCnd	High	0	0	0	0	3	6	0

AYALA ALABANG\ BOOSTER PUMP UNIT 2

Selected Date	14/02/2019 11:57:25	Speed	19.9 Hz / 1194 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

2x	2x	Soft	14/02/2019 11:57:25	0.0322	mm/s		0.0322		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:57:25	0.0926	mm/s		0.0926		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:57:25	0.0205	g		0.0205		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:57:25	0.275	g		0.275		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:57:25	0.181	g		0.181		DfCnd	High	0	0	0	0	2	4	0
4-PP-RH	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:57:25	1.01	mm/s		1.01		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:57:25	0.568	g		0.568		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:57:25	2.96	DEF		2.96		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:57:25	0.0551	mm/s		0.0551		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:57:25	0.0529	mm/s		0.0529		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:57:25	0.0495	mm/s		0.0495		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:57:25	0.0568	g		0.0568		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:57:25	0.442	g		0.442		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:57:25	0.346	g		0.346		DfCnd	High	0	0	0	0	2	4	0
4-PP-RV	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:57:25	0.610	mm/s		0.610		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:57:25	0.335	g		0.335		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:57:25	3.06	DEF		3.06		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:57:25	0.0426	mm/s		0.0426		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:57:25	0.0365	mm/s		0.0365		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:57:25	0.0574	mm/s		0.0574		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:57:25	0.0392	g		0.0392		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:57:25	0.279	g		0.279		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:57:25	0.180	g		0.180		DfCnd	High	0	0	0	0	2	4	0

AYALA ALABANG\ BOOSTER PUMP UNIT 3

Selected Date	14/02/2019 11:43:11	Speed	29.8 Hz / 1787 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

Operating param.	1	H/S	Last Date	Value	Unit	T-1	Ref.	Avg									
Ovrl:Rotation speed	Rot Spd	Hard	14/02/2019 11:43:11	1787	rpm		1787										
1-MT-Ax	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:43:11	1.58	mm/s		1.58		DfCnd	High	0	0	0	2	3.5	6	0

AYALA ALABANG\ BOOSTER PUMP UNIT 3

Selected Date	14/02/2019 11:43:11	*Speed*	29.8 Hz / 1787 rpm
Author	u1	*Connector*	
System - Serial No	FALCON - 11407	*Sensor*	

Overall Acc	IND-0002	Hard	14/02/2019 11:43:11	0.217	g		0.217		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:43:11	2.26	DEF		2.26		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:43:11	0.298	mm/s		0.298		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:43:11	0.325	mm/s		0.325		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:43:11	0.0744	mm/s		0.0744		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:43:11	0.147	g		0.147		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:43:11	0.151	g		0.151		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:43:11	0.0354	g		0.0354		DfCnd	High	0	0	0	0	2	4	0
1-MT-RH	9	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:43:11	0.915	mm/s		0.915		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:43:11	1.04	g		1.0[illegible]		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:43:11	2.00	DEF		2.00		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:43:11	0.337	mm/s		0.337		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:43:11	0.406	mm/s		0.406		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:43:11	0.0037	mm/s		0.0037		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:43:11	0.0386	g		0.0386		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:43:11	1.05	g		1.05		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:43:11	0.0470	g		0.0470		DfCnd	High	0	0	0	0	2	4	0
1-MT-RV	9	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:43:11	0.751	mm/s		0.751		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:43:11	0.127	g		0.127		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:43:11	2.28	DEF		2.28		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:43:11	0.0918	mm/s		0.0918		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:43:11	0.188	mm/s		0.188		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:43:11	0.0119	mm/s		0.0119		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:43:11	0.0643	g		0.0643		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:43:11	0.0890	g		0.0890		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:43:11	0.0613	g		0.0613		DfCnd	High	0	0	0	0	2	4	0
2-MT-Ax	9	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:43:11	0.714	mm/s		0.714		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:43:11	0.227	g		0.227		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:43:11	2.55	DEF		2.55		DfCnd	High	0	0	0	4	6	9	0

AYALA ALABANG\ BOOSTER PUMP UNIT 3

Selected Date	14/02/2019 11:43:11	Speed	29.8 Hz / 1787 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

1x	1x	Soft	14/02/2019 11:43:11	0.224	mm/s		0.224		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:43:11	0.164	mm/s		0.164		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:43:11	0.0472	mm/s		0.0472		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:43:11	0.0546	g		0.0546		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:43:11	0.0650	g		0.0650		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:43:11	0.199	g		0.199		DfCnd	High	0	0	0	0	2	4	0
2-MT-RH	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:43:11	1.20	mm/s		1.20		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:43:11	0.599	g		0.599		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:43:11	2.68	DEF		2.68		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:43:11	0.527	mm/s		0.527		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:43:11	0.524	mm/s		0.524		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:43:11	0.0046	mm/s		0.0046		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:43:11	0.0893	g		0.0893		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:43:11	0.501	g		0.501		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:43:11	0.308	g		0.308		DfCnd	High	0	0	0	0	2	4	0
2-MT-RV	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:43:11	1.16	mm/s		1.16		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:43:11	0.276	g		0.276		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:43:11	2.62	DEF		2.62		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:43:11	0.431	mm/s		0.431		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:43:11	0.687	mm/s		0.687		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:43:11	0.0421	mm/s		0.0421		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:43:11	0.0643	g		0.0643		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:43:11	0.145	g		0.145		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:43:11	0.220	g		0.220		DfCnd	High	0	0	0	0	2	4	0
3-PP-Ax	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:43:11	0.870	mm/s		0.870		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:43:11	0.609	g		0.609		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:43:11	2.86	DEF		2.86		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:43:11	0.200	mm/s		0.200		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:43:11	0.0843	mm/s		0.0843		DfCnd	High	0	0	0	0	1.5	3	0

AYALA ALABANG\ BOOSTER PUMP UNIT 3

Selected Date	14/02/2019 11:43:11	Speed	29.8 Hz / 1787 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

3x	3x	Soft	14/02/2019 11:43:11	0.0274	mm/s		0.0274		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:43:11	0.0611	g		0.0611		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:43:11	0.470	g		0.470		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:43:11	0.359	g		0.359		DfCnd	High	0	0	0	0	2	4	0
3-PP-RH	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:43:11	1.24	mm/s		1.24		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:43:11	1.09	g		1.09		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:43:11	3.14	DEF		3.14		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:43:11	0.475	mm/s		0.475		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:43:11	0.667	mm/s		0.667		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:43:11	0.0306	mm/s		0.0306		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:43:11	0.0665	g		0.0665		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:43:11	0.898	g		0.898		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:43:11	0.584	g		0.584		DfCnd	High	0	0	0	0	2	4	0
3-PP-RV	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:43:11	0.745	mm/s		0.745		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:43:11	0.631	g		0.631		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:43:11	2.89	DEF		2.89		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:43:11	0.0659	mm/s		0.0659		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:43:11	0.0334	mm/s		0.0334		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:43:11	0.0232	mm/s		0.0232		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:43:11	0.0609	g		0.0609		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:43:11	0.471	g		0.471		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:43:11	0.399	g		0.399		DfCnd	High	0	0	0	0	2	4	0
4-PP-Ax	9	H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:43:11	0.876	mm/s		0.876		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:43:11	0.799	g		0.799		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:43:11	3.03	DEF		3.03		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:43:11	0.243	mm/s		0.243		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:43:11	0.116	mm/s		0.116		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:43:11	0.0143	mm/s		0.0143		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:43:11	0.0523	g		0.0523		DfCnd	High	0	0	0	0	.15	.3	0

AYALA ALABANG\
BOOSTER PUMP UNIT 3

Selected Date	14/02/2019 11:43:11	Speed	29.8 Hz / 1787 rpm
Author	u1	Connector	
System - Serial No	FALCON - 11407	Sensor	

		H/S	Last Date	Value	Unit	T-1	Ref.	Avg	Oper.	AlmTyp	DG-	AL-	pA-	pA+	AL+	DG+	Err
En-MF	En-MF	Soft	14/02/2019 11:43:11	0.468	g		0.468		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:43:11	0.646	g		0.646		DfCnd	High	0	0	0	0	2	4	0
4-PP-RH	**9**	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:43:11	1.01	mm/s		1.01		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:43:11	1.39	g		1.39		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:43:11	3.54	DEF		3.54		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:43:11	0.0997	mm/s		0.0997		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:43:11	0.481	mm/s		0.481		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:43:11	0.0348	mm/s		0.0348		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:43:11	0.0612	g		0.0612		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:43:11	0.634	g		0.634		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:43:11	1.19	g		1.19		DfCnd	High	0	0	0	0	2	4	0
4-PP-RV	**9**	*H/S*	*Last Date*	*Value*	*Unit*	*T-1*	*Ref.*	*Avg*	*Oper.*	*AlmTyp*	*DG-*	*AL-*	*pA-*	*pA+*	*AL+*	*DG+*	*Err*
Overall Vib Vel	IND-0001	Hard	14/02/2019 11:43:11	0.744	mm/s		0.744		DfCnd	High	0	0	0	2	3.5	6	0
Overall Acc	IND-0002	Hard	14/02/2019 11:43:11	0.801	g		0.801		DfCnd	None							
Defect factor	IND-0003	Hard	14/02/2019 11:43:11	3.12	DEF		3.12		DfCnd	High	0	0	0	4	6	9	0
1x	1x	Soft	14/02/2019 11:43:11	0.108	mm/s		0.108		DfCnd	High	0	0	0	0	3	6	0
2x	2x	Soft	14/02/2019 11:43:11	0.0678	mm/s		0.0678		DfCnd	High	0	0	0	0	1.5	3	0
3x	3x	Soft	14/02/2019 11:43:11	0.0105	mm/s		0.0105		DfCnd	High	0	0	0	0	1	2	0
En-LF	En-LF	Soft	14/02/2019 11:43:11	0.0413	g		0.0413		DfCnd	High	0	0	0	0	.15	.3	0
En-MF	En-MF	Soft	14/02/2019 11:43:11	0.552	g		0.552		DfCnd	High	0	0	0	0	.5	1	0
En-HF	En-HF	Soft	14/02/2019 11:43:11	0.563	g		0.563		DfCnd	High	0	0	0	0	2	4	0

Appendix C

Bill of Quantity

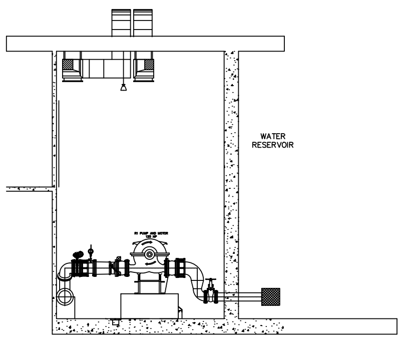
Bill of Quantity

No.	Description	Items	CAT	CS	IT	Unit Cost	Quan.	Unit	Total	Remarks
1	Pipe system	Modification of suction piping	P	2	5	300,000.00	1	lot	300,000.00	New suction line with option for long radius elbow and additional provision for straight pipe to facilitate more developed flow profile(See conceptual design)
2	Pipe system	Replace pipe/refurbish heavily detriorated pipes	P	2	1	250,000.00	1	lot	250,000.00	Pipe replacement or restoration: extensive rust removal and recoating of pipes, new material for pressure reducing valve handle to avoid galvanic corrosion
3	Pipe system	Addition of straight coupling along discharge side	P	2	6	250,000.00	1	lot	250,000.00	Provide a coupling for pipe internal inspection. Useful for determining extent of pipe scaling although quite a tedious task (see conceptual design)
4	Instrumentation and Monitoring	Installation of pressure gauge near pump flange	M	2	6	10,000.00	6	pc	60,000.00	For increased accuracy in measuring head
5	Instrumentation and Monitoring	Installation of UFM for Pumps 3 and [illegible]	M	2	6	120,000.00	2	pc	240,000.00	Basic simulation show flow is relatively develop and flow meters can gain confident measurements
6	Instrumentation and Monitoring	Addition/upgrade to Key Software modules	M	2	5	100,000.00	1	lot	100,000.00	Will log average pump efficiency, individual and total production volumes (as determined by thermodynamic device), pump energy usage and real time pump curve data
7	Instrumentation and Monitoring	Upgrade to vibration analyzer	M	2	5	100,000.00	1	lot	100,000.00	Will provide continuous monitoring of pump vibration activity and generate time based graphs of FFT and 3D spectrum
8	Pump efficiency	Replacement of existing wear rings with non metallic wear rings	M	2	5	150,000.00	6	pc	900,000.00	Clearance can be reduced to up to 50% which in turn can lead up to 5% efficiency gain
9	Lighting	lights under over sidewalk overhang	F	2	5	5,000.00	[illegible]	pc	15,000.00	For convenience rather than carrying portable lights
10	Instrumentation and Monitoring	Control panel check-up	E	2	1	-	-	-	-	Check up to resolve minor nuisances such as units, readings and displays
11	Reservoir	Check up and reinforment of reservoir walls	S	2	1	-	-	-		Walls were continued for height extension of reservoir however cracks were observed on the merging portion of the extension
12	Pump efficiency	Anti-friction coatng	M	-	5	100,000.00	8	pc	800,000.00	Further increases efficiency
14	Lubrication method	Upgrade to automatic lubricators (eg. Single point lubricant dispensers)	M	-	5	30,000.00	6	pcs	1[illegible]0,000.00	Avoids under and over-lubrication problems
15	Condition Monitoring	Regular Vibration Analysis	M	2	7	3,000.00	-	per point	160,000.00	To improve data pool and help closely monitor mechanical health via vibration analysis. (Price computed is based on perpetual basis of 15% rate)
	Total								**3,355,000.00**	

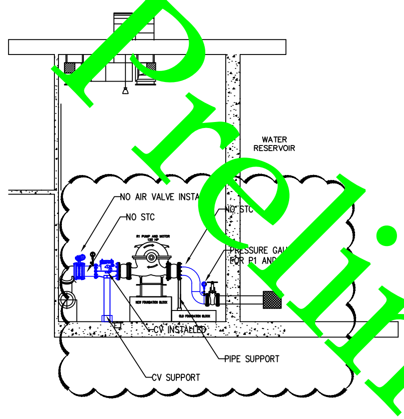
Appendix D

Drawings

AS–BUILT

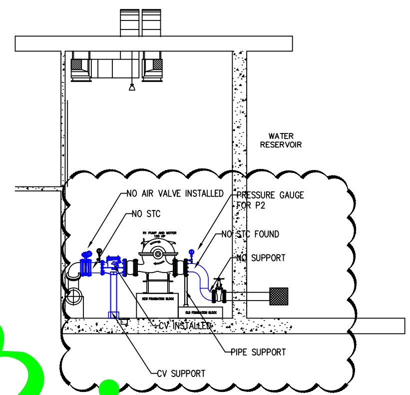


AS–FOUND P1



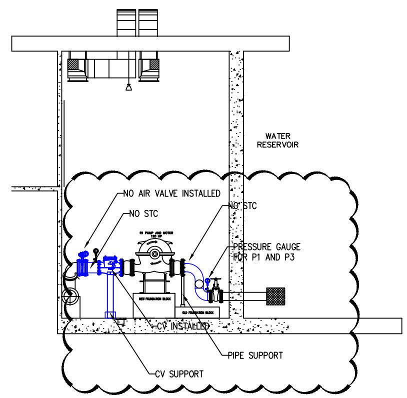
NOTE:
1. MODIFIED CONFIGURATION OF FITTINGS ON BOTH SUCTION AND DISCHARGE OBSERVE
2. ADDITIONAL SUPPORT AS REQUIRED BY MODIFICATION
3. OLD MACHINE FOUNDATION STILL EXIST

AS–FOUND P2



NOTE:
1. MODIFIED CONFIGURATION OF FITTINGS ON BOTH SUCTION AND DISCHARGE OBSERVE
2. ADDITIONAL SUPPORT AS REQUIRED BY MODIFICATION
3. OLD MACHINE FOUNDATION STILL EXIST

AS–FOUND P3



NOTE:
1. MODIFIED CONFIGURATION OF FITTINGS ON BOTH SUCTION AND DISCHARGE OBSERVE
2. ADDITIONAL SUPPORT AS REQUIRED BY MODIFICATION
3. OLD MACHINE FOUNDATION STILL EXIST

A / ME **AS-FOUND**
SCALE: 1:65

Maynilad -
CONFORME:
HEAD, Division (End User)

Maynilad -
CONFORME:
HEAD, Department (End User)

DRAWN	SURVEYED	DESIGNED	CHECKED
DRAW	SURVEYED	DESIGNED	CHECKED

REVISION

REV	DATE	BY	APPROVED BY

Checked & Certified :
ROSENDO B. SANCHEZ, PME
PROFESSIONAL MECHANICAL ENGINEER

PROFESSION : PME	PTR : 7341148
REGISTRATION NO. : 3999	DATE ISSUED : 01–07–2019
TIN : 205–811–966	PLACE ISSUED : MAKATI_CITY

GHD
11/F Alphaland Southgate Tower 2258 Chino Roces Ave corner EDSA Makati City 1232 Philippines
T 63 2 479 5600 F 63 2 479 5601
E mnlmail@ghd.com W www.ghd.com

Approved :
NAM LE
Project Manager

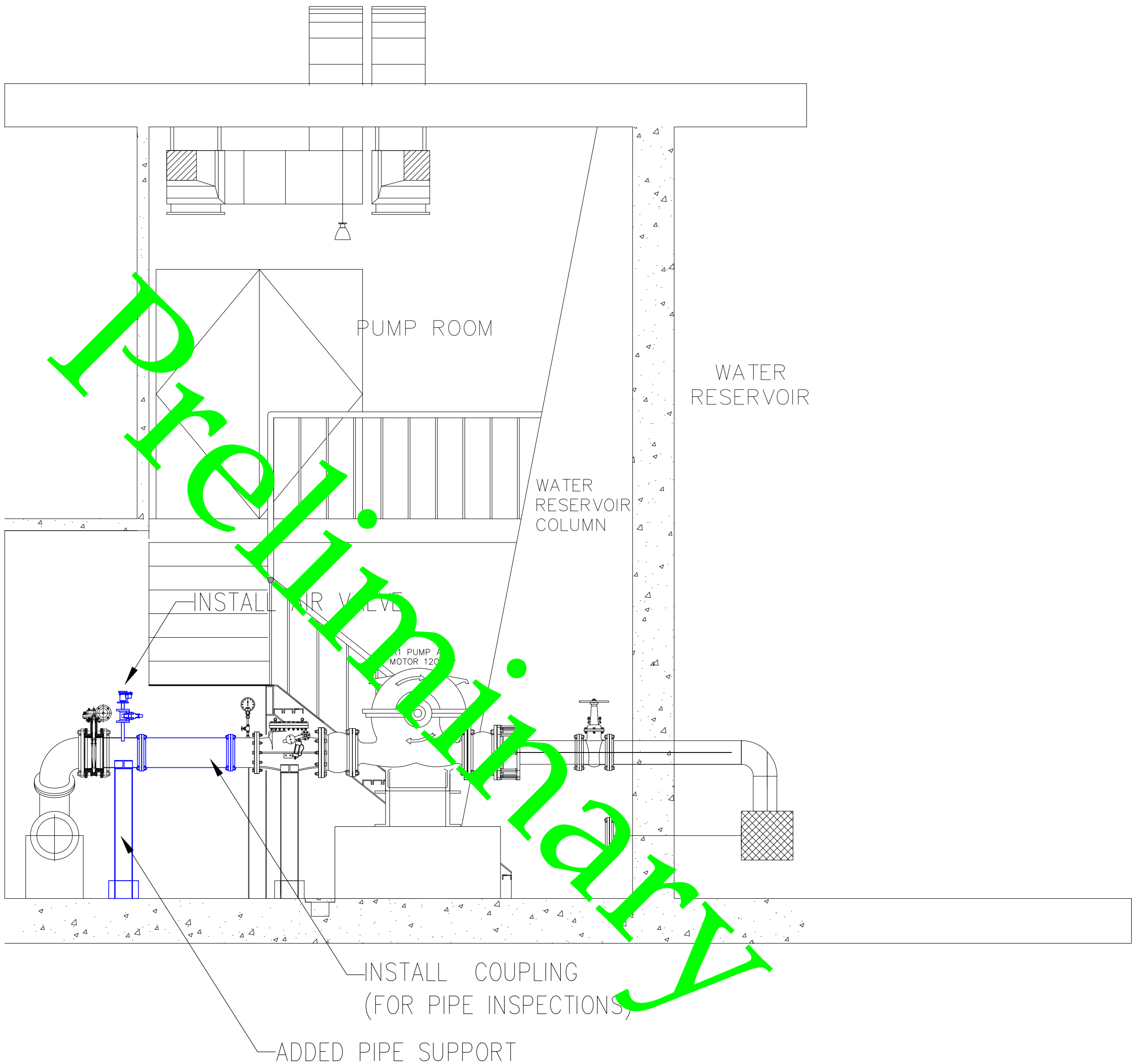
RBSANCHEZ PME CONSULTANTS & ASSOCIATES, INC.
Makati Corporate Office: 28th Floor Cityland Pasong Tamo Tower U2807, 2210 Chino Roces Avenue, Makati City, Philippines.
Telefax No. 776–5879 Cell No. +639 273 006 000
Website: www.rbs–engineers.com

RBS DESIGN UNIT
RBS DESIGN SECTION
ROSENDO B. SANCHEZ, PME
HEAD, Engineering

CONTRACT DRAWING

PROJECT TITLE: CONSULTANCY SERVICES FOR THE PLANT AUDIT IN VARIOUS PUMP STATIONS AND RESERVOIRS
LOCATION: AYALA ALABANG R1 PUMP STATION AND RESERVOIR
SHEET CONTENT: AS–BUILT CHANGES

SCALE:	CONTRACT NO.	SHEET NO.	REV.
NTS	OP18REFCS03–AAL–MECH–001	1 OF 1	A



A / ME DISCHARGE MODIFICATIONS

SCALE: 1:65

Maynilad	-	Maynilad	-
CONFORME:		CONFORME:	
HEAD, Division (End User)		HEAD, Department (End User)	
DRAWN	SURVEYED	DESIGNED	CHECKED
DRAW	SURVEYED	DESIGNED	CHECKED

REVISION

REV	DATE	BY	APPROVED BY

Checked & Certified :
ROSENDO B. SANCHEZ, PME
PROFESSIONAL MECHANICAL ENGINEER

PROFESSION : PME — PTR : 7341148
REGISTRATION NO. : 3999 — DATE ISSUED : 01-07-2019
TIN : 205-811-966 — PLACE ISSUED : MAKATI_CITY

GHD
11/F Alphaland Southgate Tower 2258 Chino Roces Ave corner EDSA Makati City 1232 Philippines
T 63 2 479 5600 F 63 2 479 5601
E mnlmail@ghd.com W www.ghd.com

Approved :
NAM LE
Project Manager

RBSANCHEZ PME CONSULTANTS & ASSOCIATES, INC.
Makati Corporate Office: 28th Floor Cityland Pasong Tamo Tower U2807, 2210 Chino Roces Avenue, Makati City, Philippines.
Telefax No. 776-5879 Cell No. +639 273 006 000
Website: www.rbs-engineers.com

RBS DESIGN UNIT
RBS DESIGN SECTION
ROSENDO B. SANCHEZ, PME
HEAD, Engineering

CONTRACT DRAWING

PROJECT TITLE: CONSULTANCY SERVICES FOR THE PLANT AUDIT IN VARIOUS PUMP STATIONS AND RESERVOIRS

LOCATION: AYALA ALABANG R1 PUMP STATION AND RESERVOIR

SHEET CONTENT: DISCHARGE MODIFICATIONS

SCALE:	CONTRACT NO.	SHEET NO.	REV.
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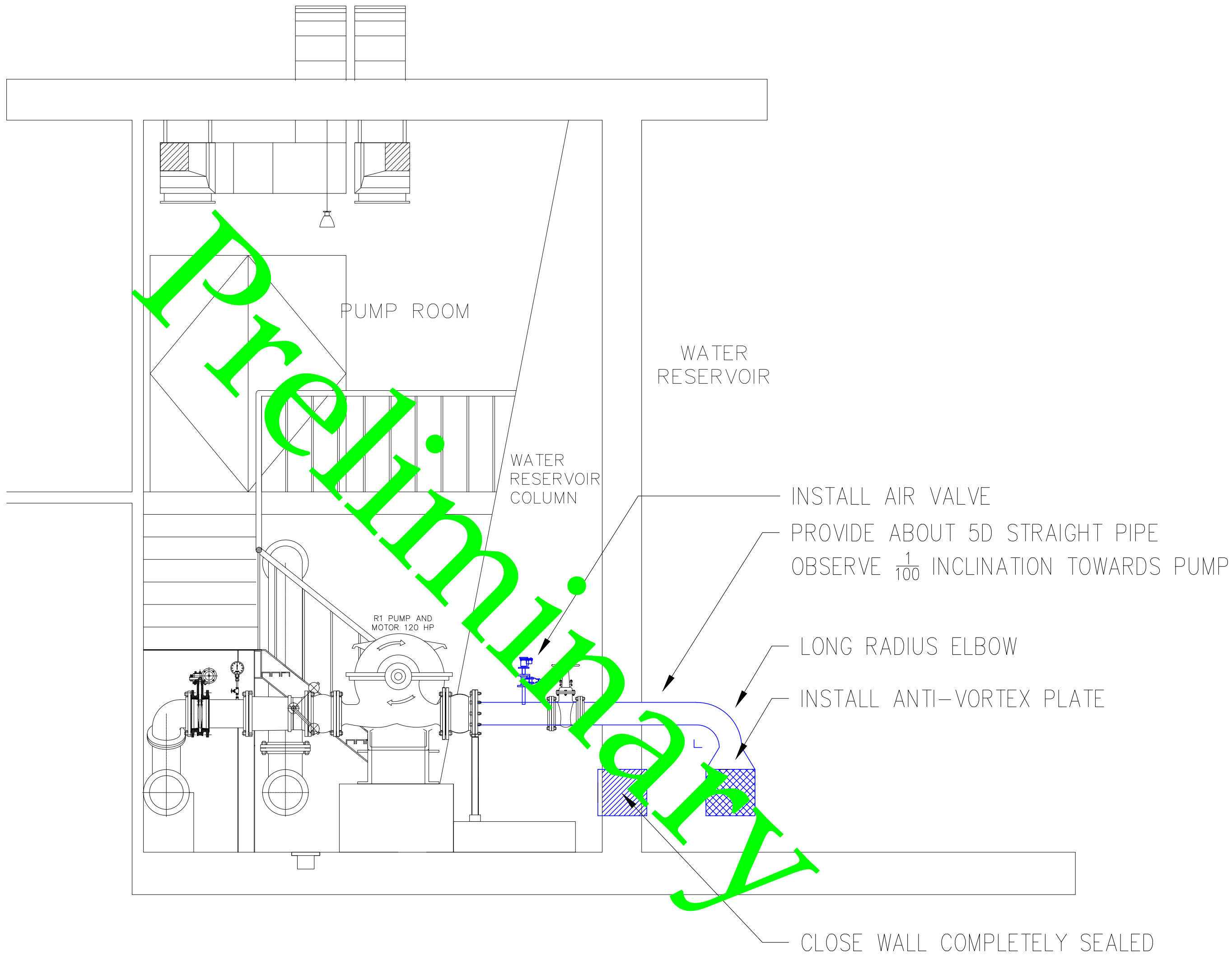

A / ME — SUCTION MODIFICATIONS
SCALE: 1:65

Maynilad - CONFORME: HEAD, Division (End User)	Maynilad - CONFORME: HEAD, Department (End User)

DRAWN	SURVEYED	DESIGNED	CHECKED
DRAW	SURVEYED	DESIGNED	CHECKED

REVISION

REV	DATE	BY	APPROVED BY

Checked & Certified :
ROSENDO B. SANCHEZ, PME
PROFESSIONAL MECHANICAL ENGINEER

PROFESSION : PME	PTR : 7341148
REGISTRATION NO. : 3999	DATE ISSUED : 01-07-2019
TIN : 205-811-966	PLACE ISSUED : MAKATI_CITY

GHD
11/F Alphaland Southgate Tower 2258 Chino Roces Ave corner EDSA Makati City 1232 Philippines
T 63 2 479 5600 F 63 2 479 5601
E mnlmail@ghd.com W www.ghd.com

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RBS DESIGN UNIT
RBS DESIGN SECTION

ROSENDO B. SANCHEZ, PME
HEAD, Engineering

CONTRACT DRAWING

PROJECT TITLE: CONSULTANCY SERVICES FOR THE PLANT AUDIT IN VARIOUS PUMP STATIONS AND RESERVOIRS
LOCATION: AYALA ALABANG R1 PUMP STATION AND RESERVOIR
SHEET CONTENT: SUCTION MODIFICATIONS

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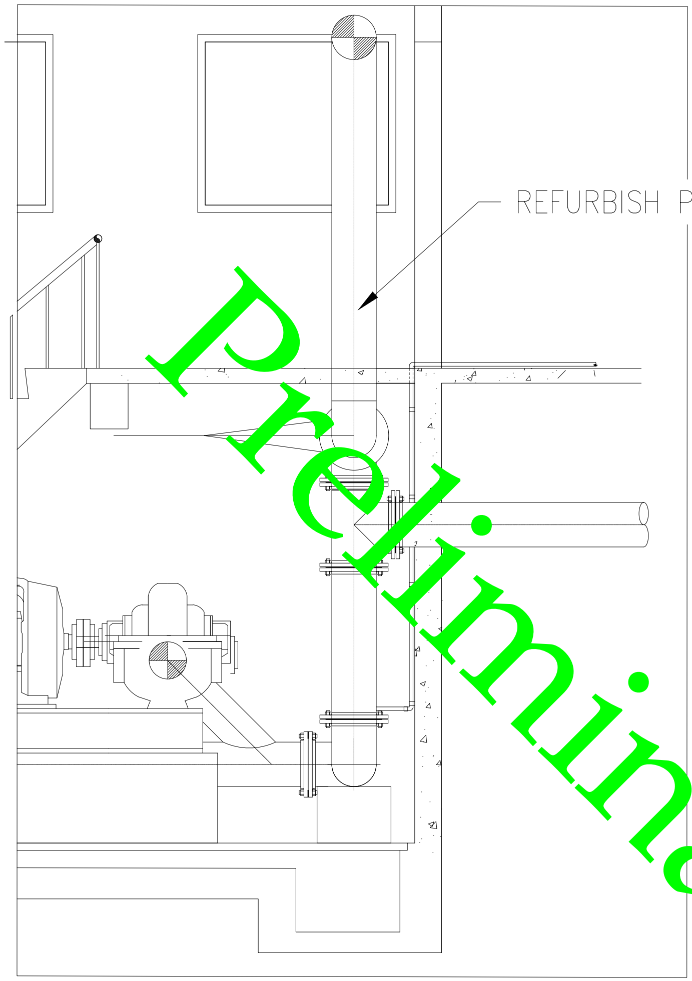
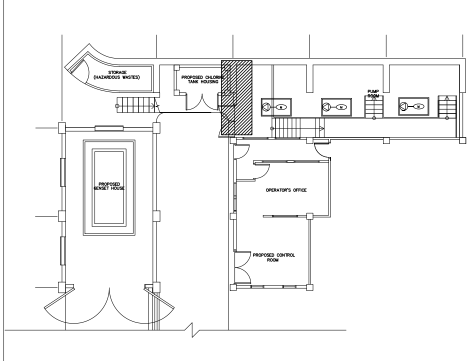
NTS	OP18REFCS03-AAL-MECH-003	1 OF 1	A



A ME **REFURBISH PIPE**

SCALE: 1:18



A ME **PUMP STATION**

SCALE: 1:150

Maynilad -	Maynilad -
CONFORME:	CONFORME:
HEAD, Division (End User)	HEAD, Department (End User)

DRAWN	SURVEYED	DESIGNED	CHECKED
DRAW	SURVEYED	DESIGNED	CHECKED

REVISION

REV	DATE	BY	APPROVED BY	

Checked & Certified :

ROSENDO B. SANCHEZ, PME
PROFESSIONAL MECHANICAL ENGINEER

PROFESSION : PME	PTR : 7341148
REGISTRATION NO. : 3999	DATE ISSUED : 01-07-2019
TIN : 205-811-966	PLACE ISSUED : MAKATI_CITY

11/F Alphaland Southgate Tower 2258 Chino Roces Ave corner EDSA Makati City 1232 Philippines
T 63 2 479 5600 F 63 2 479 5601
E mnlmail@ghd.com W www.ghd.com

Approved :

NAM LE
Project Manager

RBSANCHEZ PME CONSULTANTS & ASSOCIATES, INC.
Makati Corporate Office: 28th Floor Cityland Pasong Tamo Tower U2807, 2210 Chino Roces Avenue, Makati City, Philippines.
Telefax No. 776-5879 Cell No. +639 273 006 000
Website: www.rbs-engineers.com

RBS
DESIGN UNIT

RBS
DESIGN SECTION

ROSENDO B. SANCHEZ, PME
HEAD, Engineering

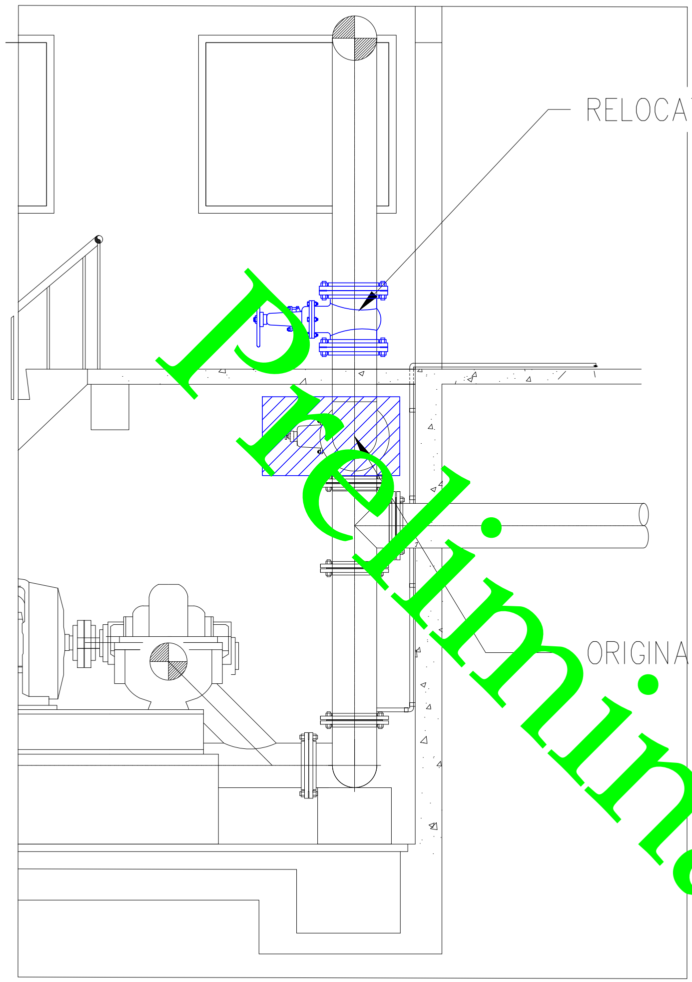
CONTRACT DRAWING

PROJECT TITLE: CONSULTANCY SERVICES FOR THE PLANT AUDIT IN VARIOUS PUMP STATIONS AND RESERVOIRS

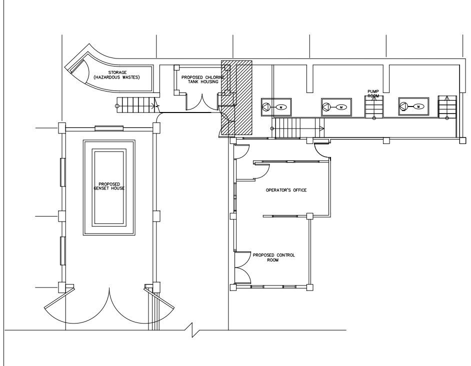
LOCATION: AYALA ALABANG R1 PUMP STATION AND RESERVOIR

SHEET CONTENT: REFURBISH PIPE

SCALE:	CONTRACT NO.	SHEET NO.	REV.
NTS	OP18REFCS03-AAL-MECH-004	1 OF 1	A



A
ME
RELOCATE VALVE
SCALE: 1:18



A
ME
PUMP STATION
SCALE: 1:150

Maynilad -	Maynilad -
CONFORME:	CONFORME:
HEAD, Division (End User)	HEAD, Department (End User)

DRAWN	SURVEYED	DESIGNED	CHECKED
DRAW	SURVEYED	DESIGNED	CHECKED

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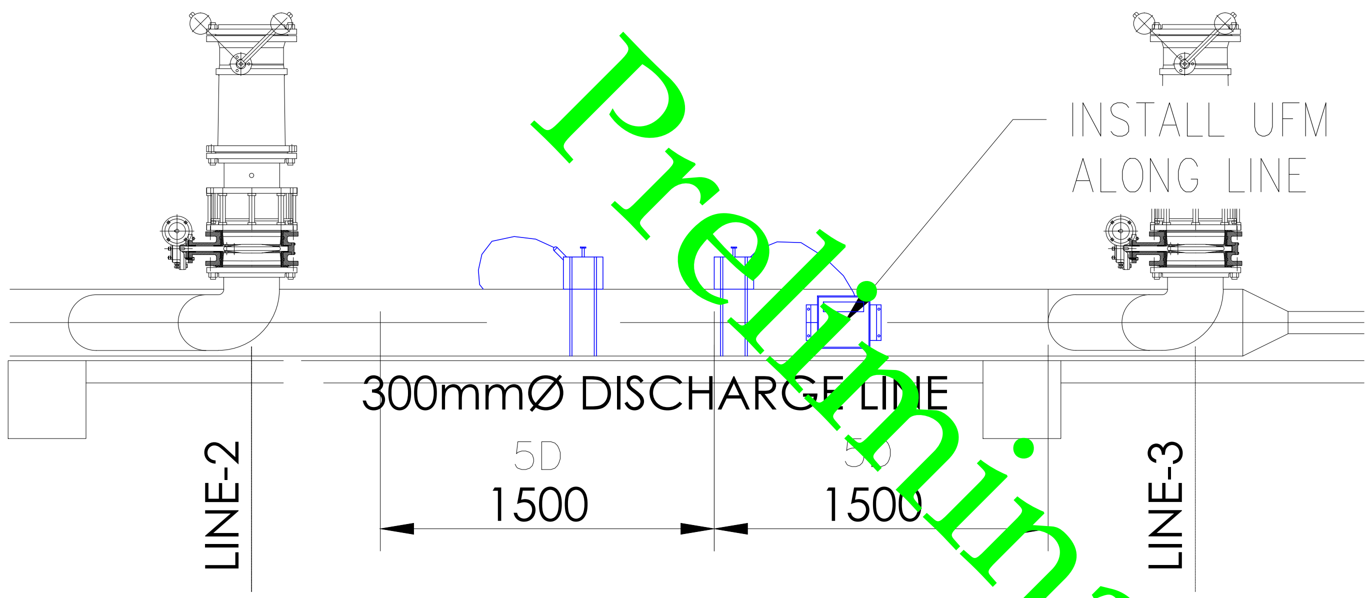
HEAD, Engineering

CONTRACT DRAWING

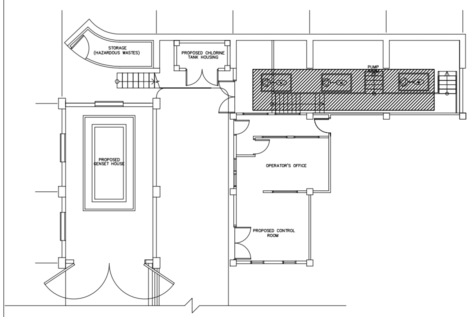
PROJECT TITLE: CONSULTANCY SERVICES FOR THE PLANT AUDIT IN VARIOUS PUMP STATIONS AND RESERVOIRS
LOCATION: AYALA ALABANG R1 PUMP STATION AND RESERVOIR
SHEET CONTENT: RELOCATE VALVE

SCALE:	CONTRACT NO.	SHEET NO.	REV.
NTS	OP18REFCS03-AAL-MECH-005	1 OF 1	A



Preliminary

A / ME — UFM INSTALLATION AREA
SCALE: 1:12



A / ME — PUMP STATION
SCALE: 1:150

Maynilad -	Maynilad -
CONFORME:	CONFORME:
HEAD, Division (End User)	HEAD, Department (End User)

DRAWN	SURVEYED	DESIGNED	CHECKED
DRAW	SURVEYED	DESIGNED	CHECKED

REVISION

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RBS DESIGN SECTION

ROSENDO B. SANCHEZ, PME
HEAD, Engineering

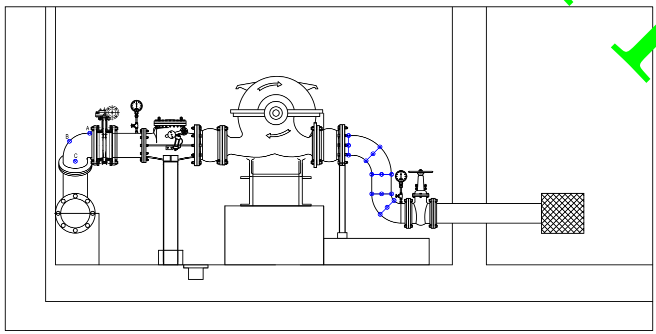
CONTRACT DRAWING

PROJECT TITLE: CONSULTANCY SERVICES FOR THE PLANT AUDIT IN VARIOUS PUMP STATIONS AND RESERVOIRS

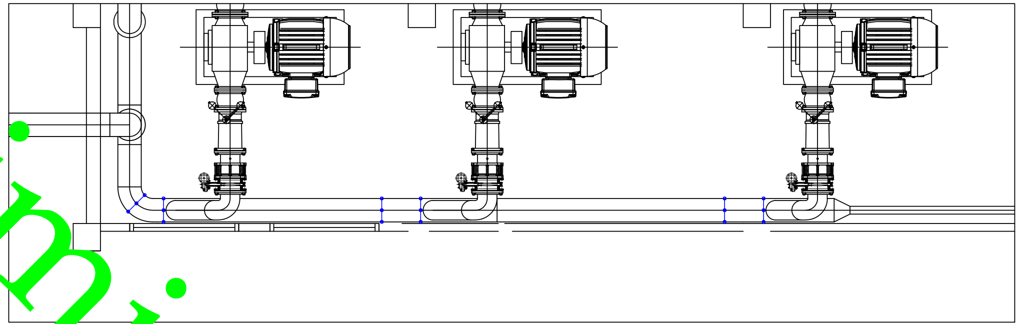
LOCATION: AYALA ALABANG R1 PUMP STATION AND RESERVOIR

SHEET CONTENT: INSTALL UFM ALONG LINE

SCALE:	CONTRACT NO.	SHEET NO.	REV.
NTS	OP18REFCS03-AAL-MECH-006	1 OF 1	A



A
ME
UTG POINTS
SCALE: 1:30



A
ME
UTG POINTS
SCALE: 1:40

Preliminary

Maynilad	-	Maynilad	-
CONFORME: HEAD, Division (End User)		CONFORME: HEAD, Department (End User)	
DRAWN	SURVEYED	DESIGNED	CHECKED
DRAW	SURVEYED	DESIGNED	CHECKED

REVISION

REV	DATE	BY	APPROVED BY

Checked & Certified :
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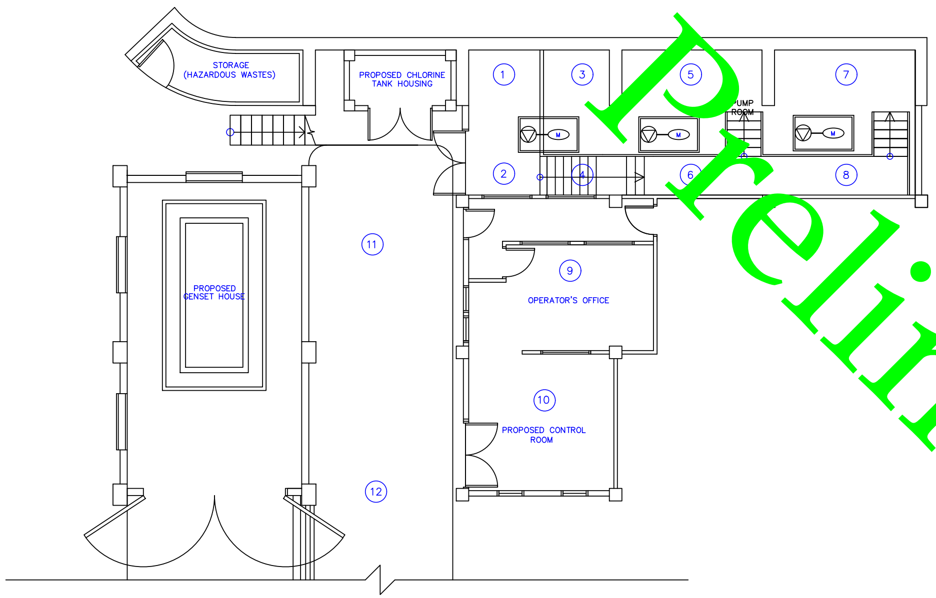
CONTRACT DRAWING

PROJECT TITLE: CONSULTANCY SERVICES FOR THE PLANT AUDIT IN VARIOUS PUMP STATIONS AND RESERVOIRS

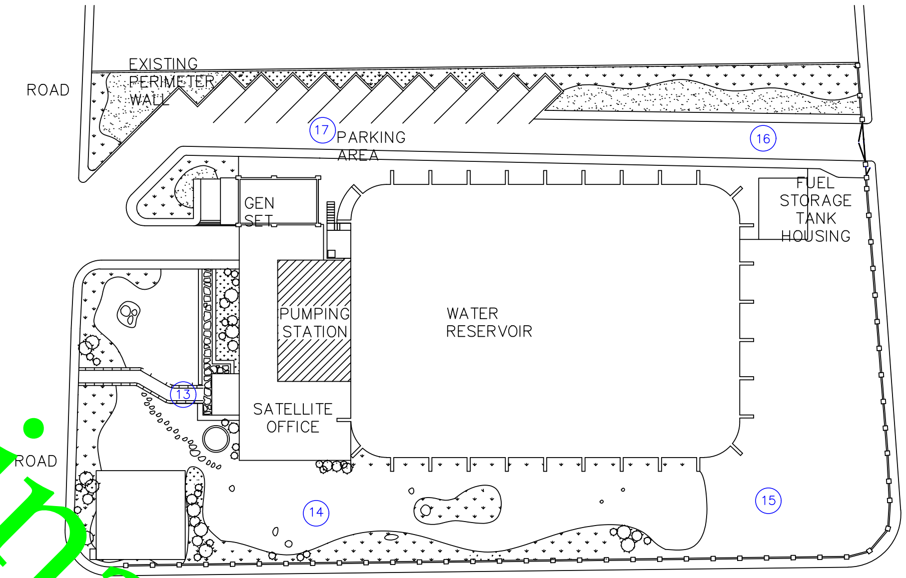
LOCATION: AYALA ALABANG R1 PUMP STATION AND RESERVOIR

SHEET CONTENT: UTG POINTS

SCALE:	CONTRACT NO.	SHEET NO.	REV.
NTS	OP18REFCS03-AAL-UTG-001	1 OF 1	A



A
ME
WEM POINTS (INSIDE PUMP STATION)
SCALE: 1:75



A
ME
WEM POINTS (OUTSIDE PUMP STATION)
SCALE: 1:300

Maynilad	-	Maynilad	-
CONFORME:		CONFORME:	
HEAD, Division (End User)		HEAD, Department (End User)	
DRAWN	SURVEYED	DESIGNED	CHECKED
DRAW	SURVEYED	DESIGNED	CHECKED

REVISION

REV	DATE	BY	APPROVED BY

Checked & Certified :
ROSENDO B. SANCHEZ, PME
PROFESSIONAL MECHANICAL ENGINEER

PROFESSION : PME	PTR : 7341148
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GHD
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EDSA Makati City 1232 Philippines
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RBS DESIGN SECTION
ROSENDO B. SANCHEZ, PME
HEAD, Engineering

CONTRACT DRAWING

PROJECT TITLE: CONSULTANCY SERVICES FOR THE PLANT AUDIT IN VARIOUS PUMP STATIONS AND RESERVOIRS
LOCATION: AYALA ALABANG R1 PUMP STATION AND RESERVOIR
SHEET CONTENT: WEM POINTS

SCALE:	CONTRACT NO.	SHEET NO.	REV.
NTS	OP18REFCS03-AAL-WEM-001	1 OF 1	A