CHAPTER 11 – CORROSION ASSESSMENT

11.1 Introduction

A corrosion and durability assessment of key water and wastewater facilities operated by GWA was performed to assess the general integrity of the utility assets from a corrosion perspective. Subsequently, various laboratory examinations and analysis were carried out on a number of soils, bedding material and steel samples. Consequently, the assessment provides a general overview of major asset classes rather than a detailed examination of component assets.

The methodology used in assessing the condition of GWA's major asset classes can be summarized as follows:

- Desktop review of GWA plans, asset listings, material specifications, water and wastewater composition data as available.
- Discussions with key GWA personnel at all levels in the organization.
- Visual examination of representatives of each class of asset and on-site testing [e.g. concrete hardness, paint thickness, cathodic protection (CP) systems] where appropriate.
- Appropriate laboratory testing of soil and bedding corrosivity.
- Preparation of Draft and Final Reports, including recommendation for any remedial work and/or further detailed inspection. Note that this report lists the site inspections in logical order from the various water sources through to the STPs. An exception is the pipelines which were unobservable during the inspection and is treated separately from the rest of the facilities.

11.2 Objectives

The objectives of this corrosion assessment study were as follows:

- To provide GWA with the current corrosion and durability status of each major class of fixed asset by assessing typical examples of water and wastewater treatment plants, water storage reservoirs, pump stations, pipelines and other major facilities.
- Extrapolating these limited studies to provide estimates of remaining life based on corrosion and materials durability issues on each class of asset.
- To provide recommendations, where appropriate, of the remedial action required to bring each asset class up to full operational efficiency.
- To recommend any further corrosion or structural engineering assessments that might be required for each asset class and assign a priority to these actions.

11.3 Site Inspections

11.3.1 General

11.3.1.1 Atmospheric Corrosivity

Guam is an island of approximately 212 square miles (550km^2) situated about 13^0 north of the equator, and typically enjoys an equatorial climate. Average temperatures are 81^{0}F (27^{0}C) with high relative humidity. Average rainfall exceeds 78" annually and typhoons are commonplace. The general weather conditions, including the exposure to salt spray on coastal facilities, render atmospheric corrosion rating as 'extreme'.

11.3.1.2 Soil Corrosivity

The geology of Guam shows that in general, the north half of the island consists of limestone formations of high permeability while the south is pyro-clastic and lava-based rock formations. Residual soils are considered pH neutral or slightly acidic. While these conditions tend to point to generally non or mildly corrosive conditions towards metallic and cementitious pipe materials, much more specific corrosivity data is required and this is discussed in Section 11.3.14 of this report.

However, of great significance is the location of Guam close to the Pacific tectonic plate edge resulting in high levels of seismic activity (in the last century over 100 seismic events of magnitude >R6.0 have been recorded). Experience has shown this can have a detrimental effect on most classes of buried water and sewermains.

11.3.1.3 Immersion

The influence of drinking water and wastewater chemical composition has a direct influence on the internal corrosion of metallic and cementitious pipelines, treatment works, pump stations and other facilities. These composition issues are influenced by Guam's geology, water sources and industrial and commercial waste streams.

The 2004 Water Quality Report provided by GWA for 2004 provides basic data on drinking water composition. Table 11-1 below provides a summary based on the corrosion related parameters contained in that report.

Table 11-1 – GWA Water Quality Data

Parameter	Ground Water		Ugum Treated Water	
	Min	Max	Min	Max
pH	7.0	8.0	7.0	7.2
Conductivity	221	1842	101	154
Alkalinity	121	352	27	50
Total Hardness	35	400	43	121
Sodium	8	270	13	13
Calcium	N/A	N/A	N/A	N/A
Magnesium	N/A	N/A	N/A	N/A
Chloride	16	736	23	50
Sulfate	3.3	73	10	10
Langlier Index (LI) *	-.43	+1.4	-1.7	-1.0

* Calculated from available data only, therefore approximate only.

The analysis figures shown in Table 11-1 do not contain any specific information on the values of either calcium or magnesium in either the ground water or Ugum treated water. Values can be partially inferred from the total hardness values by the following relationship:

Hardness (as $CaC0_3$) = 2.497 (Ca in mg/L) + 4.118 (Mg in mg/L)

If the magnesium content of the water is ignored (it is usually much less than the calcium levels) then an approximate value of calcium can be calculated as between 14 and 160mg/L for ground water and from 9 to 48mg/L for the Ugum treated supply.

The main contribution of calcium and magnesium to water corrosivity is its effect on scaling, represented in Table 11-1 by the Langlier Index (LI) although other indices can also be used. The LI is not a corrosion index but an indication of the thermodynamic tendency of a water to either dissolve or precipitate calcium carbonate. In immersion conditions this may have an influence on unlined cast iron or steel components in that saturated (positive value of LI) waters may provide a protective scale on, for example, unlined pipes. For the water analysis in Table 11-1, however, only some ground waters of positive LI would be in this position, and the main issue is whether the negative LI values would contribute to attack of cement mortar pipe linings and other concrete structures.

The data in Table 11-1, plus the calculated data for calcium levels given above, suggest that while the Ugum treated water is a relatively soft supply, moderately corrosive to concrete and cementitious materials (-1.0 to -1.7 LI), the ground water covers a very wide spectrum from soft to hard and barely potable. Contrary to received wisdom, soft waters are actually more corrosive to cementitious materials than hard waters and as previously discussed, the high chloride, high alkalinity ground waters are unlikely on the basis of the analysis shown in Table 11-1 to be significantly corrosive (positive LI).

The balance of the water supplies can be expected to be mildly corrosive to the free lime present in cementitious structures. This will normally mean a slight rise in pH values throughout the distribution system depending mainly on retention times. This is unlikely to be a significant issue but should be confirmed by distribution pH checks.

For the harder ground water supplies, however, there is a further potential corrosion issue which relates to the presence of dissolved gases, particularly carbon dioxide. Bore waters often contain significant levels of free CO_2 and this can be very corrosive indeed particularly when present as 'aggressive CO_2'. It is our understanding no such analysis is available and we would recommend this be carried out.

Recommendations

Carry out on-site testing on at least 6 deep well bores to ascertain the level of free/aggressive carbon dioxide.

Carry out pH and calcium/magnesium analysis checks throughout the system to determine the extent of lime pick-up and subsequent corrosion of cement mortar linings and other concrete structures.

No corrosion data was available for GWA's wastewater streams. Based on our experience, wastewater is usually not aggressive from a chemical composition viewpoint to cementitious and metallic materials unless excessive hydrogen sulfide is generated. These issues will be discussed in each of the appropriate following sub-sections.

11.3.2 Deep Well Pump Station (A-25)

The pump station (PS) is a standard design as detailed in GWA supplied drawing 'M1'. It consists of a 30' x 18' compound with a bore pump together with sundry fittings such as check valve, air relief valve, stop valve and bypass.

Figure 11-1 overleaf shows a general view of PS A-25 while Figure 11-2 shows some superficial corrosion on the flanges.

Figure 11-1 – Deep Well PS A-25

A general view of deep well PS A-25 showing pipework from well and chlorine tank room. Building in background is power authority-owned substation with backup generator.

Figure 11-2 – Surface Corrosion on Pipework Flange

The following brief observations were made of the deep well pump station:

- In general, all fittings and pipelines examined were in good condition with only some superficial corrosion on, in particular, the flanges.

- The chlorine tank room was in good condition although it was noticed that the room was not locked and this is considered a serious public risk.
- The telemetry junction boxes were in poor condition with severe corrosion on connections and the light gauge steelwork.
- The fences were in general good condition. However, again there was some risk arising from poor security.

The following recommendations are made as a result of this inspection:

Recommendation A

Ensure that chlorine room is secure at all times.

Recommendation B

Annually inspect and treat with waterproofing spray electrical fittings, connections and cover boxes showing signs of corrosion. Any critical fittings or one that presents a safety risk should be replaced.

Recommendation C

Place signs on all security fencing advising the public of danger and prohibiting entry to non-authorized personnel.

11.3.3 Water Booster Pump Station (WBPS) at Pago Bay

The WBPS at Pago Bay consisted of a reinforced concrete switchroom and an open-sided reinforced concrete pump room. Figure 11-3 below shows a general view of the pump station while Figure 11-4 gives a view of the pipe layout in the pump room. Figure 11-5 shows a segment of old pipe stored at the pump station.

Figure 11-3 – Pago Bay Water PS

Figure 11-4 – Internal View of PS Pipe Layout

Figure 11-5 – Segment of Old Pipe Stored at the PS

A ductile iron pipe segment showing relatively thin cement mortar lining.

The following observations were made on the pump station:

- In general all the light gauge fitments such as switchboards and light fittings were badly corroded, however, the pipework and fittings were in good condition with only superficial corrosion.
- It was noted that this station is within a half mile of the ocean and therefore subject to salt deposit.
- Some of the motor shafts were uncovered and this presents a serious safety

concern to GWA's staff and to the public.

- It was noted that the relatively new switchboard already had some surface staining due to corrosion.
- Some old pipe fittings were stored in the pump station and it was noted that the cement lining was very thin despite the fact that the external surface was only mildly corroded. This may or may not be a general issue and will be discussed in Section 3.14.

The following recommendations are made as a result of this inspection:

Recommendation A

Ensure that safety guards are placed over all motor shafts or exposed rotating machinery.

Recommendation B

Annually inspect and treat with waterproofing spray electrical fittings, connections and cover boxes showing signs of corrosion. Any critical fitting or one that presents a safety risk should be replaced.

Recommendation C

As there is exposed machinery and strategic assets, signposting the compound to advise the public that access is prohibited should be erected.

11.3.4 WBPS at Brigade Bay

The WBPS at Brigade Bay was similar to the Pago Bay PS with a switchroom adjacent to the pump station itself. Figure 11-6 shows the external view of the pump station, while Figure 11-7 gives the general arrangement of the pipework, while Figure 11-8 shows the pump supports in the station:

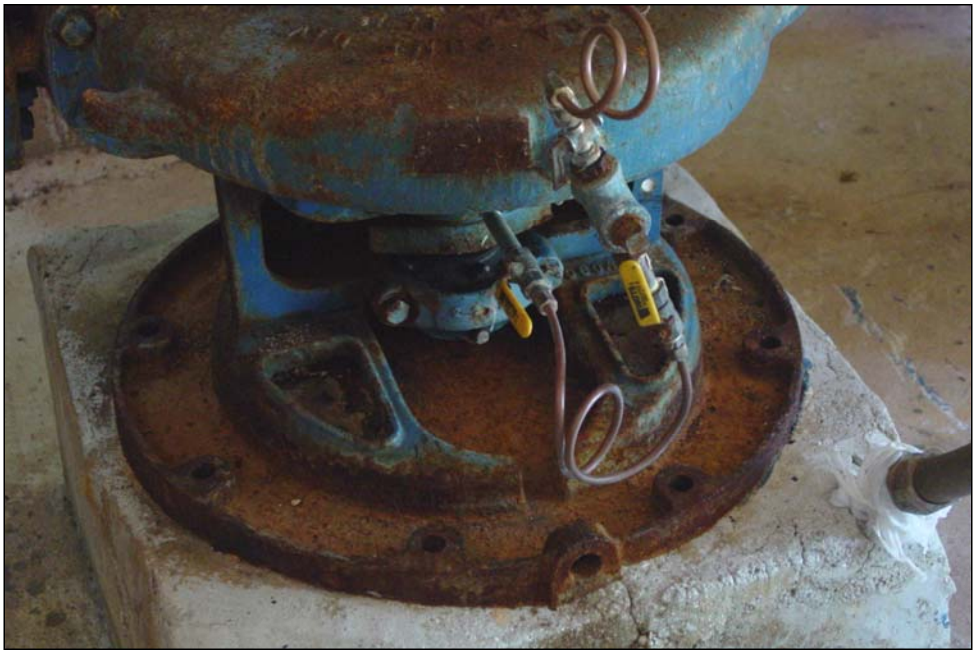
Figure 11-6 – Brigade Bay PS

An external view of Brigade Bay PS.

Figure 11-7 – Pipework

A general arrangement of pipework.

Figure 11-8 – Pump Supports



Pump base plate not bolted to concrete foundation.

The following observations were made on the pump station:

- Both structures and pipework were all in good condition, with no evidence of more than superficial corrosion.
- No. 3 pump had an overhead power supply, which although secure presents a safety hazard.

- There were no hold down bolts on all three pumps. The base plates were not secured to the concrete foundations and are only restrained by self weight and the pipe connections.

The following recommendations are made as a result of this inspection:

Recommendation A

Install hold down bolts and base grout as appropriate.

Recommendation B

Regularly inspect the power supply cable to pump No. 3 to ensure it is secure.

Recommendation C

Annually inspect and treat with waterproofing spray electrical fittings, connections and cover boxes showing signs of corrosion. Any critical fitting or one that presents a safety risk should be replaced.

11.3.5 Ugum River Intake

Figure 11-9 below shows a general view of the weir intake structure while Figure 11-10 provides a view of the two pumps at the intake works. Figure 11-11 shows the general condition of the concrete pit at the intake.

Figure 11-9 – Intake Structure

A general view of weir intake structure.

Figure 11-10 – Intake Pumps

A view of the two pumps at the intake works

Figure 11-11 – Concrete Intake Pit

Note good condition of concrete.

The following observations were made on the river inlet works:

- A small concrete weir type dam was located across the river with about 6 feet of storage with a typical extraction rate of 3.2 mgd. While it is unclear whether the yield of the river is satisfactory or not, the operators have informed us that there has been no shortage of water in the last few years. If this is the case, GWA should consider increasing the storage to increase security of supply and also investigate the value of either limiting the suction head on the pumps or lifting the pumps above flood level.
- The intake structure was encapsulated by stainless steel fencing grid with approximately 100 mm spacing. It is in satisfactory condition, although we were advised that it could become blocked under flood conditions.
- There are two pumps of 200 horse power (HP) operating as duty/standby with a spare mounting for an additional pump if required. The pipes and fittings were in good condition with some superficial corrosion. There was evidence of active

maintenance with a number of new fittings and stainless steel bolts.

- It was clear from the topography of the area that the pumps are in the floodplain and the motors are therefore exposed to flood damage. The operators advised us that there had been three instances of water near or over the pump structures in recent years.
- The switch and power rooms were all in good condition.

The following recommendations are made as a result of this inspection:

Recommendation A

Evaluate the risk to supply in regard to the level of the pumps. This may comprise a basic hydrology study to determine the frequency of flooding and an assessment of the consequences of loss of service and time required to replace flooded pumps.

11.3.6 Ugum WTP

The WTP at Ugum is a conventional sand filter plant based on a flocculation, settling and sedimentation process. It delivers 3.2mg (12ml) of treated water per day to mostly the southern region of Guam.

Figures 11-12 to 11-15 give a general view of Ugum WTP and some of the durability issues raised by the inspection.

Figure 11-12 – Ugum WTP

General view of Ugum WTP including storm damaged clear water tank.

Figure 11-13 – Filtration Tank

Filtration tank showing discolored but otherwise sound concrete.

Figure 11-14 – Pipe Gallery Under Control Room

Figure 11-15 – Close-up of Partially Collapsed Roof

The following observations were made on the Ugum WTP:

- Overall, the plant appeared to be in good condition with minor damage to aluminum railings and the reinforced concrete and generally only superficial corrosion. We also understand that there is suspected leakage from the plant, however, this was not evident at the inspection.
- The sedimentation tank had minor cracking and organic growth on the walls.
- The filter had some areas of exposed aggregate, probably due to the slightly low pH at this part of the process. Further there was some minor corrosion on pipework in this area. This was not considered serious, but should be monitored.
- The flocculation tank was in good condition, however, it was observed that the launder pipe was fixed to the walls by a combination of stainless steel nuts, galvanized plate and mild steel bolts, which has shown some minor dissimilar metals corrosion.
- The control room was in excellent condition with only minor corrosion on the air conditioning vents.
- The amenities room was in excellent condition throughout.
- The tank and pipe gallery under the control room appeared to be in reasonable condition. However, it was noted that there had been instances of leaking chlorine gas and localized areas of corrosion – particular at the southern end of the room with an open hatch cover. Further, there was evidence of loss of durability of the concrete and corrosion of the pipework near this hatch.
- The clear water tank walls appeared satisfactory from the outside. However, no internal inspection was possible as the reservoir was full at the time. The failed roof section was also inspected and it was noted that there were severe crimps at the wall to roof section that we assume to be local to a roof beam. There was a substantial depression in the roof, annular in shape. Further, the roof was unstable and deflected substantially under the weight of the inspecting team. It was suggested that this damage was incurred at the last typhoon. It is strongly recommended that this roof be stiffened as it is likely that it could fail in the next major wind event.
- The external coding of the reservoir was 400 microns thick.

The following recommendations are made as a result of these inspections:

Recommendation A

The roof of the clear water tanks requires structural stiffening as a matter of urgency.

Recommendation B

Investigations should be undertaken as a matter of urgency to confirm if there are defects in the chlorine injection system.

Recommendation C

A new hatch should be installed over the tank at the base of the pipe gallery.

11.3.7 Malojloj Water Reservoir and High Level Tank

The Malojloj reservoir complex comprises a 1 mg reservoir and a .075 mg elevated tank. Figures 11-16 to 11-19 show general and specific views of these reservoirs.

Figure 11-16 –View of Malojloj 1 mg Reservoir

Figure 11-17 – Malojloj High Level Tank

Figure 11-18 – Hold-Down Bolts on Reservoir

Picture shows extensive corrosion and total failure of hold down bolts near concrete base.

Figure 11-19 – View of Underside of High Level Tank

Picture shows view of corroded ladder and supports on high level tank.

The following observations were made on the reservoir and high level tank at Malojloj:

- The reservoir was externally only in average condition. Principally, the outstanding issue was the almost total disintegration of the hold-down bolts (see Figure 11-18). Almost 70% plus of these bolts had corroded to failure at the concrete/steel interface.
- The reservoir external coating generic type cold not be identified as details were not available, although it is probably an alkyd of some type. The coating was badly chalked and had a coating thickness of 120-180μm.
- Due to unavailability of ladders the roof could not be inspected. Similarly, it was not possible to inspect the internal surfaces of the reservoir as it was in service.
- The high level tank, built in 1994, had high gloss levels in the unspecified paint and a measured thickness of 300μm. However, there were heavily corroded areas at the legs and turnbuckle-style wind braces. The ladder of the elevated

tank was badly corroded (Figure 11-19) and unsafe for use. Work is required to bring these structures up to acceptable levels.

- No cathodic protection (CP) installation on either tank could be seen. It is possible CP was installed under the reservoir floor but no test points were available.

The following recommendations are made as a result of this inspection:

Recommendation A

A thorough, detailed inspection of both structures is required by a qualified structural engineer. This will require safe access to the roofs of both tanks.

Recommendation B

A thorough internal examination of both drained reservoirs is required to assess the degree of internal corrosion, with particular reference to the fillet welds on the floor/walls interface.

Recommendation C

Replacement of the hold-down bolts be immediately undertaken if a structural examination demonstrates empty reservoirs are in jeopardy in typhoon conditions.

11.3.8 Barrigada Heights Reservoirs

Barrigada Heights complex comprises reservoirs of one, two and three million gallons respectively. Several days before our site visit on 27 June 2005, the 1 mg reservoir collapsed catastrophically causing major damage to the two adjoining reservoirs. Although it was not directly in our brief to carry out a full investigation into this failure, it clearly has major implications for GWA's remaining steel reservoirs. Therefore, the inspection team treated this site as requiring special consideration.

Figures 11-20 to 11-27 below show some of the key views of all three reservoirs at this site.

Figure 11-20 – Part of Walls and Roof of Collapsed Reservoir

Figure 11-21 – Adjacent 2 mg Damaged Reservoir

Figure 11-22 –Collapsed Reservoir Wall Showing Positions of Sample Removed for Analysis

Figure 11-23 – Samples at Floor/Walls Fillet Weld Position

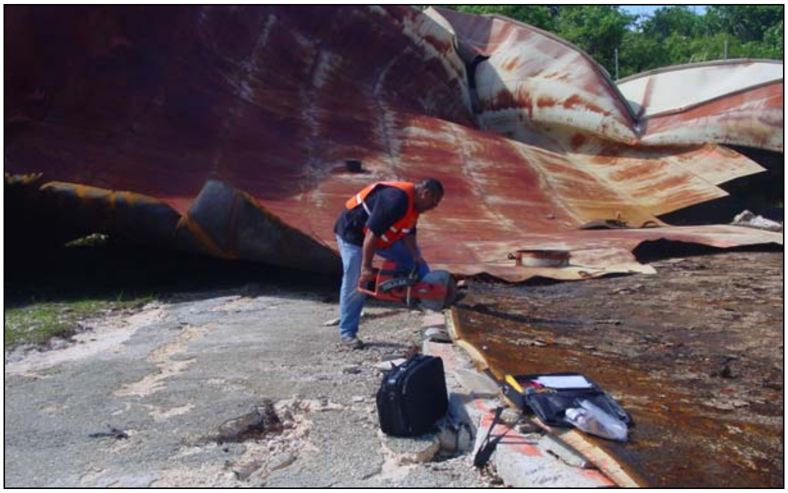


Figure 11-24 – Close-up of Sample Position at Floor

Figure 11-25 – Pitting Corrosion Damage on 1 mg Reservoir Wall

Figure 11-26 – Damage to 3 mg Reservoir

Figure 11-27 – Roof of 3 mg Reservoir

Part of conduit used for (non-operational) cathodic protection.

11.3.8.1 Barrigada No. 2 Reservoir - Summary

The 2 mg Reservoir suffered damage as shown in Figure 11-21 as a result of the collapse of No. 1 Reservoir. We did not observe any internal CP systems on this reservoir. The opportunity was taken to collect a sample of the bedding material used for under floor support for this reservoir in order to test for possible corrosivity.

It is worth noting that external paint peeling off this reservoir showed welder's chalk marks on the exposed steel, indicating a lack of suitable surface preparation when originally coated.

Tests carried out at Hunter Water Laboratories on 5 July 2005 showed that the coral/sand bedding had a pH of 9.5 and a conductivity of 55μS/cm. These results indicate a basically non-corrosive material with low soluble salts (e.g. chloride). If this is well compacted, *no* underfloor CP would be necessary, which is in fact rarely installed for water reservoirs although common for fuel tanks.

11.3.8.2 Barrigada No 3 Reservoir - Summary

Inspection of this reservoir showed it to be externally in satisfactory condition from a protective coating viewpoint. The damage to this reservoir (Figure 11-25) appears relatively minor compared with the other two and is still in partial use.

The top 3 feet of the internal surfaces of the reservoir was observable from the roof hatch and a coating was observable. Due to the poor condition of the internal ladder further access was not possible. There was clear evidence of some attempt to fit internal impressed current CP to this reservoir (Figure 11-26) but as the transformer/rectifier (T/R) unit was missing and the anode array was incomplete for effective use this was non-operational.

11.3.8.3 Barrigada No. 1 Failed Reservoir – Summary

The Barrigada No. 1 Reservoir, a 1 mg reservoir 66' in diameter and 41 feet high, constructed in 1972, is detailed by drawings 1195506 and 1195507. Of particular interest is the relatively low thickness dimensions of the steel used to construct the reservoir walls – the bottom strake is 0.29 inches (7.4 mm) and the top strake 0.19 inches (4.8 mm).

It was reported that at the time of failure the reservoir was 'approximately half full' after spending most of its life with only a few feet of water. It is understood the internals of this reservoir, along with most if not all of the steel reservoirs in Guam, had never been recoated.

Our inspection noted the following:

- A vertical failure up the wall and across the roof at about the third point on the roof plan area.
- A circumferential failure at the bottom strake to floor plate joint.
- All hold down bolts had been pulled out of the concrete ring beam. In the majority of the observable sections this appeared to be a spalling failure in the concrete due to lateral loading from the hold down bolts.
- Major structural damage to the adjacent pump house due to impact with the shell of the reservoir. This house was approximately 60 feet from the base of the reservoir.
- Substantial pitting (exceeding 4 mm in depth) on parts of the wall (see Figure 11-25), repeated on most of the internal lower strakes that could be examined.
- Evidence of poor weld penetration at the floor to wall joint.
- No evidence of underfloor CP installation remained.

A laboratory examination of the steel samples taken from the failed reservoir (see Figures 11-22 to 11-24) has been undertaken and the results are included as Exhibit 11A – CCI POPE Investigation Report at the end of this chapter. Several important issues were identified by the report:

- Steel grade was a copper-bearing 'COR-TEN A', a high-strength weathering steel While not necessarily an incorrect material, use of this grade of steel for water reservoir construction is unusual and is also noted in having poorer impact and brittle fracture characteristics than mild steels or other weathering grades.
- Internal fillet weld showed severe general and pitting corrosion, thus leading to obvious structural weakness.

Our preliminary consideration of the likely failure mechanism is:

- The failure was initiated at an area of severely corroded wall strake at about 6 feet above the base. In structural terms this approximately coincides with the level of maximum hoop load. That is, the moment restraint provided by the floor to wall weld is negligible at this height and the tank behaves as a pure hoop structure.

- We consider that the incremental load that caused failure came from high water levels but recognize the possibility of pressurizing. In discussing the operation of the reservoir and pumps with GWA staff we saw this as a low probability scenario. We also note that the wall thickness' are significantly lower than what would be considered current standard practice, and the steel is possibly more brittle than equivalent mild steel.
- There was rapid transfer of load both vertically up and vertically down.
- The base weld was poorly constructed and corroded and could not accept any further load and thus failed progressively. This in turn caused a radial force on each of the hold-down bolts shearing them through the concrete beam.
- A similar rapid transfer occurred in the vertical up direction and across the roof. It is also noted that part of the roof tear was along welded joints.
- The damage to Reservoir No. 2 was due to the rapid release of water.
- The displacement of the reservoir shell was probably due to the rapid release of strain energy in the wall together with an unbalanced hydrostatic thrust from the water and possibly even from the reflected energy after the water collided with Reservoir No. 2.
- The damage to Reservoir No. 3 was from the released water that would have picked up some more energy due to the lower elevation of this reservoir.

Our preliminary estimates suggest that the reservoir may have been at a higher water level than initially thought due to the energy required to generate the observed damage. Further it is considered that the failure had to have been extremely rapid, seconds not minutes, explosive in nature, and dangerous. This rapid failure proposition is consistent with reported remarks made by a nearby resident that he heard a loud explosive noise from the vicinity of the reservoir.

The following recommendations are made, subject to those made by the specialist consultants GWA have engaged to investigate this matter.

Recommendation A

Reservoir No. 2 should be kept empty until a comprehensive structural inspection is undertaken.

Recommendation B

All reservoirs in the GWA portfolio be subject to detailed structural internal and external inspections. This should be undertaken as a major priority.

11.3.9 As-Tumbo Reservoirs

The As-Tumbo site comprised two 1 mg reservoirs which were constructed around 1993. That is, they are relatively recent assets.

Figures 11-28 to 11-30 below show general views of each tank together with what may be an earth connection for under-tank CP.

Figure 11-28 – As-Tumbo No. 1 Reservoir

Figure 11-29 – As-Tumbo No. 2 Reservoir

Figure 11-30 – Possible Earth Connection for Under-Floor CP System

The following observations were made as a result of this inspection:

- Both tanks, but particularly No. 1 Reservoir (see Figure 11-28) had extensive surface corrosion. Again, it appeared the original coating had not been applied over a properly prepared surface.
- Hold-down bolts were again in poor condition with approximately 20% having no load carrying capacity.
- A number of CP connections were found (e.g. Figure 11-30), which presumably are for under-floor CP. No test points were found that would be required to test the effectiveness of such a system. As mentioned previously, an underfloor CP system is not standard practice for the water industry and probably not required.
- No signs of any CP installations were observed on either reservoir roof which might have indicated protection of the internal surfaces.

Recommendations for these tanks are identical to the previous recommendation 3.8.B which requires detailed internal inspection.

Recommendation

Both As-Tumbo reservoirs be subject to detail internal and, to a lesser degree, external inspection.

11.3.10 Hagatna Dry Well STP

This pump station comprised a concrete building with four (4) 100 horsepower ABS pumps, running as two duty and two standby. There is also a sump pump for removing pipework leakage. Figures 11-31 to 11-32 give general views of Hagatna STP.

Figure 11-31 – External View of Hagatna STP

Figure 11-32 –Pump Arrangement Inside Dry Well

Corrosion is largely superficial.

The following observations were made as an outcome of this inspection:

- Sump pump leakage largely came from a single check valve which is due to be repaired.
- The concrete structures were in good condition with little evidence of damage.
- Minor superficial corrosion was noted on pumps, pipework and other steel structures but this has no impact on serviceability.
- It was noted that a number of access hatches were uncovered and were without adequate safety protection.

The following recommendation is made as a result of this inspection:

Recommendation

GWA's standard operating procedures should be amended to ensure that all open hatches subject to repair works should be made safe by the use of temporary safety fencing.

11.3.11 Prison Wet Well Sewerage Pump Station (near Pago)

Figure 11-33 below shows the position of the switch room and generator room at the wet well site while Figure 11-34 shows the wet well itself.

Figure 11-33 – Prison Wet Well Site

Figure 11-34 – Wet Well

The following observations were made as an outcome of this inspection:

- The wet well structures were in generally good condition although there were no steel hatch covers. We understand that they are being repaired and will be replaced soon.
- The switch room and generator room were structurally sound with fittings observed to be in good condition.
- The security fence was in reasonable condition but is not child-proof and given the open wet well represents a major safety risk.

The following recommendation is made as a results of these observations:

Recommendation A

Place signposts on all security fencing advising the public that entry is prohibited. The security of the fence itself should be reviewed.

Recommendation B

For safety of the public and the operators ensure the both covers are replaced as a matter of urgency.

11.3.12 Hagatna STP

Hagatna STP has a theoretical capacity of 21 mgd although average dry weather flows are about 7 mgd. At the present, Hagatna STP is simply channeling effluent directly to the ocean and no chemical or physical wastewater treatment is taking place.

Figures 11-35 to 11-42 provides some examples of corrosion issues identified during the inspection of this STP.

Figure 11-35 – Corrosion of Penstock Gate Valve

Figure 11-36 – Corroded Electrical Motor

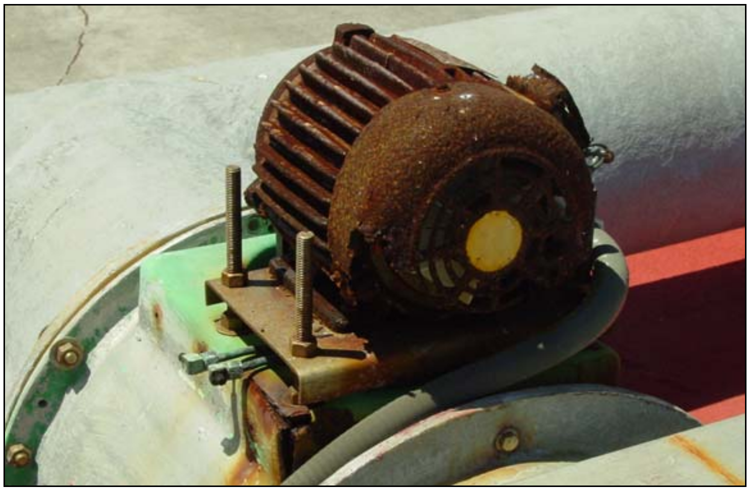


Figure 11-37 – Failed Power Supply Support to Aerator

Figure 11-38 – Corroded Primary Support Beams for Aerator

Figure 11-39 – H_2S Corroded Copper Pipe Supernatant Lines

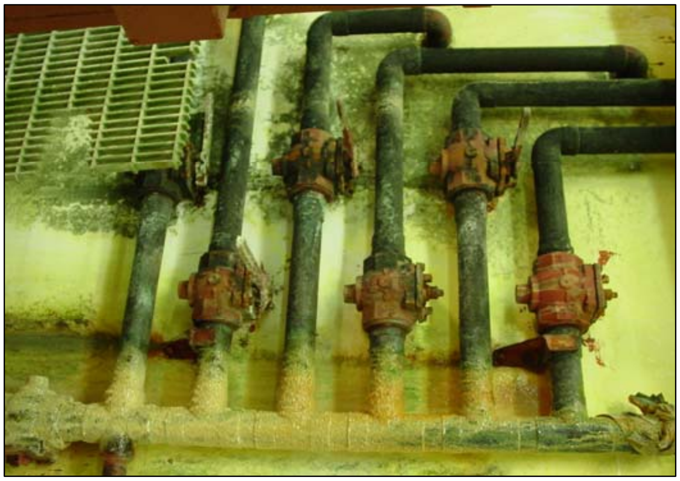


Figure 11-40 – Outlet Drop Chamber with Exposed, Corroding Rebar

Figure 11-41 – Surface Corrosion and Pitting in Pipework in Effluent BPS

Figure 11-42 – Close-up of Failed Fastener from Figure 11-41

The following observations were made as an outcome of this inspection:

- Penstock type gate valves were consistently in poor condition.
- All process pipework was in bad condition with delamination evident.
- Although it was not possible to inspect the concrete soffits, it was reported that the clarifiers and digesters had substantial concrete degradation. This was noted at the outlet drop chamber where significant loss of concrete paste had progressed to at least the centerline of the reinforcing steel (see Figure 11-40).
- The thickener building was in reasonable condition. However, all pipe and treatment structures were in very poor condition. Further, it was noticed that a number of exposed electrical motors had partially disintegrated.
- There were a number of instances of cracking in the concrete and we were advised that this all occurred from a recent major earthquake.
- The pipe gallery had loose edge strips in the concrete staircase and several instances of H_2S corrosion on the copper supernatant lines from the thickeners (see Figure 11-39). All power boards were severely corroded.
- The effluent booster pump station exhibited major surface corrosion with pitting to a depth of up to 4mm. All fasteners had failed (see Figures 11-41 to 11-42) and will need replacement.

The following recommendations are made as a result of these observations, bearing in mind that these must be considered in conjunction with the process and civil changes that will be required to bring Hagatna STP back to operating condition:

Recommendation A

All concrete structures should be examined and repaired using epoxy concrete or other approved methods. Some reinforcing bar will also need repair.

Recommendation B

Corroded valves and electrical equipment should be individually inspected and replaced where necessary.

Recommendation C

Effluent booster pump station pipework be repainted after appropriate surface preparation. All *fasteners should be replaced.*

Recommendation D

Concrete cracks in buildings and other structures should be repaired.

Recommendation E

Pipe gallery copper pipe should be cleaned so corrosion pitting depth can be assessed. If pitting is excessive pipes should be replaced.

11.3.13 Northern District STP

Northern District STP comprises coarse screening, grit removal, clarifiers and a heater digestion system. Figures 11-42 to 11-47 show key aspects of this STP.

Figure 11-43 – General View of Chlorination, Laboratory and Operational Buildings

Figure 11-44 – Pipework H_2S Corrosion at Centrifuge Building

Figure 11-45 – Corrosion on Blower Ductwork at Heater/Digester Building

Figure 11-46 – Heater/Digester Tank Roof Showing Corrosion and Ponded Water

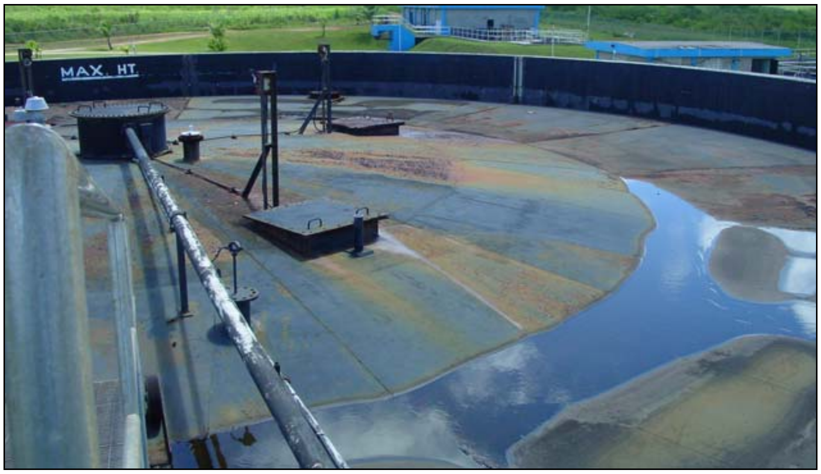


Figure 11-47 – Empty Clarifier Showing Bolt-on Sacrificial CP Anodes

Figure 11-48 – Corrosion of Perimeter Fence

The following observations were made as a result of this inspection:

- Some evidence of structural damage from recent seismic event.
- The concrete hydraulic surfaces were in a consistently good condition.
- There was minor H_2S affected copper pipes.
- It was noted that the grit removal system is under replacement and therefore all fittings and process equipment was ignored. Again, however, the concrete surfaces were in very good condition.
- The return activated sludge (RAS) pumps showed some corrosion of the bolts and pipework but do not warrant major repairs at this stage.
- The clarifiers appeared in very good condition except for corrosion on electrical controls and some of the skimmer plates. The testing of the concrete revealed compressive strengths of up to 50 megapascals (MPa) (7250 psi).
- Heater digester tanks were in good condition in regard to the visible external concrete faces but in very poor condition (see Figure 11-45) in regard to the steel members. In particular, the roof was badly corroded and we consider it prudent to expect that the underside is also in poor condition.
- The transfer pump building was in good condition throughout.
- The heater digester/polymer mixing building was in good condition with the exception of major corrosion on the blower ductwork (see Figure 11-44).
- The centrifugal building had been decommissioned due to damage by a typhoon. However, it was noted that there was plenty of evidence of H_2S damage.
- The chlorination building and laboratories were in good condition although there were a number of instances of concrete spalling due to earthquake damage.
- The effluent contact structure was generally in good condition, except for the underside of the concrete walkover where there was exposed aggregate and low strength concrete paste due to the release of H_2S down the inlet chamber.

The following recommendations are made as a result of the inspection of Northern District STP:

Recommendation A

A risk assessment should be made on the consequences of collapse of the heater/digester roof. If it is not critical to the operation of the plant then inspection and maintenance of the inside surfaces (especially the roof) can be deferred. Notwithstanding this, it is recommended that access to the roof be prohibited.

Recommendation B

The walk over bridge at the effluent contact structure should be reviewed to assess its operational importance. If not critical then repairs to the concrete may be deferred as long as there is no evidence of corrosion of the reinforcing steel. Again, however, access to the bridge should be prevented.

11.3.14 Pipelines

GWA has extensive networks of both water and sewer mains, virtually all dating from the early 1950s. From GWA Records, Table 11-2 below provides a summary of both transmission, distribution, forcemains and gravity listed in the Asset Tables:

Table 11-2 – Lengths of Water and Sewer Mains in GWA

Type of Main	Length (miles)	Materials
Water Transmission Line (1—24" dia)	153.8	Cast iron, ductile iron, steel, asbestos cement, uPVC
Water Distribution (<10")	217.7	
Sewer Forcemain	7	Concrete, uPVC, cast iron, ductile iron
Sewer Gravity	74.3	

The proportions of material in each category are not known at the time of writing this final report.

As discussed in Section 11.3.1.2 - Soil Corrosivity in Guam is not expected to be extremely aggressive to either ferrous or cementitious materials. This applies particularly to the northern part of Guam where the surface geology is largely limestone.

Samples of soil provided by GWA from seven pipeline routes in Guam have been assessed for direct measurement of corrosivity using Linear Polarization Resistance (LPR) methodology largely developed for soils in Australia. As LPR provides a measure of corrosion *rate* then it is possible to extrapolate an approximate pitting rate assuming a reasonably linear corrosion rate. Table 11-3, Corrosivity Test Results on Guam Soils, provides a summary of the results of this testing.

Table 11-3 – Corrosivity Test Results on Guam Soils

Sample No.	Soil Sample Location (from GWA)	R_p Value from LPR Test ohm/10cm^2	Extrapolated pitting rate (mm/year)
1	Manufactured bedding material from Hawaiian Rock Products	>300	<0.01
2	Manufactured bedding material from Perez Brothers	>300	<0.01
3	Trench spoil from 3-4ft depth along Route 4 near Chaot River Bridge	124	0.1
4	Trench spoil from 3-4ft depth on west side Route 4 at crest of hill at Yona	155	0.07
5	Trench spoil from 3-5ft depth in new subdivision in Yigo-Perez Estates	249	0.02
6	Sample taken from 5ft depth in Umatec on Jesus Quidachay St. during PRV replacement. Iron Pipe had minor corrosion, but age unknown. Threaded joints were corroded.	276	0.02
7	Sample taken from 4ft depth on Chalan Kanton Tasti near Merizo Pier during PRV replacement. Iron pipe had minor corrosion but age unknown. Threaded joints were corroded.	225	0.03

Table 11.3 shows that the ‘natural’ soils supplied as samples 3-7 have generally low corrosivity with a maximum pitting rate of 0.1 mm being measured for Sample 3. On a pipe of 10mm (3/8”) wall thickness this corresponds to a 100 year life before perforation.

Samples 6 and 7 were taken from PRV Valve replacements where observation of the cast/ductile iron pipe corrosion could be made. In both cases this was categorized as ‘minor’ although simple visual observation of cast iron can often be deceptive. The corrosion of threaded areas, particularly galvanized steel, noted by GWA is consistent as these components will always show a tendency to corrode faster than pipe barrels in soils of similar corrosivity, particularly if there are joint leaks. In both cases, the age of the pipes and fittings were not known.

The two bedding materials supplied and tested show very low corrosivity which is to be expected in a bedding material. From a corrosivity view point, both materials are very acceptable.

Note that accurate information regarding the number of directly corrosion related pipe failures in GWA is not readily available. However, anecdotal information indicates that this value is not high and that most issues come from joint leaks and other mechanical issues. This information is in accordance with the soil corrosivity results shown above in Table 11-3 which shows general corrosion rates to be generally low. In this case, it is likely that the relatively frequent seismic activity on Guam has a significant bearing on pipe integrity.

While there is little remedial action on existing buried pipes that is practical, for new systems and repairs there are measures that can be undertaken, and these are shown below in the following recommendations:

Recommendation A

Ensure pipes, regardless of material, are installed in well-compacted bedding material.

Recommendation B

Pipe laying and design must be carefully undertaken to minimize joint leakage and other mechanical damage.

Recommendation C

Ductile materials, such as steel, will perform better than brittle materials such as uPVC and are to be preferred where economic and practical considerations allow. However, some of the newer plastics such as polyethylene (PE) and O-PVC are acceptable materials.

11.4 Discussion and Conclusions

The methodology used in this assessment was to examine 'typical' examples of each class of GWA asset and extrapolate these to provide a snapshot of the asset type as a whole. A further objective was to give some indications of future life expectance and, most importantly, identify both remedial action and any further assessments that might be required.

It became clear during the assessment that some classes of asset were performing better than others. This is best summarized by the following general conclusions reached on each asset type.

- ***Deep Well Pump Stations***. While only a single example of these was examined in any detail, cursory looks at others during the site visit, and the general standard design that was presented, showed that as an asset class these are unlikely to cause significant future problems and given adequate maintenance will continue to provide good service. From an internal corrosion viewpoint the most concern is over the water quality itself, and particularly the presence of free/aggressive carbon dioxide.
- ***Water Pump Stations***. Good concrete construction coupled with ongoing maintenance should provide extended life for this asset class.
- ***Water Treatment Works and Ancillary Assets***. A single asset evaluated in its own right the Ugum WTP showed excellent concrete structures and generally very good condition of equipment. Leaking chlorine gas was a minor blemish but the only item of major concern was the storm damaged steel clear water tank. The condition of GWA's steel tanks and reservoirs caused more concern than any other asset class.
- ***Water Reservoirs***. While inevitably colored by the collapsed Barrigada No. 1 Reservoir, this asset class is generally in either unknown or poor shape. Based on the seven reservoirs examined all have external paint problems and clear lack of inspection of the internal surfaces, typified by the lack of ladders for roof access. CP systems (all non-operational as far as could be ascertained) were largely limited to underfloor protection, probably not needed, and was absent from the internal surfaces where it certainly is required. If Barrigada No. 1 represents typical internal corrosion, then potentially very serious issues apply to the remaining tanks, which may have limited future life unless significant remedial work is carried out. Further, there is a risk of catastrophic failure with consequences for the safety of the public.
- ***Sewerage Pump Stations***. Good concrete and only minor corrosion and durability issues mean this asset class has extensive future life providing maintenance is continued.
- ***Sewage Treatment Plants***. Based on those examined, this asset class has significant corrosion and durability issues. While the concrete exposed to atmosphere was generally

excellent, concrete (and steel) exposed to H_2S in non-ventilated conditions is often in degraded condition and requires extensive remedial work. Further, much equipment and pipework is corroded and also requires attention.

- ***Pipelines***. By their very nature none of this asset class was able to be directly examined. The limited failure data obtained did not indicate significant corrosion related failures and this is supported by the random soil corrosivity data measured in the laboratory. However, the seismic influence on mechanical failure is likely to be significant and the performance overall of both water and sewer mains, as GWA's largest asset cost, should be carefully monitored.

11.5 Summary of Recommendations

11.3.1.3		Carry out on-site testing on at least 6 deep well bores to ascertain the level of free/aggressive carbon dioxide.
11.3.2	A	Ensure that chlorine room is secure at all times.
	B	Annually inspect and treat with waterproofing spray electrical fittings, connections and cover boxes showing signs of corrosion. Any critical fittings or one that presents a safety risk should be replaced.
	C	Place signs on all security fencing advising the public of danger and prohibiting entry to non-authorized personnel.
11.3.3	A	Ensure that safety guards are placed over all motor shafts or exposed rotating machinery.
	B	Annually inspect and treat with waterproofing spray electrical fittings, connections and cover boxes showing signs of corrosion. Any critical fitting or one that presents a safety risk should be replaced.
	C	As there is exposed machinery and strategic assets, signposting the compound to advise the public that access is prohibited should be erected.
11.3.4	A	Install hold down bolts and base grout as appropriate.
	B	Regularly inspect the power supply cable to pump No. 3 to ensure it is secure.
	C	Annually inspect and treat with waterproofing spray electrical fittings, connections and cover boxes showing signs of corrosion. Any critical fitting or one that presents a safety risk should be replaced.
11.3.5		Evaluate the risk to supply in regard to the level of the pumps. This may comprise a basic hydrology study to determine the frequency of flooding and an assessment of the consequences of loss of service and time required to replace flooded pumps.
11.3.6	A	The roof of the clear water tanks requires structural stiffening as a matter of urgency.
	B	Investigations should be undertaken as a matter of urgency to confirm if there are defects in the chlorine injection system.
	C	A new hatch should be installed over the tank at the base of the pipe gallery.

11.3.7 A A thorough, detailed inspection of both structures is required by a qualified structural engineer. This will require safe access to the roofs of both tanks.

B A thorough internal examination of both drained reservoirs is required to assess the degree of internal corrosion, with particular reference to the fillet welds on the floor/walls interface.

C Replacement of the hold-down bolts should be immediately undertaken if a structural examination demonstrates empty reservoirs are in jeopardy during typhoon conditions.

11.3.8 A Reservoir No. 2 should be kept empty until an inspection is made of the internal surfaces.

B All reservoirs in the GWA portfolio should be subject to detail internal and, to a lesser degree, external inspection. This should be undertaken on the priority of age unless it can be demonstrated that some work has been undertaken on internal protective coatings.

11.3.9 Both As-Tumbo reservoirs be subject to detail internal and, to a lesser degree, external inspection.

11.3.10 GWA's standard operating procedures should be amended to ensure that all open hatches subject to repair works should be made safe by the use of temporary safety fencing.

11.3.11 A Place signposts on all security fencing advising the public that entry is prohibited. The actual security of the fence itself should be reviewed.

B For safety of the public and the operators ensure the both covers are replaced as a matter of urgency.

11.3.12 A All concrete structures should be examined and repaired using epoxy concrete or other approved methods. Some reinforcing bar will also need repair.

B Corroded valves and electrical equipment should be individually inspected and replaced where necessary.

C Effluent booster pump station pipework be repainted after appropriate surface preparation. All fasteners should be replaced.

D Concrete cracks in buildings and other structures should be repaired.

E Pipe gallery copper pipe should be cleaned so corrosion pitting depth can be assessed. If pitting is excessive pipes should be replaced.

11.3.13 A A risk assessment should be made on the consequences of collapse of the heater/digester roof. If it is not critical to the operation of the plant then inspection and maintenance of the inside surfaces (especially the roof) can be deferred. Notwithstanding this, it is recommended that access to the roof be prohibited.

B The walk over bridge at the effluent contact structure should be reviewed to assess its operational importance. If not critical then repairs to the concrete may be deferred as long as there is no evidence of corrosion of the reinforcing steel. Again, however, access to the bridge should be prevented.

11.3.14 A Ensure pipes, regardless of material, are installed in well-compacted bedding material.

B Pipe laying and design must be carefully undertaken to minimize joint leakage and other mechanical damage.

C Ductile materials, such as steel, will perform better than brittle materials such as uPVC and are to be preferred where economic and practical considerations allow.

Exhibit 11A

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INVESTIGATION REPORT

Our Reference:05/INV4698/1 Date: 29 July 2005

Client: Hunter Water Order No.:

Client Contact: Dr D Nicholas

Description: Water Tank Failure – Guam

1 INTRODUCTION

At the request of Dr D Nicholas, Hunter Water, two samples taken from the floor to shell plate weld on a failed water storage tank in Guam, have been examined. The age of the tank was not known accurately but it was suspected to have been constructed in the early 1970's. The circumstances leading to the failure were unknown.

2 VISUAL EXAMINATION

Figures 1 and 2 show the two samples as received for examination. It was evident that the tank had been constructed by fillet welding on both the internal and external sides of the shell/floor connection. Failure of the tank had resulted in the shell plate shearing the welds for most of the length of the samples supplied. Severe internal corrosion of the floor plate was evident. The samples were cleaned in inhibited hydrochloric acid and they are shown in figures 3 and 4 after this cleaning. Severe general and pitting corrosion of the internal fillet weld was revealed.

3 MACRO EXAMINATION

A macro specimen was prepared from one sample through the welded connection. The specimen is shown figure 5. The shear of the weld between the shell plate and the floor is shown as well as pitting attack at the toe of the internal weld.

On Behalf Of:Hunter Water
Report No.:05/INV4698/1
Date: 7/29/2005

4 CHEMICAL ANALYSIS

The floor and wall plates were analysed by Atomic Emission Spectrometry with results attached as Appendices 1 and 2. This material satisfies the chemical requirements of CorTen A which was produced as a weathering, high strength, low alloy steel. The minimum yield strength of this material was equivalent to 345MPa.

5 SUMMARY

The samples supplied from the shell/floor weld area on the failed tank indicated that construction had involved fillet welding both internally and externally for this connection. The floor and wall had been manufactured from material similar to CorTen A, a high strength, low alloy weathering steel. These steels have some resistance to atmospheric corrosion due to their alloy content.

The internal fillet weld at the connection showed evidence of severe general and pitting corrosion. The floor remote from the weld also showed severe internal attack.

Author: M O'Brien
Principal Consultant
Metallurgist

Reviewed: S Krismer
Consultant Materials
Engineer

On Behalf Of:Hunter Water
Report No.:05/INV4698/1
Date: 7/29/2005

Figures 1 & 2
Show the two samples received for examination.

On Behalf Of:Hunter Water
Report No.:05/INV4698/1
Date: 7/29/2005

Figures 3 & 4
Show the samples after cleaning in an inhibited hydrochloric acid solution.

On Behalf Of:Hunter Water
Report No.:05/INV4698/1
Date: 7/29/2005

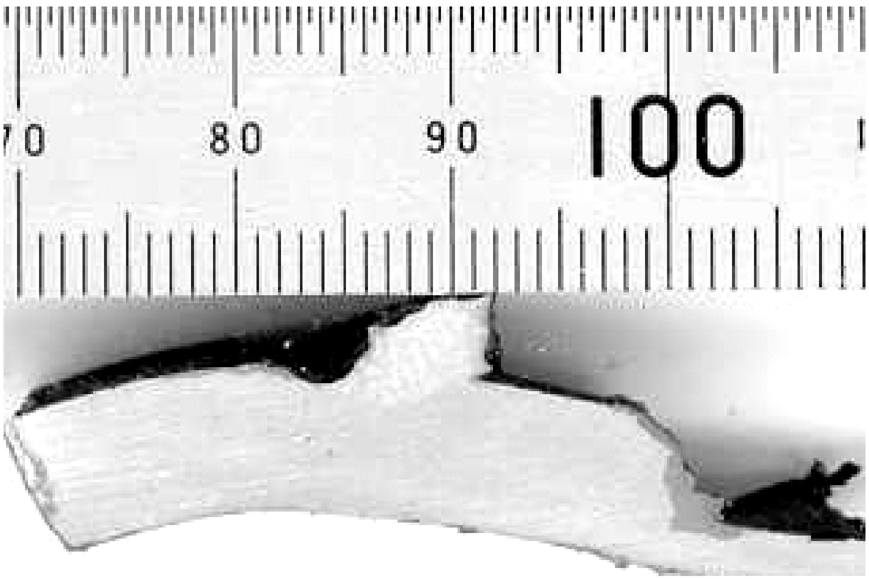

Figure 5
Shows the macro sample removed from a sample from the tank to shell plate weld. The location which the shell plate originally occupied is arrowed. Note the corrosion on the internal fillet weld toe.

On Behalf Of:Hunter Water
Report No.:05/INV4698/1
Date: 7/29/2005

APPENDICES 1

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Email: ccipope@ccipope.com.au

CHEMICAL ANALYSIS CERTIFICATE

Certificate Number: INV4698/0527Y **Issue Date:** 08-07-05

Client: Hunter Water
Order Number:
CCI Pope Job Number: INV4698
CCI Pope Identification : INV4698
Sample Description : Guam Water Storage Tank Failure Floor Plate
Test Date: 08-07-05

CHEMICAL COMPOSITION (W/W%)
Analysis performed by Atomic Emission Spectrometry using CCI Pope procedure MH037 TST

C	Mn	P	S	Si	Ni	Cr	Mo	V	Al	Cu	Ti
0.10	0.40	0.095	0.018	0.41	0.20	0.57	0.01	0.006	0.031	0.28	0.040

Remarks:

The results on this certificate relate only to the item(s) tested. To the best knowledge of the company the results on this report are correct. However, no legal responsibility will be accepted for or arising from their use. Samples are tested as received unless stated otherwise. Unless otherwise advised, samples are held for 3 months prior to disposal. This report shall not be reproduced unless in full.

Certified By: MOBrien

X M. O'Brien

Approved Signatories

Checked By: SK

NATA Accredited Laboratory No. 785
This Laboratory is accredited by the National Association of Testing Authorities, Australia. The tests reported herein have been performed in accordance with its scope of accreditation.

APPENDICES 2

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CHEMICAL ANALYSIS CERTIFICATE

Certificate Number: INV4698/0528H **Issue Date:** 14-07-05

Client: Hunter Water
Order Number:
CCI Pope Job Number: INV4698
CCI Pope Identification : INV4698H
Sample Description : Guam Water Storage Tank Failure Wall Plate
Test Date: 14-07-05

CHEMICAL COMPOSITION (W/W%)
Analysis performed by Atomic Emission Spectrometry using CCI Pope procedure MH037 TST

C	Mn	P	S	Si	Ni	Cr	Mo	V	Al	Cu	Ti
0.09	0.44	0.080	0.015	0.44	0.16	0.58	0.01	0.003	0.037	0.28	0.045

Remarks:

The results on this certificate relate only to the item(s) tested. To the best knowledge of the company the results on this report are correct. However, no legal responsibility will be accepted for or arising from their use. Samples are tested as received unless stated otherwise. Unless otherwise advised, samples are held for 3 months prior to disposal. This report shall not be reproduced unless in full.

Certified By:

☐ M. O'Brien ☒ B. Murray

Approved Signatories

Checked By:

NATA

NATA Accredited Laboratory No. 785
This Laboratory is accredited by the National Association of Testing Authorities, Australia. The tests reported herein have been performed in accordance with its scope of accreditation.

Page 7 of 8

On Behalf Of:Hunter Water
Report No.:05/INV4698/1
Date: 7/29/2005

Sample Disposal
Test samples and off-cuts of client test samples sent to CCI Pope for investigation will be retained in a weatherproof area for approximately one month after the issue of this report and for a further two months in external storage before disposal. If these parts are required by you then you must contact CCI Pope to arrange pick up before this term has elapsed.