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EVALUATION OF STAINLESS STEEL PIPING FOR HIGHLY CORROSIVE LOCATIONS

Main Category:	Mechanical Engineering
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Course #:	MEC-140
Course Content:	67 pgs
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Exam Preview:

1. According to the reference material, the external pitting was measured using a Thorpe pit-depth gauge.
   a. True
   b. False
2. According to the reference material, the data in Table C1 (Appendix C) shows that the deepest pitting was ___ mils on an 8-inch pipe, with an original wall thickness of 315 mils.
   a. 225
   b. 260
   c. 280
   d. 300
3. According to the reference material, the only candidate materials for water-line replacement were galvanized steel, 304L stainless steel and 316L stainless steel.
   a. True
   b. False
4. Both grades of stainless steel perform equally well when exposed as a large surface, such as a pipe, but grade 316L offers better corrosion prevention against crevice attack that can occur at flanges and bolted connections. The research team selected 304L for the piping, however, because it is __% lower in cost than 316L stainless.
   a. 15
   b. 20
   c. 30
   d. 40

5. According to the reference material, the pipeline was assembled using metal inert gas (MIG) welding. Pipe segments were joined at a stationary location to form longer segments, which were then transported to the appointed final assembly location.
    a. True
    b. False
6. Each section of pipe was also subjected to hydrostatic testing in accordance with ASME B31.3. Each pipe section was filled with water and then pressurized to ___ psi. The pressure was monitored for at least 4 hours and the line was examined for leaks.
    a. 200
    b. 250
    c. 275
    d. 300
7. According to the reference, painting a pipeline can serve two purposes: providing corrosion protection for mild steel pipes or color-coding lines to identify the fluid inside.
    a. True
    b. False
8. Although the material costs for the demonstrated grades of stainless steel are higher than for standard carbon steel pipes, the labor costs for installation are the same. The calculated ROI of 1.21 is attributable to reduced maintenance and repair costs over the expected system service life of __ years.
    a. 15
    b. 20
    c. 30
    d. 40
9. Using Appendix D: Pipeline Pressure Calculations for Existing Pipe at Corroded Area, what was the estimated remaining service life that was calculated for the existing 5-inch pipe?
    a. 2.8 years
    b. 3.8 years
    c. 4.3 years
    d. 4.8 years
10. Using Appendix F: Pipeline Pressure Calculations for New Pipeline Segments, what was the maximum allowable working pressure for the 8-inch 304L SS pipeline?
    a. 683 psi
    b. 622 psi
    c. 559 psi
    d. 487 psi

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Preface

This document details a real world evaluation of piping in a highly corrosive location. The evaluation was originally performed for the Office of the Secretary of De-fense (OSD) under Department of Defense (DoD) Corrosion Prevention and Control Project F07-AR15, “Advanced Corrosion Resistant Steel for Rehabilitation of Fire Suppression System Pipelines for Okinawa Fuel Tanks” The proponent was the U.S. Army Office of the Assistant Chief of Staff for Installation Management (ACSIM) and the stakeholder was the U.S. Army Installation Management Command (IMCOM). The technical monitors were Daniel J. Dunmire (OUSD(AT&L)), Bernie Rodriguez
(IMPW-E), and Valerie D. Hines (DAIM-ODF).

The work was performed by the Materials and Structures Branch of the Facilities Division (CEERD-CFM), U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL), Champaign, IL. The ERDC-CERL project manager was Steven C. Sweeney. Significant portions of this work were performed by Mr. Ralph Eichlin of Corrosion Control Incorporated, Rutledge, GA. The contributions of subcontractor Nanseki Kaihatsu, Ltd. (NSK) are also acknowledged. At the time this report was published, Vicki L. Van Blaricum was Chief, CEERD-CFM; Donald K. Hicks was Chief, CEERD-CF; and Kurt Kinnevan, CEERD-CZT, was the Technical Director for Adaptive and Resilient Installations. The Deputy Director of ERDC-CERL is Dr. Kirankumar Topudurti and the Director is Dr. Ilker Adiguzel.

The following personnel are gratefully acknowledged for their support and assistance in this project:

- Mr. Dan Zhira, Director of Public Works, Tori Station, Okinawa
- Mr. Ken Hoff, 505th QMBN, Okinawa

The Commander of ERDC is COL Bryan S. Green and the Director is Dr. David W. Pittman.

Unit Conversion Factors

Multiply	By	To Obtain
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
mils	0.0254	millimeters
square feet	0.09290304	square meters

1 Introduction

1.1 Problem statement

Corrosion prevention and control represents a major cost for Department of Defense (DoD) installations, particularly those located in marine coastal settings around the world. The cost of corrosion in these environments is always significant, but the problem is greatly compounded when the affected infrastructure is critical to mission and operational safety. One example of such critical infrastructure is above-ground piping networks that supply the water for fire protection of fueling facilities. In coastal salt-spray environments, exposed steel pipes require a high maintenance investment to prevent system failure.

The 505th Army Quarter Masters Battalion (QMBN) operates the Defense Energy Support Center (DESC) fuel delivery system at Okinawa Island, Japan, a small island located about 400 miles south of the main island that hosts many military bases and training sites. This fueling system includes marine receiving facilities, transfer pipelines, pump stations, bulk storage tank farms, truck stands, and issue manifolds at various military installations. The bulk fuel storage tank farms each consist of large underground cut-and-cover tanks with interconnecting underground fuel lines. Six tank farms are strategically located across the island. On the east coast, north of Marine Corps Base (MCB) Camp Cortney, are located three tank farms called Chimu-Wan 1, 2, and 3. These facilities are near the ocean coastline and continually exposed to salt spray. Each tank farm has welded carbon-steel pipelines that route water to remotely operated water cannons around each tank used for fire protection. When originally constructed, the carbon steel pipes were abrasive blasted and coated with an industrial enamel product. Due to the harsh environment, these coatings require continual maintenance. Historically, the coatings have not been as well maintained in the most difficult-to-access areas. Some pipes have severely corroded and leaked, primarily along the bottom, at flanged fittings and supports. The resulting leaks have rendered the fire protection systems inoperable.

To address this problem, which is common in many similar installation locations, the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) executed a demonstration/validation project to select, install, monitor, and evaluate the corrosion performance of improved piping materials.

1.2 Objective

The objective of this project was to select, demonstrate, and evaluate alternate materials for corroded fire-suppression water pipelines at the Chimu-Wan tank farms on Okinawa Island, Japan.

1.3 Approach

Members of the research team inspected piping at the three Chimu-Wan tank farms. Chimu-Wan 3 was determined to be in the poorest condition, so it was selected as the test site. Given the highly corrosive chloride-infused environment at the site, SAE* low-carbon stainless steel grades 304L (pipe sections) and 316L (flange fasteners) were selected as the demonstration materials. A rehabilitation design was developed, installed and tested on above-ground sections of fire-protection piping.

Quality control was a critical part of the project to ensure that the new pipe would perform to specifications under the operating conditions for fire protection. Quality control testing was performed at several stages of pipeline assembly, culminating in an operational test and static pressure hold.

Exposure coupon testing was originally planned to supplement visual inspections of the demonstrated pipe materials, but coupon testing was abandoned because the project performance period was not long enough to provide conclusive results. Long-term performance was assessed based on the results of onsite visual inspections and photographic documentation provided by Okinawa DPW† personnel in March 2017.

1.4 Metrics

For successful application, the materials must be installed in the existing fire-suppression system such that no galvanic corrosion is caused by contact between dissimilar metals. The absence of such galvanic corrosion is determined through visual inspection by qualified personnel.

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* SAE International (Warrendale, PA).

† Directorate of Public Works.

Also, the observed corrosion rates of the demonstrated materials must be low enough to provide the projected life-cycle cost savings versus the cost of using standard carbon-steel pipe in the same environment. Corrosion-rate data developed previously for use by the CPC Program (see Appendix A) were used as the reference for observations made onsite by research team members and installation personnel.

2 Technical Investigation

2.1 Project overview

In May 2008, members of the research team made an initial site visit to the Chim-Wan bulk fuel tank farms to document the condition of standard carbon steel piping and fitting. An in-depth failure analysis of a section of removed pipe was completed in July 2008. The full results are presented in Appendix B.

After meeting with QMBN and Directorate of Public Works (DPW) at Camp Cortney, inspections of the fire-protection pipelines were conducted at each of the three Chim-Wan bulk fuel tank farms. Within each tank farm, the fire protection pipelines were examined, noting areas of active corrosion. The piping within all three tank farms exhibited areas of significant corrosion activity and metal loss. The most significant corrosion was on the piping within Chimu-Wan 3 tank farm. Extensive corrosion was found along the bottom, at supports, risers, and valves of the above grade piping. Figure 1 shows severe corrosion at a pipe support, and Figure 2 shows a severely corroded flange bolt at a valve.

Figure 1. Severe corrosion at pipe support.

Figure 2. Severely corroded flange bolt

Ultrasonic testing (UT) was used to make thickness measurements, which were transcribed by hand to sections of the water lines near heavily corroded areas. The UT readings were obtained where the metal was relatively free of corrosion, and determined the nominal wall thickness. The UT measurements were obtained using a Panametrics NDT model 37DL meter. The external pitting was measured using a Thorpe pit-depth gauge. The pipe wall thickness data are provided in Appendix C. This data was used to determine the minimum allowable wall thickness, amount of metal loss, rate of corrosion, and remaining service life for the existing piping. The pipeline service-life calculations are provided in Appendix D. The data in Table C1 (Appendix C) shows that the deepest pitting was 280 mils on an 8 inch pipe, with an original wall thickness of 315 mils. The calculations show that the existing pipe had thinned to a minimum of 35 mils, with a corrosion rate of 10.8 mils per year, and had a remaining service life of 0.8 years (9 months). The pipe would burst if placed in operation after this brief period of operation without repairs.

It is important to note that some of the water lines within the tank farms had already been repaired. The pipes were originally constructed in 1981. DPW maintenance records show that the first leaks occurred in 1998. Therefore, the assumed service life of coated carbon steel under local environmental conditions is 17 years. At the time of the inspection, some pipe repairs had been completed as recently as January 2007.

Drawings of the fire-suppression system were obtained and marked to identify areas of significant corrosion. Fittings requiring replacement, points of turn, connections to cannons, transitions from below grade and existing supports were also noted. A set of weight-loss corrosion coupons were exposed at the tank farm, to compare material corrosion rates.

The underground fuel lines for each of the bulk fuel tank farms are coated and protected by impressed-current cathodic protection. The water lines are electrically grounded to the fuel lines, so they also benefit from the cathodic protection systems. Electro-chemical potentials were recorded where the underground water lines exit the soil. The measurements were recorded using a Fluke Model 179 voltmeter with a saturated copper/copper-sulfate reference cell. These data are presented in Appendix E. The data show that the underground water lines were effectively protected, meeting the NACE RP0285-2002 -850 mV instant-off criterion. The cathodic protection system only protects the below grade segments. The above-grade risers were severely pitted, as shown in Figure 3.

Figure 3. Severe pitting on above-grade riser.

As noted in section 1.3, the candidate materials for water-line replacement were FRP, galvanized steel, 304L stainless steel and 316L stainless steel. FRP was the first preference because, properly formulated, it is resistant to ultraviolet degradation and not susceptible to chloride-driven corrosion. However, National Fire Protection Agency (NFPA) Standard 15 requires that above-grade fire-protection water pipes must be made of noncombustible materials, so FRP was eliminated from consideration. Galvanized steel provides a desirable service life in most environments. However, when subjected to salt-water mist, the zinc coating is not stable and will dissipate within several years, leaving the pipe directly exposed to the environment. Galvanized steel fencing materials on Okinawa seldom provide more than 10 years of service, so this material also was ruled out.

Both SAE 304L and 316L stainless steels are known in the engineering community to provide excellent atmospheric service in marine environments. Both grades of stainless steel perform equally well when exposed as a large surface, such as a pipe, but grade 316L offers better corrosion prevention against crevice attack that can occur at flanges and bolted connections. The research team selected 304L for the piping, however, because it is 40% lower in cost than 316L stainless. However, the bolts and washers were specified as 316L due to its enhanced resistance to crevice attack. Both grades have the same corrosion potential and, therefore, will not create a corrosion cell due to dissimilar metals. Construction plans were developed to replace the pipe sections identified to have the most severe metal loss.

2.2 Installation of demonstration sections

2.2.1 Construction

The new pipelines were installed as replacements to existing pipelines. As such, detailed designs for supports and seismic analysis were not required. Calculations were performed in accordance with ASME B31.3, *Standards for Pressure Pipelines*, to verify the pipe wall thickness exceeded the minimum required for the pipeline operating pressure (see Appendix F).

The pipeline was assembled using tungsten inert gas (TIG) arc welding. Pipe segments were joined at a stationary location to form longer segments, which were then transported to the appointed final assembly location. Figure 4 shows workers welding the new pipe together.

Figure 4. Arc welding replacement pipes.

The project budget supported the installation of 400 ft of 200 mm (8 in.) diameter pipe and 600 ft of 125 mm (5 in.) diameter pipe. A preliminary survey conducted in November 2007 determined the locations where the replacement sections would be installed. The locations were based on severity of corrosion on the existing pipe as well as construction equipment accessibility. The locations of the demonstration pipe sections are shown in Appendix G.

As noted previously, the underground sections of the existing pipe network were connected to an impressed current CP system. As part of the new design for this project, flange-isolation kits were installed between the new stainless steel sections and existing carbon steel sections. The purpose of the gaskets was to eliminate contact between dissimilar metals which, in a damp, high-chloride environment, will quickly produce aggressive corrosion at those joints. However, this solution created a secondary problem by electrically isolating the underground water lines from the cathodic protection system. The solution was to provide galvanic CP to the affected sections by installing and connecting magnesium anodes directly to each isolated underground pipe. Test measurements of the added CP are presented in Appendix H. The data show that the added galvanic anodes satisfied the CP requirements of NACE TM0497.

2.2.2 Quality control and assurance

The quality of the welds joining the new pipe sections was tested several times. First, an independent testing firm was retained to inspect each weld using nondestructive procedures. A liquid dye penetrant test (DPT) was applied after the weld was completed (Figure 5). The results of that testing are provided in Appendix I. No defective welds were discovered. The results of the DPT were logged with identification of each joint.

Figure 5. DPT application for nondestructive testing of welds.

The pipeline was assembled in sections. After assembly of a section was complete, but before inserting it into the active pipeline, a pneumatic test of the section was conducted. Pneumatic testing at a pressure not exceeding 15 psi was performed to verify there were no pinholes in the welds. All sections of the pipe passed the pneumatic test.

Each section of pipe was also subjected to hydrostatic testing in accordance with ASME B31.3. Each pipe section was filled with water and then pressurized to 275 psi. The pressure was monitored for at least 4 hours and the line was examined for leaks. No leaks were observed. Test data are shown in Appendix J.

After all pipeline sections were assembled, an operational test was performed by the installation fire department. The cannons in the work area were operated for at least 10 minutes at normal operating pressure. The valves were then closed and a static pressure test with at least 300 psi was performed for 5 minutes. All sections of the fire-suppression system passed the hydrostatic quality-assurance tests.

2.2.3 Performance monitoring

With reference to the performance metrics stated in section 1.4, ERDC-CERL researchers determined that onsite atmospheric exposure testing using SAE 304L and 316L stainless steel coupons would be of minimal empirical value given the limited performance period of the demonstration. Therefore, performance monitoring focused on measurement and observation of joints between dissimilar metals (i.e., existing carbon steel and new stainless steel sections) for evidence of galvanic corrosion. Also, arrangements were made for installation personnel to communicate with the research team upon any visual observations of surface corrosion or system leakage.

3 Discussion

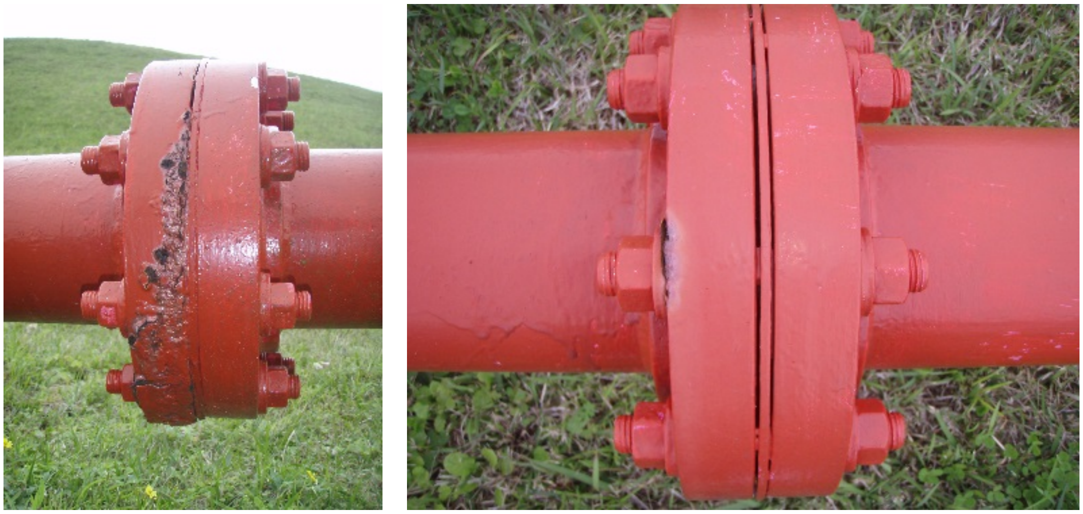
3.1 Results

The replaced fire-suppression system pipes were visually inspected in March 2017 to evaluate the performance of the demonstrated technology. The inspection found all sections of the piping to be in good condition, with the replaced pipes and supports showing no significant corrosion damage. Figure 6 shows examples of spotting and running on pipe supports that indicate some recent touch-up recoating was done to a few sections of pipe. Installation records show that no contracted painting has been done on these areas since the installation, so it is likely that the touch-up work was done by DPW personnel or the tank farm operator.

Figure 6. Two sections of installed pipe showing evidence of touch up painting.

Photographs of the replaced pipe confirm that the overall condition is good. Some surface corrosion has occurred, mainly at flanges and bolted connections (Figure 7). These areas were not typical, and the level of corrosion is not considered significant. However, the inspection results confirm that periodic inspections and maintenance should be performed to clean and coat such areas.

Figure 7. Corrosion at a pipe flange (left) and bolted connection (right).



Based on the inspection report, the pipe appears to be performing as expected. Routine maintenance will be required to address the areas of surface corrosion. With proper maintenance (a $5,000 annual maintenance budget is assumed in the cost analysis) this pipe should easily meet the expected 30 year useful life projected for this application.

3.2 Lessons learned

3.2.1 Installation method

In general, the project was completed without complications. Several factors helped to account for success in planning and implementation. First, the duration of the assembly period was reduced by welding multiple sections of pipe at a stationary work site. The longer sections were then transported to a final assembly position, reducing the time needed to move and set up welding operations. All sections of pipe were assembled over the route of the existing pipe and pressure tested before connecting to the existing pipe (Figure 8). This reduced the period of time needed to have the fire lines out of service for tie-in. Flanged connections were also pre-assembled to make tie-ins quickly, with only two welds necessary for the final assembly of each section. This method allowed the work to be completed more quickly and at lower labor cost than other similar projects.

Figure 8. Pipe placement before removal of existing lines.

3.2.2 Pipeline marking for installation fire departments

Because stainless steel pipes are usually specified for their inherent corrosion resistance, they are not typically painted with a protective coating. However, during the course of the project the installation fire department advised that the pipe had to be painted red in order to signify its fire-suppression function. Consequently, the project scope of work was revised to comply with the requirement.

Painting a pipeline can serve two purposes: providing corrosion protection for mild steel pipes or color-coding lines to identify the fluid inside. The fire department's request for coating the pipe was based on the assumed practice of specifying mild carbon steel for fire-protection lines. However, when using stainless steel pipes in an application like the one demonstrated, fully coating the pipeline would add a considerable first cost plus a coating-maintenance requirement. When implementing a stainless steel pipe network where carbon steel was formerly used, the project managers may need to coordinate with the installation fire department to develop a pipe-marking system that meets fire-protection requirements without imposing excessive coating burdens for the DPW. For example, installation personnel could develop economical marking standards that satisfy fire department requirements, such as striping or labeling the pipes in red at regular intervals.

4 Economic Summary

4.1 Costs and assumptions

Actual costs for this project are broken down in Table 1, and the costs for field demonstration and validation are shown in Table 2.

Table 1. Breakdown of total project costs.

Description	Amount, $K
Labor	181
Materials	35
Contracts	529
Travel	55
Reporting	30
Air Force and Navy participation	10
Total	840

Table 2. Field demonstration costs.

Description	Amount, $K
Labor for project management and execution	34.0
Travel for project management	17.0
Cost for materials - piping	22.6
Subcontract for design, installation, performance monitoring, and analysis	455.1
Total	528.7

Alternative 1 (Current Technology). There are three tank farms at Chimu-Wan. Replacement of the failing system is assumed to occur at Chimu-Wan 3 in Year 3, so all costs for this analysis begin in Year 3. Failing segments of the pipeline will be replaced in Year 3 at a cost of $500K. Under this scenario, the replacement pipeline segments will be made of the currently used grade of steel. The total cost will be $500K in Year 3, which is included under Baseline Costs in Table 3. The annual maintenance costs for the Chimu-Wan 3 facility, also included under Baseline Costs, will be $5K the year after replacement, and it will increase linearly to $50K over the 20 year life of the pipe. The new pipeline segments will last for 20 years and need to be replaced again in Year 23. The same maintenance cost cycle stated above will begin again in Year 24, and again they are included under Baseline Costs.

It is assumed that the existing technology will also be used for pipe replacement at the Chimu-Wan 1 and Chimu-Wan 2 facilities, and that replacement of failed pipes will occur in Years 6 and 9. All assumptions for Chimu-Wan 1 and 2 are the same used for Chimu-Wan 3; baseline costs start in the year of replacement and are included under Baseline Costs in Table 3. These sections will have to be replaced again in Years 26 and 29 respectively at a cost of $500K each.

Alternative 2 (Stainless Steel Pipes). Implementing stainless steel pipeline segments at an initial demonstration project investment of $840K both extends pipeline service life and reduces maintenance requirements. Installation is assumed to occur in year three of the project. The demonstrated technology will require annual maintenance costs of $5K, shown under New System Costs in Table 3 for Year 4 to Year 30. The new pipeline segments will last beyond the 30 year window for ROI calculation..

It is assumed that the new technology will also be installed at Chimu-Wan 1 and Chimu-Wan 2 in Years 6 and 9 when they require replacement at a cost of $500k each and with all of the same maintenance cost assumptions as assumed for the initial demonstration site. The $500k installation cost and the annual 5k maintenance cost per year per site are also included under new system costs in Table 3.

4.2 Projected return on investment (ROI)

The ROI for this technology was computed using methods prescribed by Office of Management and Budget (OMB) Circular No. A-94, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*. Comparing the costs and benefits of the two alternatives described above, and assuming the technology will be used at three sites, the potential return on investment (ROI) for Alternative 2 is projected to be 1.21 (Table 3). The return on investment will be greater if implemented at additional sites at other locations.

Table 3. Projected ROI ($K).

Return on Investment Calculation

Investment Required			**840**
Return on Investment Ratio	**1.21**	**Percent**	**121%**
Net Present Value of Costs and Benefits/Savings	**722**	**1,740**	**1,018**

A Future Year	B Baseline Costs	C Baseline Benefits/Savings	D New System Costs	E New System Benefits/Savings	F Present Value of Costs	G Present Value of Savings	H Total Present Value
1							
2							
3	500					408	408
4	5		5		4	4	
5	5		5		4	4	
6	510		505		336	340	3
7	15		10		6	9	3
8	20		10		6	12	6
9	525		510		277	286	8
10	35		15		8	18	10
11	40		15		7	19	12
12	50		15		7	22	16
13	55		15		6	23	17
14	65		15		6	25	19
15	70		15		5	25	20
16	80		15		5	27	22
17	85		15		5	27	22
18	95		15		4	28	24
19	100		15		4	28	24
20	110		15		4	28	25
21	115		15		4	28	24
22	125		15		3	28	25
23	580		15		3	122	119
24	90		15		3	18	15
25	95		15		3	17	15
26	555		15		3	96	93
27	60		15		2	10	7
28	70		15		2	11	8
29	525		15		2	74	72
30	35		15		2	5	3

5 Conclusions and Recommendations

5.1 Conclusions

The findings of this project show that the two demonstrated low-carbon stainless steel piping materials can be expected to perform very well in the coastal salt-spray environment on Okinawa Island. While traditional mild steel utility piping rapidly pits and progresses toward premature failure in this marine location, both the 304L stainless steel used for replacement piping and the 316L stainless used as fasteners showed a high level of corrosion resistance. The replacement sections, both tested individually and after integration into the existing fire-protection system, met all applicable performance standards established by ASME, ASTM International, NACE International, and USACE engineering guidance. Therefore, it is concluded that the demonstrated grades stainless steel are viable alternatives to traditional carbon steel pipe for above-grade fire-protection pipelines where coastal salt spray creates conditions for aggressive corrosion.

Although the material costs for the demonstrated grades of stainless steel are higher than for standard carbon steel pipes, the labor costs for installation are the same. The calculated ROI of 1.21 is attributable to reduced maintenance and repair costs over the expected system service life of 30 years. One factor that may reduce the ROI is any pipe-coating requirement imposed by standards, regulations, or local fire department practice. Such requirements are motivated by the need to mark pipeline content or function, but they serve no anticorrosion function. Therefore, to maximize the cost savings projected in the ROI analysis, installations should consider developing alternate pipe-marking designs that minimize the amount of labor and materials required to label the functionality of fire-suppression pipe networks.

5.2 Recommendations

5.2.1 Applicability

Based on the results of this demonstration, DoD users should consider the use of the demonstrated stainless steel materials for pipe networks located in aggressively corrosive coastal locations. Stainless steel can be considered for applications other than fire protection pipes, including those intended for transporting fuels and gases. In every case, however, system design must ensure that all dissimilar-metal contact in the network is prevented and that every section of the pipe has NACE-compliant cathodic protection.

5.2.2 Implementation

UFC 3-600-01, *Fire Protection Engineering for Facilities*, incorporates NFPA 15 by reference. This NFPA standard already allows for the use of stainless steel pipe in water-spray fixed systems. However, to facilitate the use of stainless steel pipe throughout DoD, the language of UFC 3-600-01, section 4.3, could be revised to explicitly to state that stainless steel is a cost-effective option to mild carbon steel in highly corrosive environments for pipelines containing liquid or gaseous products. Because both of these standards already permit the use of stainless steel in fire-protection pipelines, material specifications are readily available for piping applications.

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Appendix A: Representative Steel Corrosion-Rate Data for Coastal and Island Locations

[Editor's note: The text below reprints a Memorandum For Record prepared by ERDC-CERL engineering personnel in 2010 for the U.S. Army Engineer Construction Division, Huntsville, AL at the request of the U.S. Army Space and Missile Defense Command. The authors were tasked to develop a supportable estimate for steel corrosion rates at the U.S. Army Garrison–Kwajalein Island based on corrosion-rate data for various areas around the world and aboard ships. Although testing was not specifically performed on Kwajalein Island, ERDC-CERL metallurgists determined that the corrosion rates are likely to be similar to those prevailing on oceangoing Navy and Coast Guard vessels. For the present study, the estimated Kwajalein corrosion rates are assumed to be suitable proxy values for steel structures subject to the climate and chloride exposure conditions on Okinawa. Section 2, below, discusses ERDC-CERL corrosion-rate data acquisition and assumptions.]

CEERD-CF-M 4 Aug 2010

MEMORANDUM FOR RECORD

Subject: Corrosion Rates and Materials at Kwajalein Atoll

1. Background. Infrastructure on Kwajalein Island deteriorates at a higher rate than almost anywhere in the world. U.S. Army Engineer Research Development Center/Construction Engineering Research Laboratory (USA ERDC/CERL) was asked by U.S. Army Space and Missile Defense Command to quantify the observed high infrastructure corrosion rates. A previous report by the U.S. Naval Civil Engineering Laboratory[1] indicates that the atmosphere on Kwajalein Island is more corrosive than either, Port Hueneme, California or Kaneohe Bay, Hawaii. Historical weather statistics show that the temperature varies typically from 77° F to 89° F with the extremes of 68° F and 98° F. The rainfall averages 89 inches per year and there rain almost daily. The relative humidity ranges from 83% at noon to 78% at midnight. The continuous trade winds (5 to 25 mph) keep a high salt concentration in the air. This scenario creates a very corrosive atmosphere for metallic structures on the islands of the atoll. The U.S. Army Corps of Engineers Pacific Ocean Division has been battling to improve the life cycle of the infrastructure on Kwajalein Island. They have developed an Installation Design Guide[2] that addresses the corrosion problems as well as the aesthetics. Mr. Andrew Kohashi Chief, Military Branch, Programs and Project Management Division supplied detailed comments regarding the current construction practices.

The OSD/IMCOM/ACSIM Corrosion Prevention and Control (CPC) program has conducted tests[3] to determine corrosion rates for various areas around the world and aboard ships. Although Kwajalein was not specifically tested in this program, the corrosion problems are probably similar to those on board Navy and Coast Guard vessels.

2. Review of CPC Corrosion Rates. The corrosion rates for the CPC program study[3] were determined from panels exposed to the atmosphere at various locations across the country, at many coastal locations, and on board ships of the U.S. Navy and Coast Guard. Corrosion rates for these locations are contained in the table below. The corrosion rate of steel for the USS Halyburton is the highest in this group. The corrosion rates for steel were determined for five facilities in CONUS and include: Ft. Rucker, Hood, Drum, Campbell, and Eustis. The average rate for these sites is 24,846 µg/cm^2/y (1.25 MPY). Two other sites tested as part of this work were Daytona Beach and Vandenberg Air Force Base. They both had higher corrosion rates than the in-land facilities but not as high as the ship board testing. *Based on experience[1], the corrosion rates for Kwajalein Atoll will be higher than Daytona or Vandenberg and may be as high as the shipboard rates. The presence of the constant wind and almost daily rain make it very likely that the corrosion rate for Kwajalein Atoll is similar to that aboard ship. Conservatively, if the rate at Kwajalein is similar to the average of Daytona Beach and Vandenberg rates then it is 185,284 µg/cm^2/yr (9.29 MPY), which is a factor of 7.5 times more corrosive than the CONUS based facilities. If the corrosion rate at Kwajalein is equal to the shipboard rate then it is a factor of 22.25 times as corrosive as the CONUS based facilities.* [Editor's note: typographic emphasis added.]

Test Site	Corrosion Rate for One Year	
	(µg/cm²/yr)	MPY
USS Halyburton	553,708	27.76
Daytona Beach	157,033	7.87
Vandenberg AFB	213,535	10.71
Average - Shore	185,284	9.29
Ft. Rucker	21,782	1.09
Ft. Hood	13,454	0.67
Ft Drum	23,541	1.18
Ft Campbell	26,949	1.35
Ft. Eustis	38,506	1.93
Average - CONUS	24,846	1.25

3. Current Practices. The Installation Design Guide[2] for construction on Kwajalein includes many warnings about designing for highly corrosive environments. One section of the guide, 8.3.5.1.2 specifically states: "*Choose materials for their longevity, maintenance characteristics and corrosive resistance. The greatest concentration of corrosive atmosphere caused by the salt-laden environment on Kwajalein is between sea level (ground level) and approximately 30 feet above sea level. The severe corrosion is caused by the high humidity, salt spray, abundant precipitation, high temperatures, blown coral dust, strong UV from the sun and constant wind*." [Editor's note: typographic emphasis in original memo text.] There is also a complete section on Corrosion Control. Windscreens are also recommended to divert the constant salt spray and coral dust carried by the wind.

Current construction practices, as reported by Mr. Kohashi, include stainless steel and epoxy coated rebar. When the epoxy coated rebar is cut to length for installation, the exposed ends are subject to corrosion. The cut ends of the bar shapes are where corrosion starts. The cut ends are field coated, but are not as resistant to corrosion as the factory applied coating. The rebar wire ties are corrosion points. When epoxy coated ties are used the twisting and tying tends to crack or chip the coating. Anywhere these wire ties touch the formwork that is not completely covered by concrete is a location where the salt air will start corrosion of the wire ties and cause rust streaking. While mostly cosmetic, these corroded wires do create a route for moisture and corrosion to start into the reinforced concrete elements.

Recently, a set of stairs were constructed for emergency egress from the upper floors of a renovated launch control facility on Meck Island. The stairs were installed 2-3 years ago and were made of coated aluminum. As of April 2010 there was no apparent degradation.

Type 316 stainless steel is used extensively. Galvanized fasteners do not last. Pre-cast and tilt up concrete construction has been used for a couple of recent facilities. This has worked well.

Laying out new facilities is done very carefully, avoiding entrances on the windward facing sides of buildings. On a recently constructed Fire Station, the entrances and opening to the fire truck bay were all placed on the leeward side of the building. That helps reduce the corrosion indoors and keeps the equipment out of the direct salt spray and sand blasting effects. Unfortunately this layout means the emergency generator room is on the back of the building and only accessible from the windward side. The wall louvers and the equipment inside the generator room already look to be degrading.

5. Recommendations. The first recommendation is to establish a corrosion rate test station on Kwajalein to obtain accurate data to determine the corrosion rates over one year. Facility DPW should continue to use type 316 stainless steel wherever there is a need for metal in construction that is exposed to the atmosphere. The CPC program has demonstrated ceramic coated rebar for concrete construction in corrosive environments such as retaining walls, stairways, and walk ways in or near seawater. The demonstration has shown the coatings to hold up well in these applications. The demonstration did not include field applied coatings for cut ends.

A number of Corrosion Prevention and Control technologies have been demonstrated and validated on Army Facilities under the sponsorship of the Office of Secretary of Defense, Corrosion Prevention and Control and the Department of the Army (ACSIM and IMCOM). Programs relevant to the Kwajalein Atoll are listed below:

1. F08AR01: Use of Reactive Vitreous-Coatings on Reinforcement Steel To Prevent Corrosion and Concrete Failure at Corpus Christi Depot, Sean Morefield, CEERD-CF-M[6, 7].

2. F08AR23: Electro-Osmotic Pulse and Dehumidification Technologies for Prevention of Corrosion of Munitions and Equipment in Ammunition Bunkers in Kawakami, Japan and Guam, Orange Marshall, CEERD-CF-M[8].

3. F09AR05A: Novel Additive for Concrete Structures Exposed to Salt Environments, Orange Marshall, CEERD-CF-M[9, 10].

4. F07AR08: Rehabilitation of Metal Roofing at Wheeler Army Airfield, David Bailey[11].

5. F08AR07: Polymer Composite Wrapping and Galvanic Cathodic Protection System for Pilings in Hawaii, Richard Lampo, CEERD-CF-M[12].

6. F07AR19: Inherently Conductive Additives for Reducing Zinc Dust Content in Corrosion–Inhibiting Primers for Steel, Susan Drozdz, CEERD-CF-M[13].

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12. Bailey, David M., Jorge Costa, Richard G. Lampo, Vincent Hock, Matt Miltenberger, Thomas Tehada, Corrosion Potential Monitoring For Composite Pile Wrap System With CP, Corrosion & Prevention 2009, Australia, 15-18 November 2009.
13. Drozdz, S., T. Hawkins, Novel Epoxy Coating System Using Carbon Nanotechnology, Corrosion & Prevention 2009, Australia, 15-18 November 2009.

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Appendix B: Failure Analysis of Fire Suppression System Water Pipe at Chimyu-Wan Tank Farm #3, Okinawa, Japan

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Background

The fire suppression system at Chimyu-Wan Tank Farm #3 is a deluge system that conducts water under pressure to three water cannons surrounding the underground fuel storage tank. There are two of these systems on the two underground storage tanks. Figure B1 shows one of the systems at Chimyu-Wan. The pipes supplying the water to the cannon are susceptible to external corrosion induced by the atmosphere and the concrete support saddles and the frequent rains. The pipes have been replaced several times through the years and have failed again. Inspection of the pipe shows that there are sections of carbon steel and galvanized steel. Figure B2 shows the water cannon and supply pipe. Figure B3 shows the galvanized supply pipe in the system. Sections of the supply pipe are being replaced with type 304L stainless steel as part of the Corrosion Prevention and Control program. Certain sections and two valves were removed and replaced with the stainless steel. Figure B4 shows one of the valves to be replaced. Figure B5 shows the structural damage from the corrosion processes. As part of this replacement process a short section of the removed carbon steel pipe was sent to ERDC/CERL for analysis to determine the source of the corrosion attack on the carbon steel pipe and structural steel components. Previously a trip was made to Okinawa to inspect the installation of the new pipe and see the damage created by the corrosion processes.

Approach

The pipe was visually inspected as received and then was cut into smaller sections for analysis in a scanning electron microscope (SEM). The SEM was used to examine the surface morphology and the surface chemistry by energy dispersive x-ray (EDX) analysis. Samples of the corrosion products were collected for analysis in the SEM/EDX system also.

Results and Discussion

The pipe was visually inspected upon arrival at ERDC/CERL. Figures A6 through A8 show exterior views of the pipe section as received. Figures A9 and 10 show the interior of the pipe with light general corrosion and the beginnings of pitting corrosion. The corrosion is more extensive on the exterior of the pipe, especially in the vicinity of the concrete support saddles.

Figure B11 shows a cross section of the whole pipe through the area of extensive corrosion damage (note the extreme thinning of the wall in the area near where the support saddle was located). Figure B12 is a close-up of the thinned area. The pipe wall thickness was measured at the thinnest point with a thread caliper. The nominal wall thickness of new pipe is 0.322 inch. The deepest corrosion pit area has 0.036 inch remaining wall thickness or approximately 10% remaining wall thickness. The extremely thinned area would be the next area to leak.

Samples of this corroded area near the saddle, both internal and external, were machined and placed in the SEM for visual and x-ray energy analysis. Figure B13 shows a photomacrograph of the outside corroded area. Figure B14 is the EDX graph of the x-ray counts versus energy for a scan of this area. Table B1 contains the results of the quantitative analysis of the graph in Figure B14 that shows relative concentrations of the elements identified. Note the presence of chlorine on the surface at 0.51 wt%. This amount at the surface can aid in the corrosion of the steel especially when partially protected from the elements by the coating and the corrosion products themselves. The interior surface is shown in Figure B15. Figure B16 is the EDX graph showing the counts versus x-ray energy for the area seen in Figure B15. Table B2 shows the results of the quantitative analysis of the elements identified in the Figure B16. The interior of the pipe has a tightly adhered coating of corrosion scale. This protects the wall of the pipe against fast acting corrosion. Figure B17 is a photomacrograph of the corrosion products removed from the exterior of the pipe near the area of deepest penetration. Figure 18 is the graph of the EDX scan from Figure B17 showing the x-ray counts versus energy. Table B3 is the results of the quantitative analysis of the data in Figure B18. The chloride content of the corrosion products is in excess of three times what was found on the exterior surface. Sources for the chlorine are the atmosphere because of the close proximity to the ocean and the concrete used for the support saddles. Even though the pipe was to be insulated from the concrete it was obvious from the site visit pictures that there were breaches in the insulation. Corrosion products had built up under the saddle strap such that the pressure under the strap had either pulled the bolts loose from the concrete by breaking the concrete or broke the bolts themselves. The bolts holding the straps had also corroded and were susceptible to failure under tension. Chlorine from whichever source combines with water to make either hydrochloric or hydrochlorous acids that are corrosive to steel. Having chlorine in these concentrations means that the acids are present and the corrosion is due to attack by the acids.

The pipe was painted but the maintenance on the paint was not kept up with. Pinholes opened up in the paint coating and allowed the chlorine and water to get at the steel. The installation of the stainless steel pipe will slow down this process considerably but stainless steel is not totally impervious to chloride attack. The new pipes are painted with a primer and two finish coats and are insulated from the concrete saddles by Teflon sheets. The bolted flange joints between the stainless and carbon steels are also protected with Teflon washers and sleeves that electrically insulate the joint to stop galvanic corrosion on the carbon steel pipe.

Conclusions and Recommendations

The cause of the corrosion of the water supply pipe for the fire suppression system at Chimyu-Wan Tank Farm #3, Okinawa, Japan was the presence of chlorides at the surface of the steel under the paint. The chlorides joined with the frequent rain water to make hydrochloride or hydrochlorous acid that caused the corrosion of the carbon steel pipe. The source of the chlorides is either from the atmosphere that initially comes from the nearby ocean or the concrete saddle supports.

The normal recommendations would be to replace the failed pipe with a corrosion resistant material and provide isolation from the concrete and the remaining carbon steel. Since the corrosion program calls for these items already, the only additional recommendation would be to keep up with the maintenance of the paint coatings on the whole system.

Table B1. Results of quantitative analysis of the data from the graph shown in Figure B14.

Acquisition Time:12:58:47	Date:10-Jul-2008					
kV:12.00	Tilt: 0.00	Take-off:35.00	Tc:35.0			
Detector Type :SUTW-Sapphire	Resolution :134.18	Lsec :100				
EDAX ZAF Quantification	Standardless					
Element Normalized						
SEC Table : Default						
Element	Wt %	At %	K-Ratio	Z	A	F
O K	17.59	41.61	0.1267	1.1497	0.6249	1.003
SiK	3.46	4.67	0.027	1.0973	0.7093	1.0005
ClK	0.51	0.55	0.0048	1.0302	0.9005	1.0037
FeK	78.43	53.17	0.7473	0.9518	1.001	1
Total	100	100				
Element	Net Intensity	Bkgd Intensity	Inte. Error	P/B		
O K	27.11	0.25	1.94	108.44		
SiK	5.15	0.99	5.18	5.2		
ClK	0.64	0.99	25.29	0.65		
FeK	16.72	0.45	2.51	37.16		

Table B2. Results of quantitative analysis of the data from the graph shown in Figure B16.

Acquisition Time:13:22:01	Date:10-Jul-2008					
kV:15.00	Tilt: 0.00	Take-off:35.00	Tc:35.0			
Detector Type :SUTW-Sapphire	Resolution :134.18	Lsec :100				
EDAX ZAF Quantification	Standardless					
Element Normalized						
SEC Table : Default						
Element	Wt %	At %	K-Ratio	Z	A	F
O K	29.88	58.61	0.184	1.1122	0.5524	1.0022
SiK	1.45	1.62	0.0099	1.0673	0.6398	1.0013
P K	0.73	0.74	0.0055	1.0282	0.7371	1.0021
S K	1.24	1.21	0.0106	1.0509	0.815	1.0031
ClK	0.54	0.48	0.0047	1.0032	0.8697	1.0052
CaK	0.73	0.57	0.0074	1.0281	0.9633	1.0281
FeK	65.44	36.77	0.6113	0.9319	1.0025	1
Total	100	100				

Element	Net Intensity	Bkgd Intensity	Inte. Error	P/B
O K	21.85	0.11	2.15	198.64
SiK	1.24	0.45	11.8	2.76
P K	0.61	0.5	20.8	1.22
S K	1.09	0.5	13.26	2.18
ClK	0.44	0.44	26.11	1
CaK	0.49	0.36	22.45	1.36
FeK	14.42	0.15	2.66	96.13

Table B3. Results of quantitative analysis of the data from the graph shown in Figure B18.

Acquisition Time:13:42:27	Date:10-Jul-2008		
kV:12.00	Tilt: 0.00	Take-off:32.53	Tc:35.0
Detector Type :SUTW-Sapphire	Resolution :134.18	Lsec :100	
EDAX ZAF Quantification	Standardless		
Element Normalized			
SEC Table : Default			

Element	Wt %	At %	K-Ratio	Z	A	F
O K	30.19	58.39	0.2058	1.1184	0.6084	1.0019
SiK	2.6	2.87	0.0202	1.065	0.7262	1.0011
P K	0.95	0.95	0.0078	1.0252	0.8018	1.0017
S K	0.78	0.76	0.0071	1.0485	0.863	1.0026
ClK	1.8	1.57	0.0164	1.0012	0.9066	1.0034
CaK	0.81	0.63	0.0082	1.0242	0.9731	1.0187
FeK	62.86	34.84	0.5804	0.9221	1.0014	1
Total	100	100				

Element	Net Intensity	Bkgd Intensity	Inte. Error	P/B
O K	80.21	0.32	1.12	250.66
SiK	7.1	1.92	4.66	3.7
P K	2.37	2.4	11.3	0.99
S K	1.97	2.6	13.59	0.76
ClK	4.05	3.04	7.86	1.33
CaK	1.32	2.46	18.92	0.54
FeK	24.06	0.75	2.1	32.08

Figure B1. Photograph of the water-cannon aimed at one underground tank at Chimyu-Wan fuel storage facility, Okinawa, Japan.

Figure B2. Photograph of the deluge system showing a water cannon and the supply pipe.

Figure B3. Photograph of the fire suppression supply pipe that was galvanized.

Figure B4. Photograph of one of the corrosion damaged valves that was replaced at the Chimyu-Wan Tanks Farm #3, Okinawa, Japan.

Figure B5. Photograph of the structural damage caused by corrosion of the pipe at the Chimyu-Wan Tank Farm #3, Okinawa, Japan.

Figure B6. Photograph of the pipe section as received from Okinawa showing the area near and under the support saddle.

Figure B7. Photograph of the area of the pipe in contact with the concrete saddle in the field.

Figure B8. Photograph of the pipe section showing the area under the strap used to hold the pipe to the saddle.

Figure B9. Photograph of the interior of the pipe
as received from Okinawa showing light general corrosion.

Figure B10. Photograph of the interior of the pipe
showing the beginning of pitting corrosion from the water carried in the pipe.

Figure B11. Photograph of the cross section
of the pipe showing the wall thinning near the area of the support saddle.

Figure B12. Photograph of the deeply corroded area on the outside of the pipe.

Figure B13. Photomacrograph of the exterior surface from the supply pipe of the fire suppression system at Chimyu-Wan fuel storage, Okinawa, Japan. (90x)

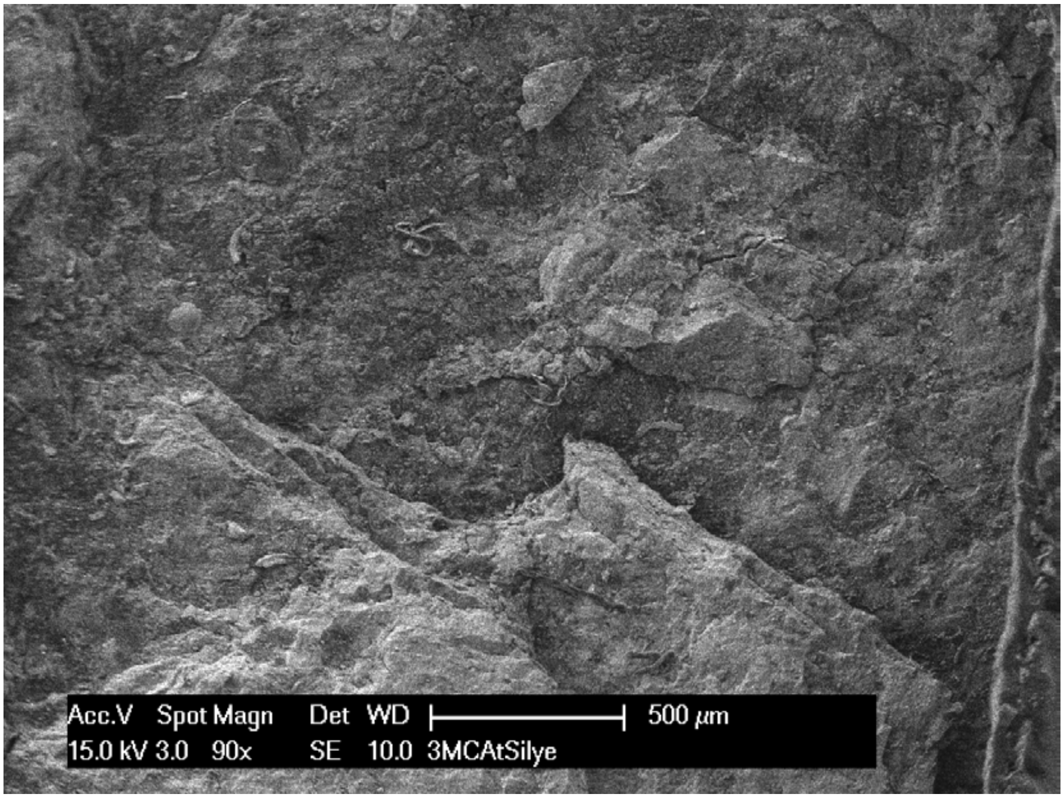


Figure B14. Graph of the x-ray energy versus the number of counts for the area shown in Figure B13.

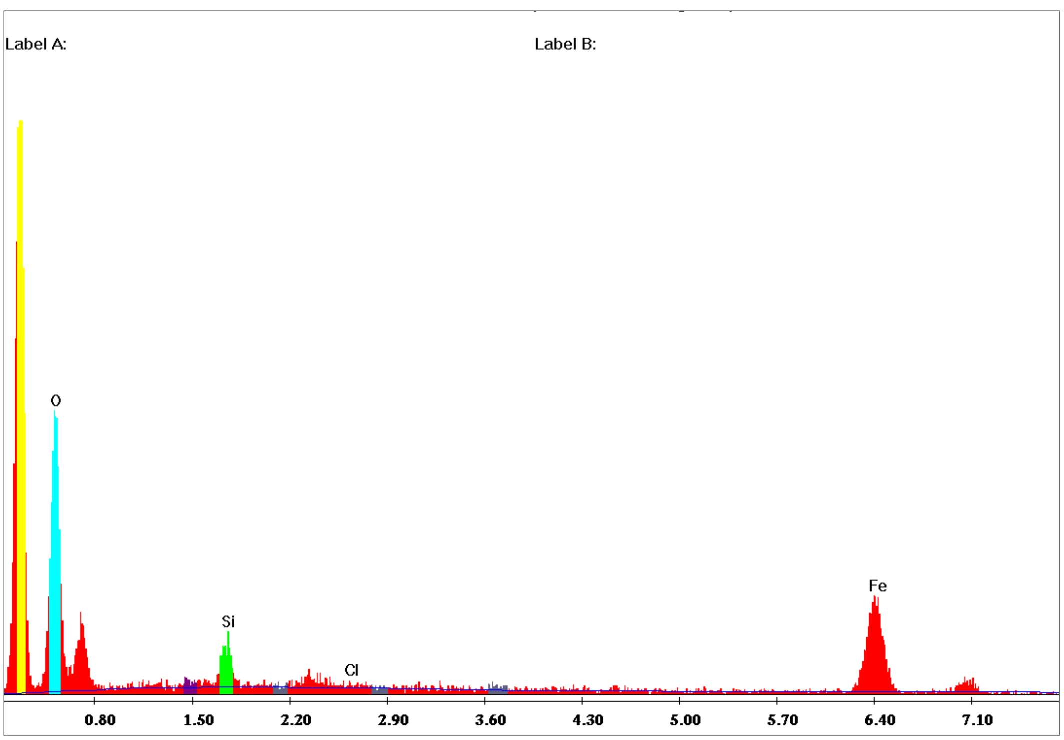


Figure B15. Photomacrograph of the interior surface of the pipe sample where corrosion had thinned the pipe wall. (76x)

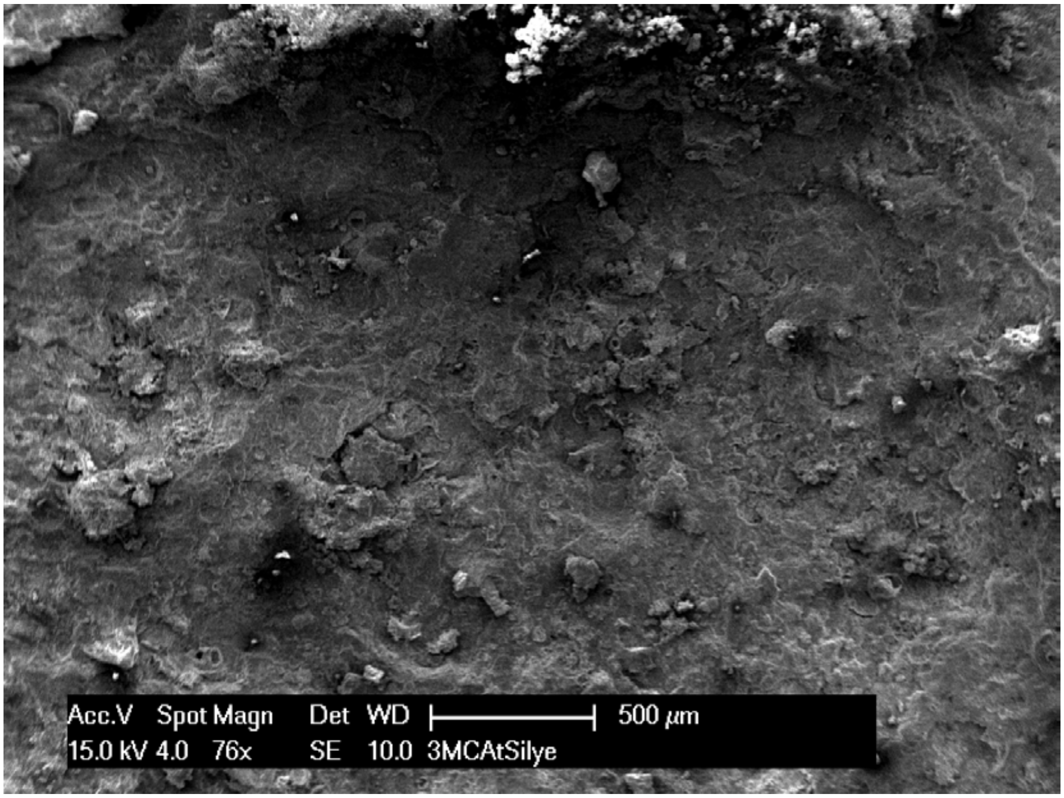


Figure B16. Graph of counts versus energy for the interior surface of the corroded pipe shown in Figure B15 from Chimyu-Wan Fuel Storage Facility, Okinawa, Japan.

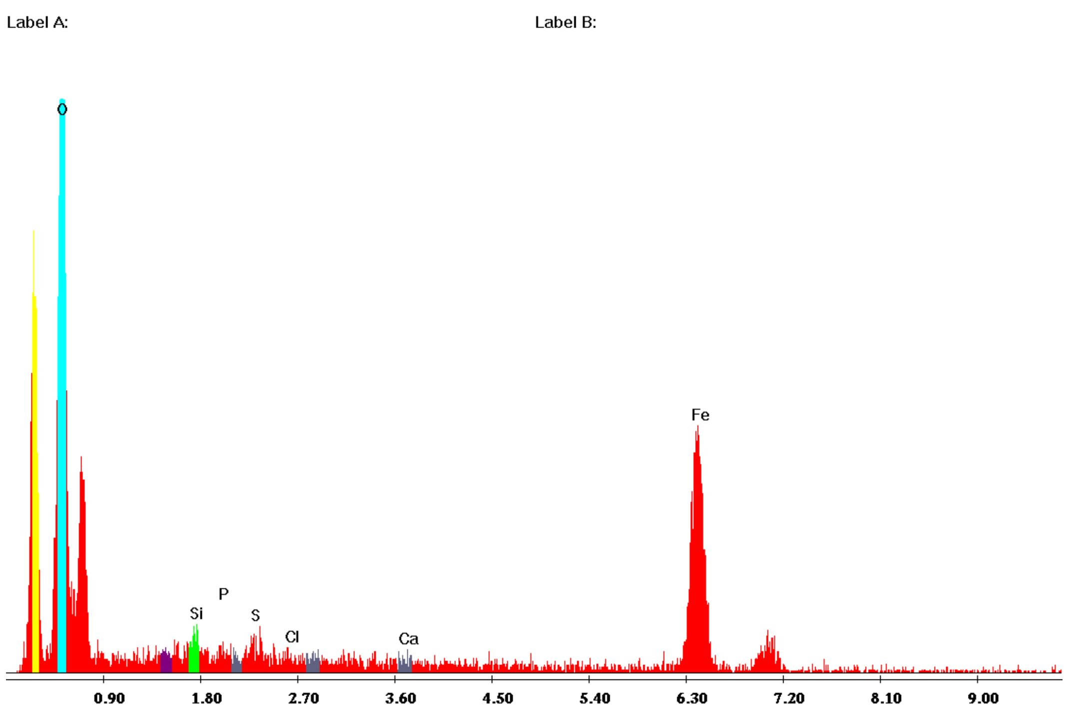


Figure B17. Photomacrograph of the scale from the exterior of the pipe. (90x)

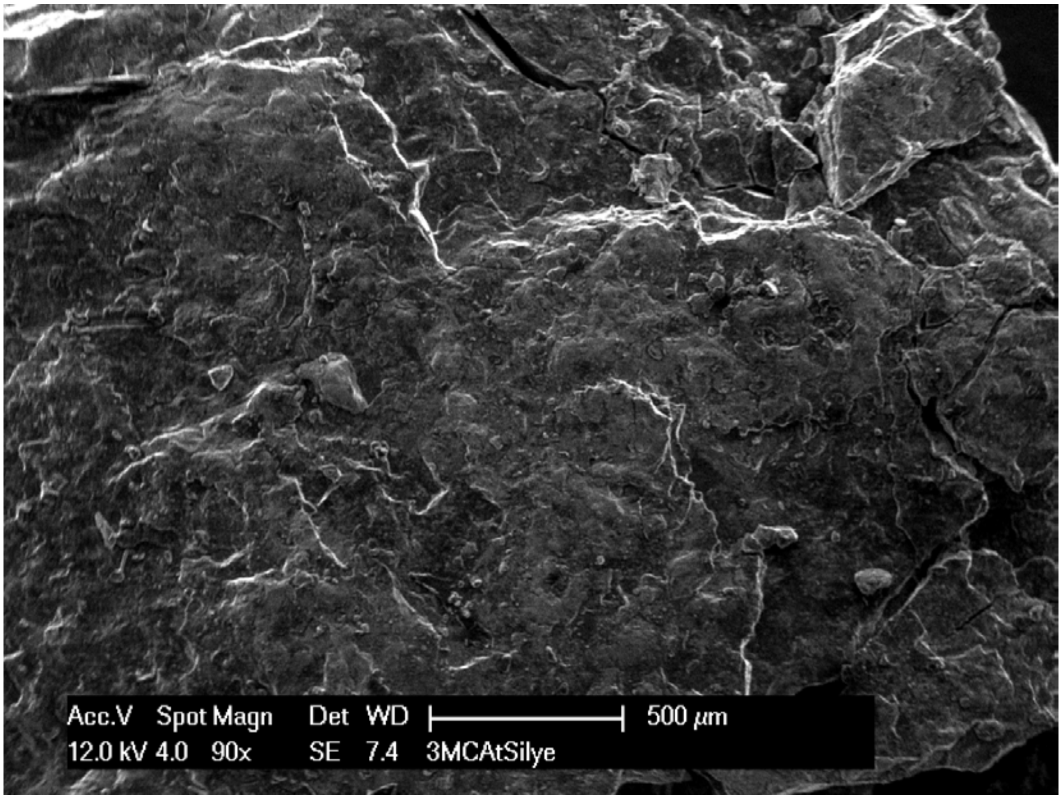
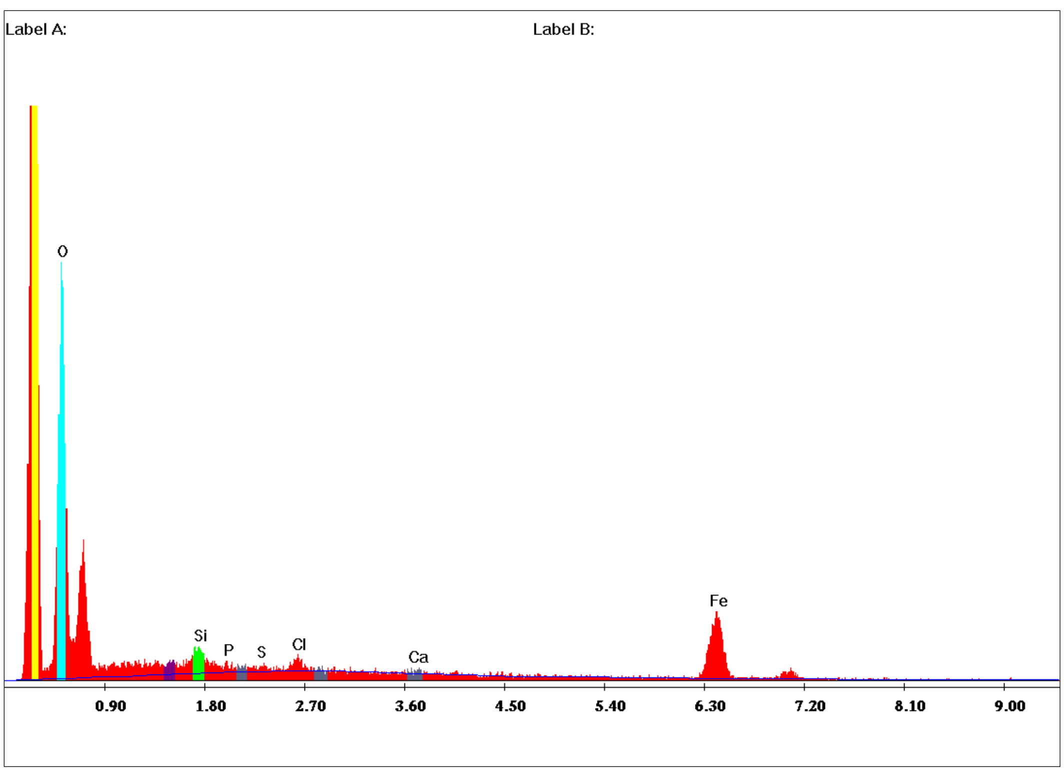


Figure B18. Graph of the x-ray energy versus counts for the area shown in Figure B17.



Appendix C: Pipe Wall Thickness Data for Existing Carbon Steel Pipes

[Editor's note: The contractor's report form, below, is incorrectly labeled as "cathodic protection field data." However, the form is in fact populated with pipe wall thickness data.]

Table C1. CP field data.

CORROSION CONTROL INCORPORATED
CATHODIC PROTECTION FIELD DATA

TABLE I
SHEET 1 OF 2

SITE NAME: Chimu-Wan 3 Tank Farm	1. Ultrasonic thickness (UT) of pipe at 0° (mils)
STRUCTURE: Fire Water Pipelines	2. Ultrasonic thickness (UT) of pipe at 90° (mils)
DATE OBTAINED: 7 November 2007	3. Ultrasonic thickness (UT) of pipe at 180° (mils)
SURVEYED BY: R. Eichlin	4. Ultrasonic thickness (UT) of pipe at 270° (mils)
	5. Depth of Pitting (mils) 6. Orientation of Pitting

NO.	LOCATION	1	2	3	4	5	6	COMMENTS
1	Line D, 5" mild steel	252	--	--	--	100	60	
2	Main Line, 8" mild steel	322	--	--	--	160	270 to 90	
3 M	Main Line, 8" mild steel	312	315	305	307	150	270 to 90	
3 G	Main Line 8" Galvanized	221	220	222	221	--	--	
4	Line A, 8" mild steel	324	317	312	310	130	0	pitting top and bottom, most severe at 0°
5	Line A, 8" mild steel, at Pipe Support 7	315	--	--	--	150	0	
6	Line A, 8" mild steel at Pipe Support 10	320	--	--	--	100	300	
7	Line A, 8" mild steel at Pipe Support 11	310	--	--	--	150	300	
8	Line A, 8" mild steel	320	--	--	--	220	180	
9	Line A, 8" mild steel at Pipe Support 14	315	--	--	--	110	0	
10	Line A, 8" mild steel at Pipe Support 15	310	--	--	--	160	0	
11	Line A, 8" mild steel at Pipe Support 16	319	--	--	--	220	0	
12	Line A, 8" mild steel at Pipe Support 17	322	--	--	--	30	180	
13	Line A, 8" mild steel at Pipe Support 19	315	--	--	--	85	180	
14	Line A, 8" mild steel, south side of drive	320	--	--	--	240	180	
15	Line A, 8" mild steel, at FM 1	322	315	--	316	280	300	
16	Line C, 8" mild steel	315	--	--	--	--	60	
17	Line A, 8" mild steel	320	--	--	--	140	310	
18	Line A, 8" mild steel, riser at S/A interface	314	--	--	--	240	90 to 240	

Table C1 (concluded).

CORROSION CONTROL INCORPORATED
CATHODIC PROTECTION FIELD DATA

TABLE I
SHEET 2 OF 2

SITE NAME: Chimu-Wan 3 Tank Farm			1. Ultrasonic thickness (UT) of pipe at 0° (mils)					
STRUCTURE: Fire Water Pipelines			2. Ultrasonic thickness (UT) of pipe at 90° (mils)					
DATE OBTAINED: 7 November 2007			3. Ultrasonic thickness (UT) of pipe at 180° (mils)					
SURVEYED BY: R. Eichlin			4. Ultrasonic thickness (UT) of pipe at 270° (mils)					
			5. Depth of Pitting (mils)			6. Orientation of Pitting		
NO.	**LOCATION**	**1**	**2**	**3**	**4**	**5**	**6**	**COMMENTS**
19	Line B, 8" mild steel	--	--	--	--	50	180	
20	Line B, 8" mild steel	319	315	316	318	--	--	
21	Line B, 5" mild steel	254	252	259	259	120	0	
22	Line B, 5" mild steel	315	311	311	314	150	0	
23	Line B, 5" mild steel	258	--	--	--	210	0	
24	Line C, 5" mild steel	249	--	--	--	100	0	

#793

Appendix D: Pipeline Pressure Calculations for Existing Pipe at Corroded Area

API-570 INTEGRITY INSPECTION
CALCULATION SHEET
CORROSION CONTROL INCORPORATED

Inspection Date: November 7, 2007

Inspector: R. H. Eichlin

Location: Chimu-wan 3 Tank Farm, Okinawa

Pipe Section: Fire Protection – Existing 8"ϕ

Base Thickness: 315 (T in mils)

Maximum Pit: 280 (Pd in mils)

Minimum Remaining Thickness: 35 (t in mils)

Operating Pressure: 125 psi (P)

Date Constructed: 1981 (Y)

A. Corrosion Rate (API-570 section 7.1.1)

$$C_R = \frac{T - t}{2007 - Y} = \frac{315 - 35}{2007 - 1981} = 10.8 \text{ mils/yr}$$

B. Minimum Allowable Thickness (tmin)(ASTM B31.3 section 304.1.2)

$$tm = \frac{PD}{2(SE + PY)} \qquad D = \text{Pipe Outside Diameter}$$

$$= \frac{(125)(8.625)}{2((20000)(1) + (125)(0.4))}$$

$$= 27 \text{ mils minimum}$$

C. Remaining Service Life (API-570 section 7.1.1)

$$L = \frac{t - tm}{C_R} = \frac{35 - 27}{10.8} = 0.8 \text{ years (9 months)}$$

D. Time to Next Inspection (API-570 section 6.3)

$$I_t = L/2 > 5 \text{ months}$$

E. Maximum Allowable Working Pressure (MAWP) at Next Inspection

$$P = \frac{2SE\,(t - (2)(C_R)(I_t))}{D}$$

$$= \frac{2\,(20000)(1)(0.035 - (2)(0.011)(0.4))}{8.625}$$

$$= 121 \text{ psi}$$

API-570 INTEGRITY INSPECTION
CALCULATION SHEET
CORROSION CONTROL INCORPORATED

Inspection Date: November 7, 2007

Inspector: R. H. Eichlin

Location: Chimu-wan 3 Tank Farm, Okinawa

Pipe Section: Fire Protection – Existing 5"ϕ

Base Thickness: 258 (T in mils)

Maximum Pit: 210 (Pd in mils)

Minimum Remaining Thickness: 48 (t in mils)

Operating Pressure: 125 psi (P)

Date Constructed: 1981 (Y)

A. Corrosion Rate (API-570 section 7.1.1)

$$C_R = \frac{T - t}{2007 - Y} = \frac{258 - 48}{2007 - 1981} = 8.1 \text{ mils/yr}$$

B. Minimum Allowable Thickness (tmin)(ASTM B31.3 section 304.1.2)

$$tm = \frac{PD}{2(SE + PY)} \qquad D = \text{Pipe Outside Diameter}$$

$$= \frac{(125)(5.563)}{2((20000)(1) + (125)(0.4))}$$

$$= 17 \text{ mils minimum}$$

C. Remaining Service Life (API-570 section 7.1.1)

$$L = \frac{t - tm}{C_R} = \frac{48 - 17}{8.1} = 3.8 \text{ years}$$

D. Time to Next Inspection (API-570 section 6.3)

$$I_t = L/2 > 1.9 \text{ years}$$

E. Maximum Allowable Working Pressure (MAWP) at Next Inspection

$$P = \frac{2SE\,(t - (2)(C_R)(I_t))}{D}$$

$$= \frac{2\,(20000)(1)((0.048)-(2)(0.0081)(1.9))}{5.563}$$

$$= 123 \text{ psi}$$

#789

Appendix E: Data from Cathodic Protection Measurements (Contractor Submittal)

CORROSION CONTROL INCORPORATED
CATHODIC PROTECTION FIELD DATA

TABLE II
SHEET 1 OF 1

SITE NAME:	Chimu-Wan 3 Tank Farm	1. Potential with rectifier on (mV)
STRUCTURE:	Fire Water Pipelines	2. Potential with rectifier interrupted (mV)
DATE OBTAINED:	7 November 2007	
SURVEYED BY:	R. Eichlin	

NO.	LOCATION	1	2	3	4		COMMENTS
1	8" riser north of driveway north of 3001	-1750	-998				
2	8" riser south of driveway north of 3001	-1950	-931				
3	8" riser south of main line, riser to Line A	-1760	-909				
4	8" riser at top of hill	-1950	-1060				
5	8" riser at main driveway east of fire pump	-1605	-960				
6	5" riser at C3001	-1075	-875				

Appendix F: Pipeline Pressure Calculations for New Pipeline Segments

VERIFY ADEQUACY OF NEW STAINLESS STEEL PIPE
CALCULATION SHEET
CORROSION CONTROL INCORPORATED

Inspection Date:	March 2008
Inspector:	R. H. Eichlin
Location:	Chimu-wan 3 Tank Farm
Pipe Section:	5"ϕ 304L SS Fire Protection Pipeline
Pipe Diameter:	5.563 inches O.D. (D) (ASME B31.3 Table A-1)
Base Thickness:	134 (T in mils)
Allowable Stress:	16,700 (S)
Operating Pressure:	200 psi (P)
Joint Efficiency:	0.85 (E) (includes hydrostatic test pressure) (ASME B31.3 Table 302.3.4)

A. Minimum Allowable Thickness (tmin)(ASTM B31.3 section 304.1.2)

$$tm = \frac{PD}{2(SE + PY)}$$

$$= \frac{(200)(5.563)}{2((16700)(0.85 + (200)(0.4))}$$

$$= 39 \text{ mils minimum}$$

The wall thickness of 134 mils exceeds the minimum required.

B. Maximum Allowable Working Pressure (MAWP) for pipe wall thickness

$$P = \frac{2SEt}{D}$$

$$= \frac{2\,(167000)(0.85)(0.134)}{5.563}$$

$$= 683 \text{ psi}$$

The operating pressure is less than the maximum allowed.

VERIFY ADEQUACY OF NEW STAINLESS STEEL PIPE
CALCULATION SHEET

CORROSION CONTROL INCORPORATED

Inspection Date:	March 2008
Inspector:	R. H. Eichlin
Location:	Chimu-wan 3 Tank Farm
Pipe Section:	8"ϕ 304L SS Fire Protection Pipeline
Pipe Diameter:	8.625 inches O.D. (D) (ASME B31.3 Table A-1)
Base Thickness:	148 (T in mils)
Allowable Stress:	16,700 (S)
Operating Pressure:	200 psi (P)
Joint Efficiency:	0.85 (E) (includes hydrostatic test pressure) (ASME B31.3 Table 302.3.4)

A. Minimum Allowable Thickness (tmin)(ASTM B31.3 section 304.1.2)

$$tm = \frac{PD}{2(SE + PY)}$$

$$= \frac{(200)(8.625)}{2((16700)(0.85 + (200)(0.4))}$$

$$= 61 \text{ mils minimum}$$

The wall thickness of 148 mils exceeds the minimum required.

B. Maximum Allowable Working Pressure (MAWP) for pipe wall thickness

$$P = \frac{2SEt}{D}$$

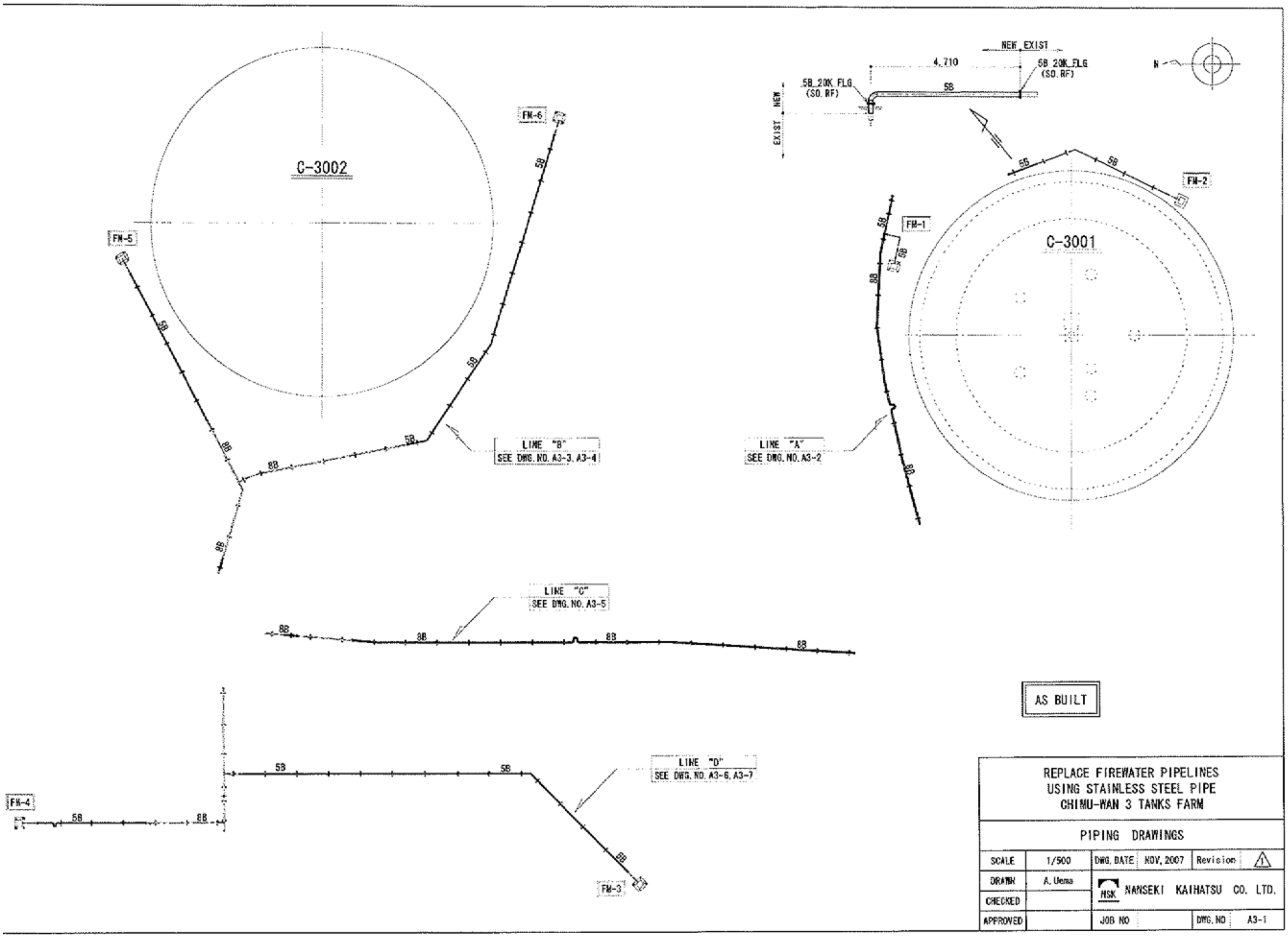
$$= \frac{2\,(167000)(0.85)(0.148)}{8.625}$$

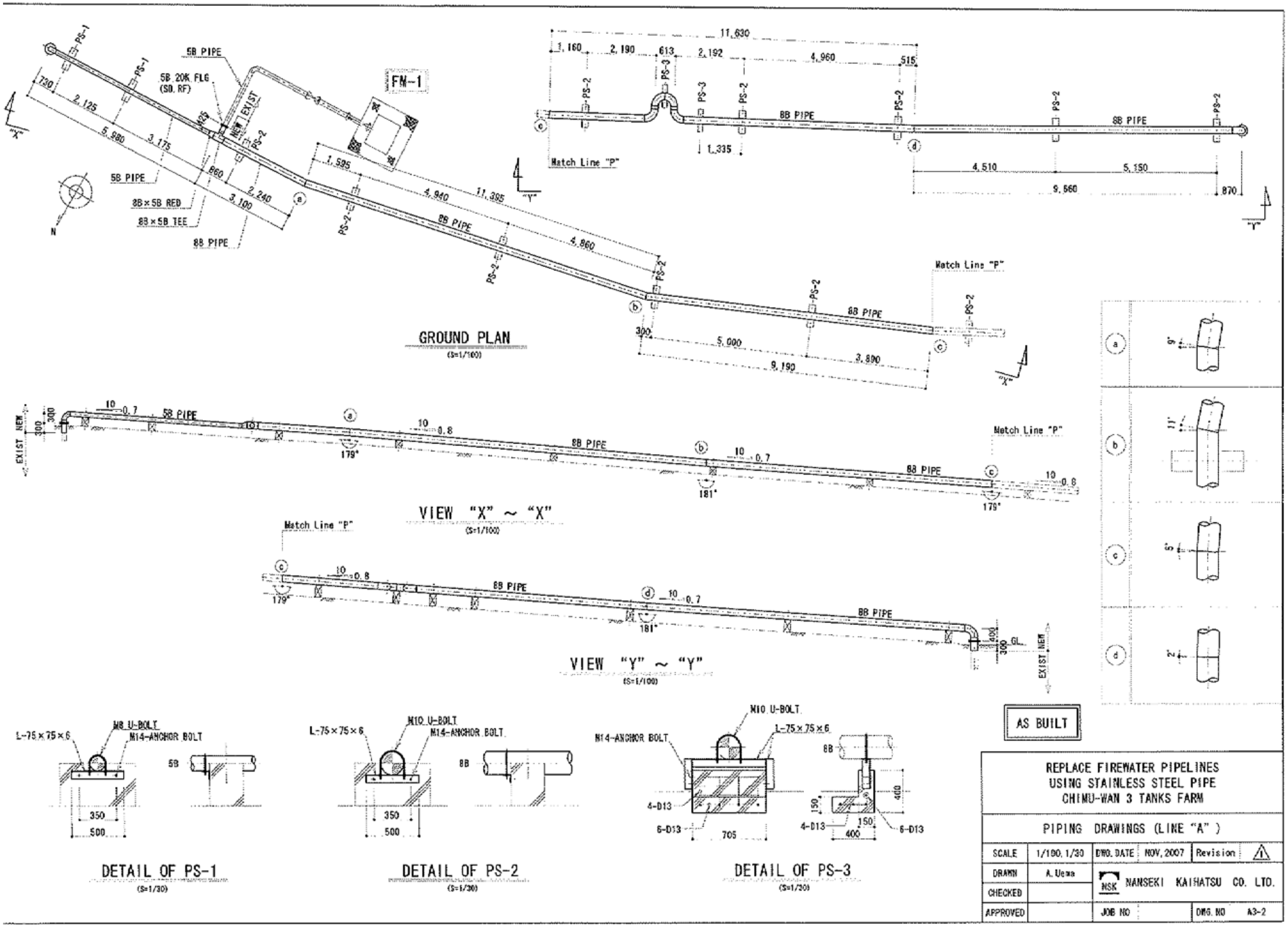
$$= 487 \text{ psi}$$

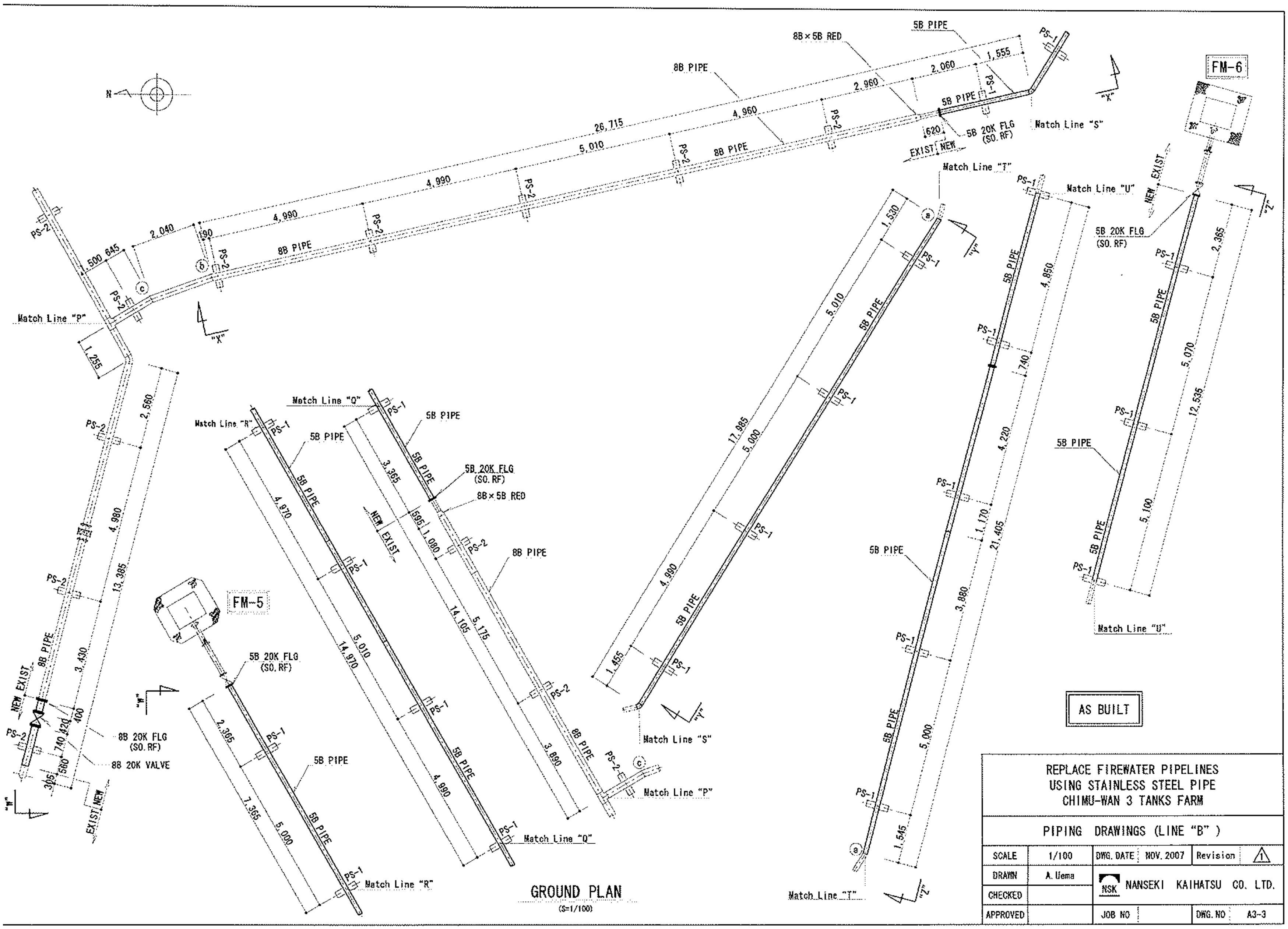
The operating pressure is less than the maximum allowed.

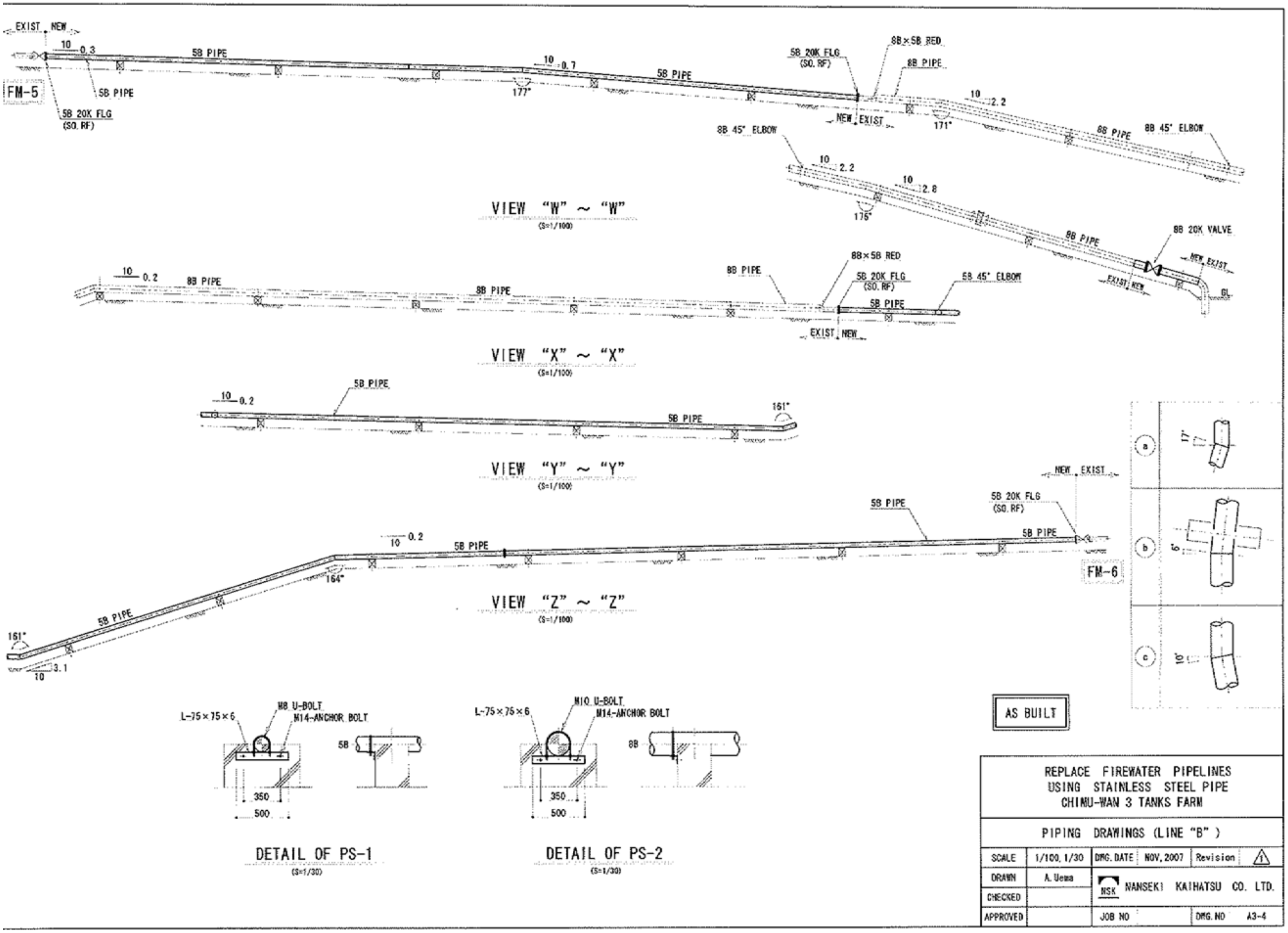
#779

Appendix G: Project Drawings

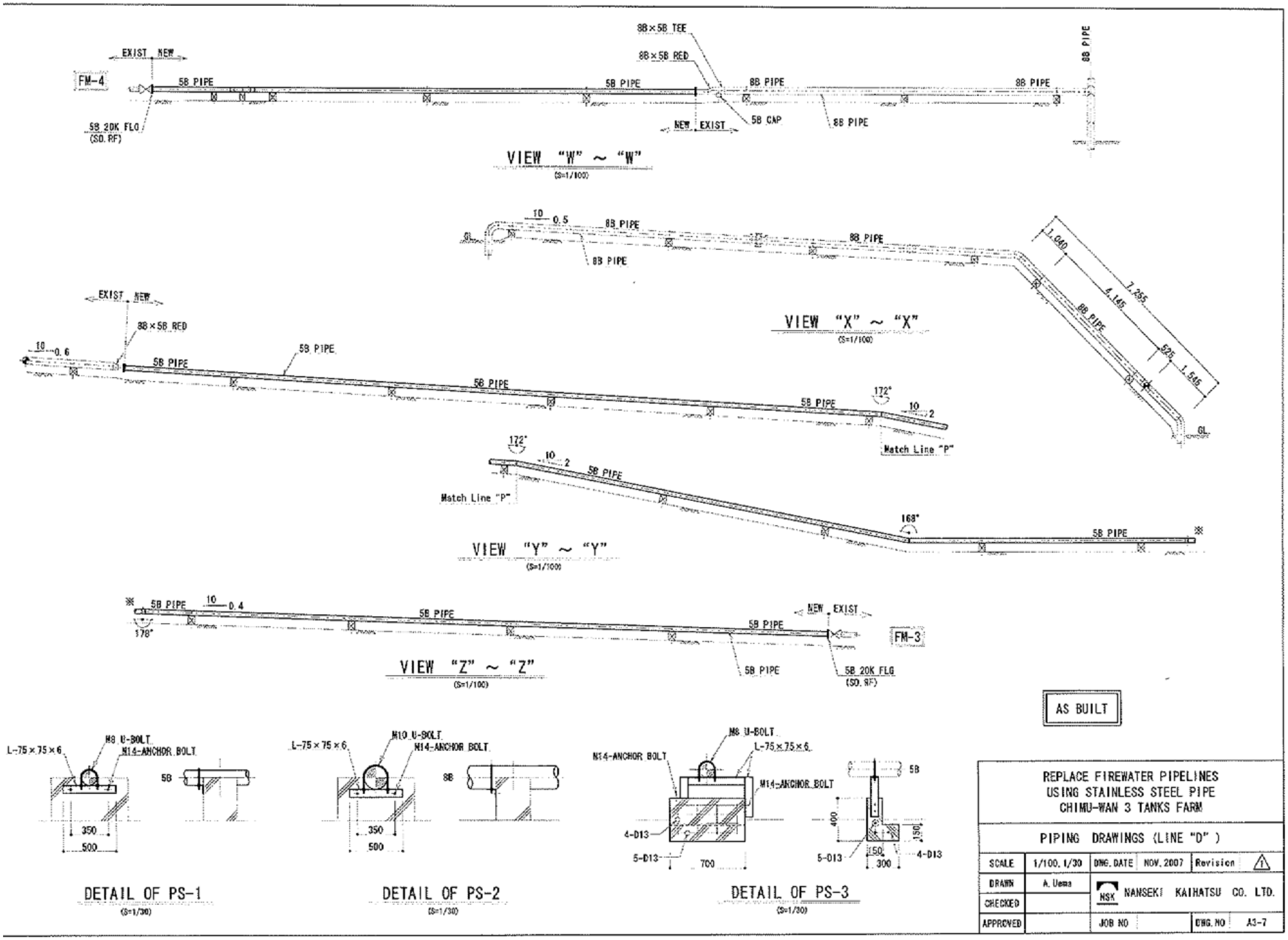

C-3002
C-3001
FM-1
FM-2
FM-3
FM-4
FM-5
FM-6
LINE "A"
SEE DWG. NO. A3-2
LINE "B"
SEE DWG. NO. A3-3, A3-4
LINE "C"
SEE DWG. NO. A3-5
LINE "D"
SEE DWG. NO. A3-6, A3-7
NEW EXIST
4,710
5B 20K FLG
(SO. RF)
5B
EXIST NEW
AS BUILT
REPLACE FIREWATER PIPELINES
USING STAINLESS STEEL PIPE
CHIMU-WAN 3 TANKS FARM
PIPING DRAWINGS
SCALE 1/500
DWG. DATE NOV. 2007
Revision
DRAWN A. Uema
CHECKED
APPROVED
NSK NANSEKI KAIHATSU CO. LTD.
JOB NO
DWG. NO A3-1

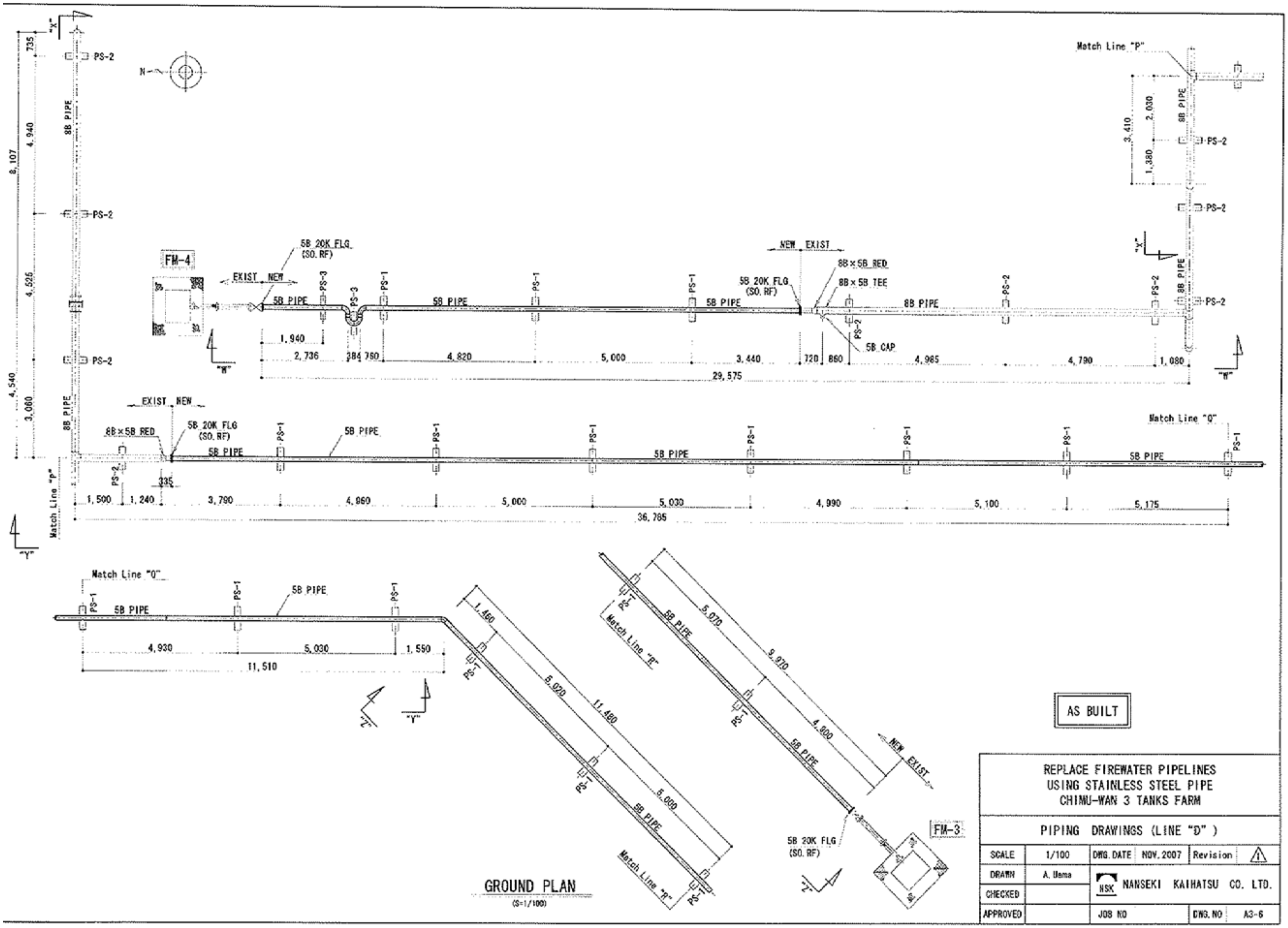

GROUND PLAN
(S=1/100)
VIEW "X" ~ "X"
(S=1/100)
VIEW "Y" ~ "Y"
(S=1/100)
DETAIL OF PS-1
(S=1/30)
DETAIL OF PS-2
(S=1/30)
DETAIL OF PS-3
(S=1/30)
FM-1
5B PIPE
5B 20K FLG
(SO. RF)
8B×5B RED
8B×5B TEE
8B PIPE
Match Line "P"
L-75×75×6
M8 U-BOLT
M10 U-BOLT
M14-ANCHOR BOLT
4-D13
6-D13
AS BUILT
REPLACE FIREWATER PIPELINES
USING STAINLESS STEEL PIPE
CHIMU-WAN 3 TANKS FARM
PIPING DRAWINGS (LINE "A")
SCALE
1/100, 1/30
DWG. DATE
NOV, 2007
Revision
DRAWN
A. Uema
CHECKED
APPROVED
NSK NANSEKI KAIHATSU CO. LTD.
JOB NO
DWG. NO
A3-2

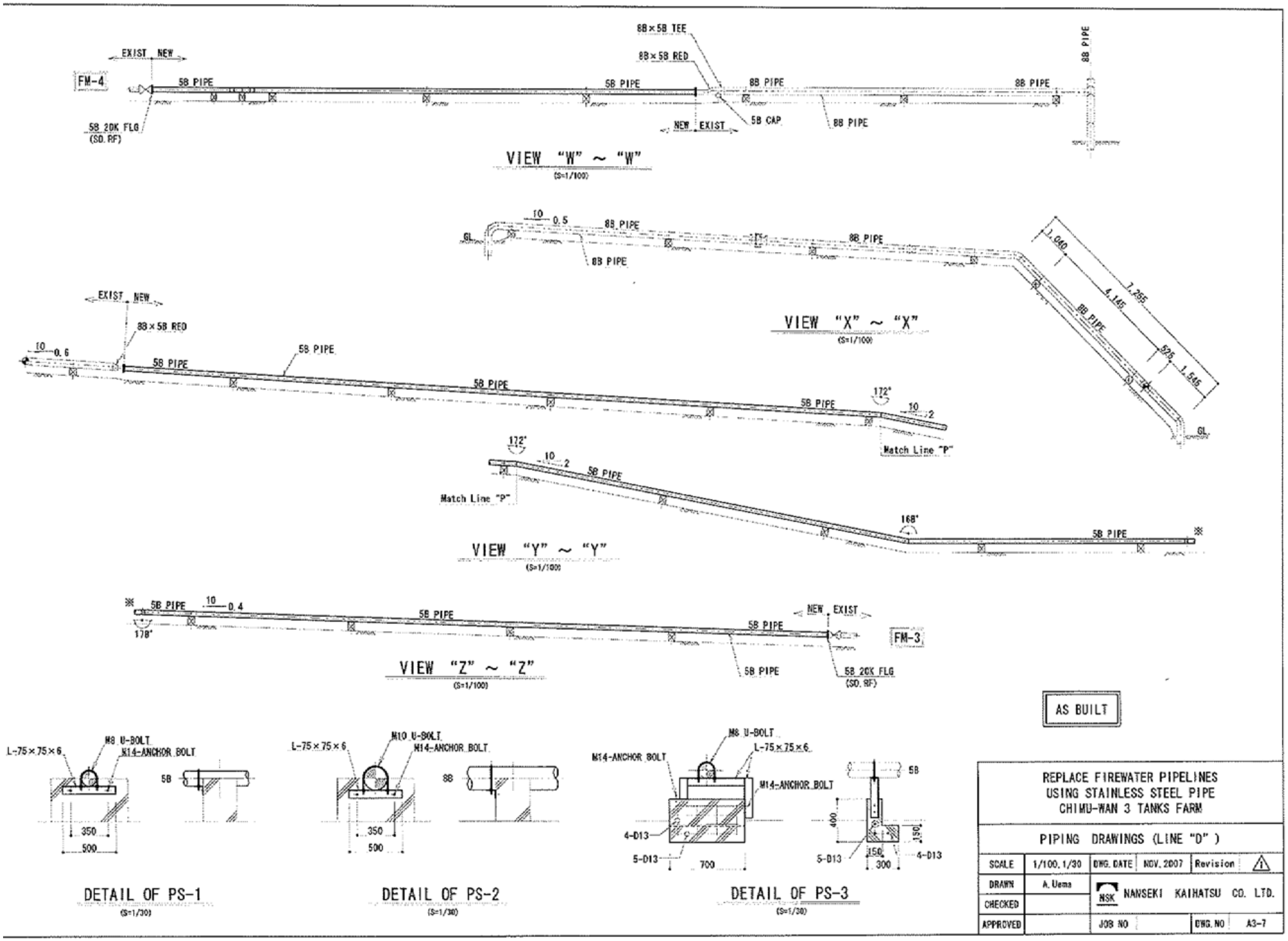

FM-5
FM-6
GROUND PLAN
(S=1/100)
AS BUILT
Match Line "P"
Match Line "Q"
Match Line "R"
Match Line "S"
Match Line "T"
Match Line "U"
8B PIPE
5B PIPE
8B×5B RED
5B 20K FLG
(SO.RF)
8B 20K FLG
(SO.RF)
8B 20K VALVE
NEW EXIST
REPLACE FIREWATER PIPELINES
USING STAINLESS STEEL PIPE
CHIMU-WAN 3 TANKS FARM
PIPING DRAWINGS (LINE "B")
SCALE 1/100
DWG. DATE NOV. 2007
Revision
DRAWN A. Uema
CHECKED
APPROVED
NSK NANSEKI KAIHATSU CO. LTD.
JOB NO
DWG. NO A3-3



EXIST NEW
FM-5
5B PIPE
5B 20K FLG
(SO.RF)
177°
8B×5B RED
8B PIPE
NEW EXIST
171°
8B 45° ELBOW
175°
8B 20K VALVE
GL
VIEW "W" ~ "W"
(S=1/100)
8B PIPE
5B 20K FLG
(SO.RF)
5B 45° ELBOW
5B PIPE
EXIST NEW
VIEW "X" ~ "X"
(S=1/100)
5B PIPE
161°
VIEW "Y" ~ "Y"
(S=1/100)
NEW EXIST
5B 20K FLG
(SO.RF)
5B PIPE
FM-6
164°
161°
VIEW "Z" ~ "Z"
(S=1/100)
L-75×75×6
M8 U-BOLT
M14-ANCHOR BOLT
5B
350
500
DETAIL OF PS-1
(S=1/30)
L-75×75×6
M10 U-BOLT
M14-ANCHOR BOLT
8B
350
500
DETAIL OF PS-2
(S=1/30)
AS BUILT
REPLACE FIREWATER PIPELINES
USING STAINLESS STEEL PIPE
CHIMU-WAN 3 TANKS FARM
PIPING DRAWINGS (LINE "B")
SCALE 1/100, 1/30
DWG. DATE NOV, 2007
Revision
DRAWN A. Uema
CHECKED
APPROVED
NSK NANSEKI KAIHATSU CO. LTD.
JOB NO
DWG. NO A3-4


FM-4
EXIST NEW
5B PIPE
5B 20K FLG (SO. RF)
8B×5B TEE
8B×5B RED
5B CAP
NEW EXIST
8B PIPE
VIEW "W" ~ "W"
(S=1/100)
10
0.5
GL
VIEW "X" ~ "X"
(S=1/100)
1,040
7,255
4,145
525
1,545
172°
168°
Match Line "P"
VIEW "Y" ~ "Y"
(S=1/100)
178°
0.4
FM-3
VIEW "Z" ~ "Z"
(S=1/100)
AS BUILT
L-75×75×6
M8 U-BOLT
M10 U-BOLT
M14-ANCHOR BOLT
4-D13
5-D13
350
500
700
400
150
300
190
DETAIL OF PS-1
(S=1/30)
DETAIL OF PS-2
(S=1/30)
DETAIL OF PS-3
(S=1/30)
REPLACE FIREWATER PIPELINES
USING STAINLESS STEEL PIPE
CHIMU-WAN 3 TANKS FARM
PIPING DRAWINGS (LINE "D")
SCALE 1/100, 1/30
DWG. DATE NOV. 2007
Revision
DRAWN A. Uema
CHECKED
APPROVED
NSK NANSEKI KAIHATSU CO. LTD.
JOB NO
DWG. NO A3-7


Match Line "P"
Match Line "Q"
Match Line "R"
FM-4
FM-3
5B 20K FLG
(SO. RF)
EXIST NEW
NEW EXIST
8B×5B RED
8B×5B TEE
5B CAP
5B PIPE
8B PIPE
PS-1
PS-2
PS-3
1,940
2,736
384
760
4,820
5,000
3,440
720
860
4,985
4,790
1,080
29,575
1,500
1,240
335
3,790
4,960
5,030
4,990
5,100
5,175
36,785
4,930
1,590
11,510
1,460
5,020
11,480
5,070
9,970
4,900
735
4,940
8,107
4,525
4,540
3,060
3,410
2,030
1,380
"X"
"Y"
"Z"
"W"
AS BUILT
GROUND PLAN
(S=1/100)
REPLACE FIREWATER PIPELINES
USING STAINLESS STEEL PIPE
CHIMU-WAN 3 TANKS FARM
PIPING DRAWINGS (LINE "D")
SCALE 1/100
DWG. DATE NOV. 2007
Revision
DRAWN A. Uema
CHECKED
APPROVED
NSK NANSEKI KAIHATSU CO. LTD.
JOB NO
DWG. NO A3-6



FM-4
EXIST NEW
5B PIPE
5B PIPE
8B×5B TEE
8B×5B RED
8B PIPE
8B PIPE
8B PIPE
5B 20K FLG
(SD. RF)
NEW EXIST
5B CAP
8B PIPE
VIEW "W" ~ "W"
(S=1/100)
GL
8B PIPE
8B PIPE
8B PIPE
1,040
7,255
4,145
8B PIPE
525
1,545
GL
VIEW "X" ~ "X"
(S=1/100)
EXIST NEW
8B×5B RED
5B PIPE
5B PIPE
5B PIPE
5B PIPE
172°
Match Line "P"
172°
5B PIPE
Match Line "P"
168°
5B PIPE
VIEW "Y" ~ "Y"
(S=1/100)
5B PIPE
5B PIPE
178°
5B PIPE
NEW EXIST
FM-3
5B PIPE
5B 20K FLG
(SD. RF)
VIEW "Z" ~ "Z"
(S=1/100)
AS BUILT
L-75×75×6
M8 U-BOLT
M14-ANCHOR BOLT
5B
350
500
DETAIL OF PS-1
(S=1/30)
L-75×75×6
M10 U-BOLT
M14-ANCHOR BOLT
8B
350
500
DETAIL OF PS-2
(S=1/30)
M8 U-BOLT
M14-ANCHOR BOLT
L-75×75×6
M14-ANCHOR BOLT
4-D13
5-D13
700
5B
400
150
150
300
5-D13
4-D13
DETAIL OF PS-3
(S=1/30)
REPLACE FIREWATER PIPELINES
USING STAINLESS STEEL PIPE
CHIMU-WAN 3 TANKS FARM
PIPING DRAWINGS (LINE "D")
SCALE 1/100, 1/30
DWG. DATE NOV. 2007
Revision
DRAWN A. Uema
CHECKED
APPROVED
NSK NANSEKI KAIHATSU CO. LTD.
JOB NO
DWG. NO A3-7

Appendix H: Cathodic Protection Measurement Data for Replaced Piping

CORROSION CONTROL INCORPORATED
CATHODIC PROTECTION FIELD DATA

TABLE III
SHEET 1 OF 1

SITE NAME:	Chimu-Wan 3 Tank Farm	Potentials recorded after pipeline repairs in isolated sections
STRUCTURE:	Fire Water Pipelines	1. Potential with galvanic anodes connected to isolated sections of pipe - below grade (mV)
DATE OBTAINED:	7 June 2008	2. Potential with galvanic anodes connected to isolated sections of pipe - above insulator (mV)
SURVEYED BY:	R. Eichlin	

NO.	LOCATION	1	2				COMMENTS
1	5" riser north side of driveway at C3001	-1950	-251				
2	5" riser south side of driveway at C3001	-1378	-58				
3	8" riser north side of driveway northwest of C3001	-1923	-793				
4	8" riser south side of driveway northwest of C3001	-1590	-1210				

Appendix I: Results of Nondestructive Weld Examination

南石開発株式会社 殿

CHIMU-WAN3 TANKS FARM
配管現場溶接部
（浸透探傷検査報告書）

Dye Penetrate Test

平成２０年５月

May 2008

沖縄非破壊検査株式会社
〒904-2172 沖縄市泡瀬３丁目３９番７号
TEL 098-929-3335 FAX 098-929-3337

浸透探傷検査記録

Report of Dye Penetrate test

沖縄非破壊検査株式会社
〒904-2172 沖縄県沖縄市泡瀬3－3191－7
TEL. (098) 929-3335 FAX. (098) 929-3337

注文主	南石開発 株式会社 殿	検査日時	Date 平成２０年4月１０日～5月２６日
工事名称	CHIMU-WAN3 TANKS FARM	検査時期	溶接最終層
		表面状態	ワイヤーブラシ仕上げ
検査物	配管現場溶接継手	検査方法	溶剤除去性染色浸透探傷検査
材質	Material SUS 304	検査面温度	常温
数量	８B、１０B １６箇所	浸透時間	5分 / 現像時間 １０分

浸透探傷材料				
銘柄	浸透剤	UP－ST	浸透探傷法	F：蛍光 V：染色
	洗浄剤	UR－ST	浸透剤のタイプ	A：水洗性
	現像剤	UD－ST		B：後乳化性
	乳化剤	－		C：溶剤除去性
メーカー		マークテック㈱	現像方法	D：乾式
				A：湿式 S：速乾式

概要

◎ **適用範囲** Application Standard

８B、１０B消火配管現場溶接部最終層（１６箇所）

Welding points

◎ **適用規格** Standard

・JIS Z ２３４３-2001 「浸透探傷試験方法及び浸透指示模様の分類」

◎ **検査結果** Test Record Clear

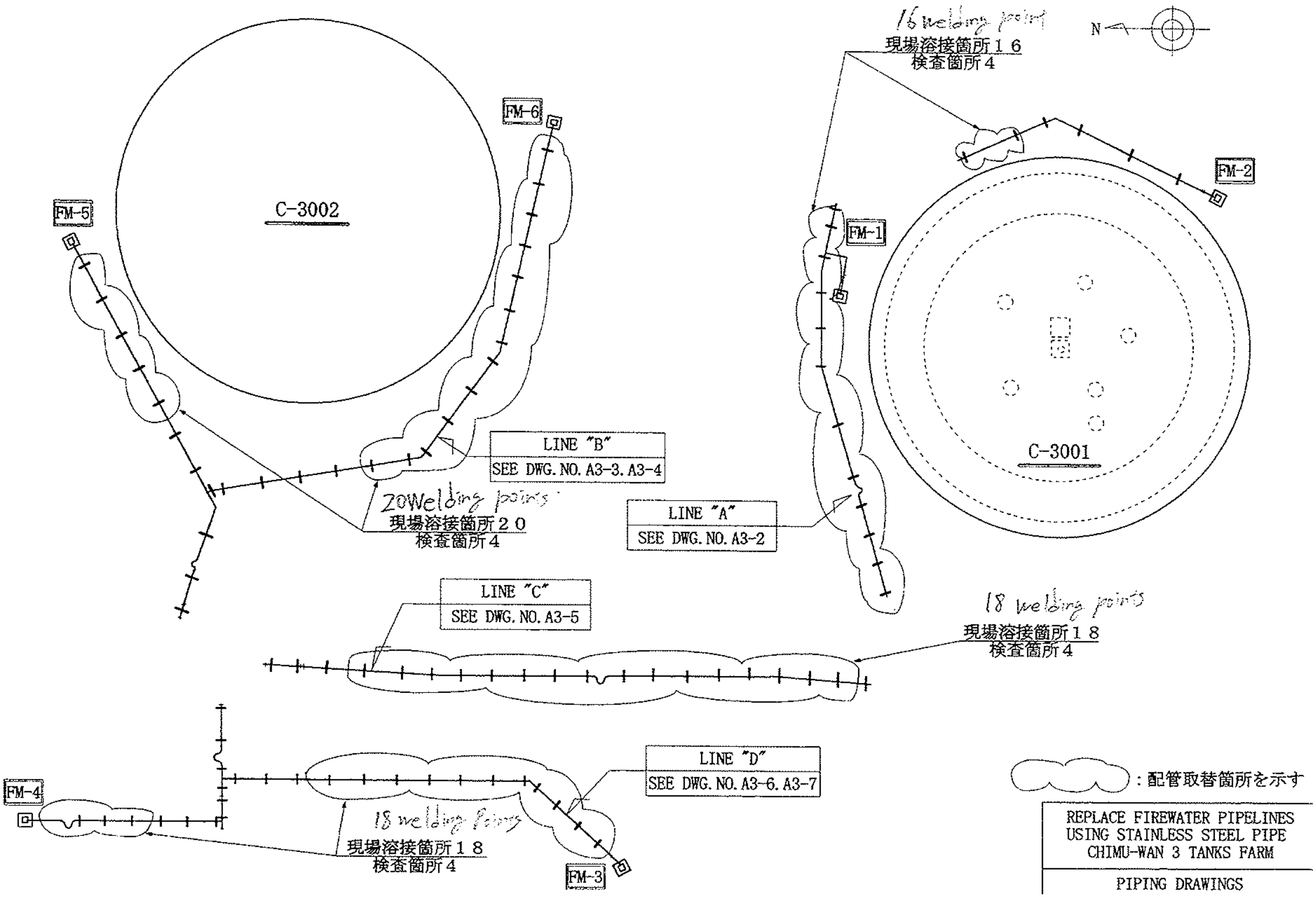
有害な浸透指示模様を認めず。 合格

検査員 Inspector : Yoshihide kinjyo

License Number

氏名	資格	免許番号
金城 善秀	浸透探傷試験・レベル2	N10017456

備考



16 welding point
現場溶接箇所１６
検査箇所４
N
FM-6
FM-5
C-3002
FM-1
FM-2
C-3001
LINE "B"
SEE DWG. NO. A3-3. A3-4
20 Welding points
現場溶接箇所２０
検査箇所４
LINE "A"
SEE DWG. NO. A3-2
LINE "C"
SEE DWG. NO. A3-5
18 welding points
現場溶接箇所１８
検査箇所４
LINE "D"
SEE DWG. NO. A3-6. A3-7
FM-4
18 welding points
現場溶接箇所１８
検査箇所４
FM-3
：配管取替箇所を示す
REPLACE FIREWATER PIPELINES USING STAINLESS STEEL PIPE CHIMU-WAN 3 TANKS FARM
PIPING DRAWINGS

Appendix J: Hydrostatic Pressure Testing Results

Hydrostatic Test: Line A / FM-1
April, 2008

Time:	Pressure:
13:00 hours	200 psig
13:30 hours	240 psig
14:00 hours	250 psig
14:30 hours	250 psig
15:00 hours	260 psig
15:30 hours	260 psig
16:00 hours	250 psig
16:30 hours	250 psig
17:00 hours	240 psig

Hydrostatic Test: Line C 8" dia. Line
May 8, 2008

Time:	Pressure:
15:15 hours	200 psig
16:15 hours	230 psig
16:30 hours	245 psig
17:00 hours	260 psig
17:30 hours	260 psig
18:00 hours	260 psig
18:30 hours	248 psig
19:00 hours	235 psig
19:30 hours	220 psig

Hydrostatic Test: Line B / FM-6
May 16, 2008

Time:	Pressure:
12:00 hours	200 psig
12:30 hours	250 psig
13:00 hours	260 psig
13:30 hours	245 psig
14:00 hours	240 psig
14:30 hours	280 psig
15:00 hours	260 psig
15:30 hours	276 psig
16:00 hours	255 psig

Hydrostatic Test: Line B / FM-5
May 24, 2008

Time:	Pressure:
12:00 hours	200 psig
13:00 hours	240 psig
14:00 hours	250 psig
14:30 hours	260 psig
15:00 hours	260 psig
16:00 hours	250 psig

Hydrostatic Test: Line D / FM-3
May, 2008

Time:	Pressure:
12:00 hours	200 psig
13:00 hours	250 psig
14:00 hours	260 psig
14:30 hours	260 psig
15:00 hours	255 psig
16:00 hours	250 psig

Hydrostatic Test: Line D / FM-4
May 26, 2008

Time:	Pressure:
9:00 hours	200 psig
9:30 hours	210 psig
10:00 hours	230 psig
10:30 hours	250 psig
11:00 hours	230 psig
11:30 hours	240 psig
12:00 hours	230 psig
12:30 hours	230 psig
13:00 hours	225 psig

#793