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CACTUS – GADALAJARA LPG PIPELINE SYSTEM REHABILITATION

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ABSTRACT.

This paper describes the work that was undertaken to re-qualify the Cactus-Guadalajara LPG pipeline for a higher MAOP without taking the pipeline out of service for a hydrostatic test. It demonstrates how geo-positioning technology, high-resolution in-line inspection, and data management systems can be successfully utilized for such project, even when the record-keeping associated with previous pipeline repairs has been deficient.

By establishing a geo-referenced pipeline asset management system that integrates physical asset description, operational data, internal inspection and pipeline repair data, a sound foundation has been created for the future integrity management of this pipeline.

KEYWORDS.

Geo-positioning, in-line inspection, defect assessment, MAOP re-qualification, records management.

INTRODUCTION.

This paper describes the rehabilitation work related to the Cactus-Guadalajara 24"-20"-14" LPG Pipeline system

that traverses the states of Chiapas, Tabasco, Veracruz, Tlaxcala, Puebla, Mexico, Querétaro, Guanajuato and Jalisco. Its total length is 1231 km, of which 717 km of the pipeline was included in the rehabilitation project. The system is a main artery of the national pipeline grid, managed and operated by Pemex Gas y Petroquímica Básica (PGPB), a division of Pemex.

The age of individual parts of the LPG pipeline system varies but, on average, the pipeline is about 30 years old and it has been confirmed to be subject to external corrosion hazard. In view of the importance of the LPG Pipeline system, PGPB has over the years employed industry-accepted technologies in order to monitor and control this hazard. As a result, PGPB has not experienced major outages caused by leaks or pipeline ruptures.

The rehabilitation program objectives were to maintain this record of safe and reliable performance in the future and establish the integrity of the pipeline to allow a safe increase of the Maximum Allowable Operating Pressure (MAOP) from the current 6,374 kPa to 7,355 kPa. Such business objectives have a practical chance of being achieved only if one deploys the state-of-the-art technologies capable to size and locate

corrosion with accuracy specified for high-resolution inspection tools. This type of inspection data was obtained in the past but documentation of existing repairs was often insufficient to conclusively confirm that the right and acceptable repairs were in the required locations.

Thus, the added key requirement for this Project was to provide accurate three-dimensional mapping of the pipeline location to allow the results of the last inspection and the past repairs to be reliably cross-referenced to the new geographical co-ordinates established in the Project.

The paper presents an overall case study in a form other pipeline operators may find useful. It starts with an overview of the objectives and scope of work, and continues with highlighting the challenges and the methodology the contractor implemented to meet the objectives of the Project.

OBJECTIVES.

The prime objective of the Project was to re-establish the integrity of the specified 10 sections of this pipeline at the MAOP of 7,355 kPa. This result was to be endorsed by a Certifying Company who would issue a Certificate of Mechanical Integrity at the re-established MAOP, for a specified period of two-and-a-half years.

Defect assessment and subsequent rehabilitation work required to achieve this objective was to be performed in accordance with the methodology and procedures approved by a Certifying Company.

Other key objectives included:

- ◆ Producing a precise three-dimensional mapping (geo-positioning) of the specified pipeline sections and using this as a reference basis for developing and implementing Intelligent Data Management System Software (IDMS) to organise and store the documentation required for the Integrity Certification process.
- ◆ Cross-referencing all defect indications, reported previously by the in-line inspection ultrasonic tool, with the established continuous geographical co-ordinates to achieve a location accuracy of +/- 0.5m along the pipeline axis in the field.
- ◆ Training of the designated PGPB personnel in effective use of the Intelligent Data Management System, as well as the Geodent™ and Geodisplay™ Software tools used to display all data and reports obtained from the geo-positioning tool runs.

SCOPE OF THE PROJECT.

The overall scope of work for this Project was related to geo-positioning, rehabilitation and certifying 717 km of the 1,231 km of the Cactus-Guadalajara 24”-20”-14” LPG

Pipeline. The total length of the pipeline system to be rehabilitated was divided into 10 sections as indicated below in Table 1:

No.	From	To	Diam.	Length (km)
1	Cactus	Benito Juarez	24	52.65
2	Benito Juarez	Los Cocos	24	81.63
3	Los Cocos	Juan D.Covarrubias		24.00
4	Zapoapita	Cd. Mendoza	24	29.32
5	Tecamachalco	San Martín Texm	24	90.39
6	San Martín Tex	Venta de Carpio	24	84.53
7	Santa Ana	Palmillas	14	69.23
8	Palmillas	Apaseo	14	84.54
9	Apaseo	Abasolo	14	94.80
10	Puente Grande	Term. Sat. Guadal.	14	41.68

Table 1: Ten pipeline sections included in the scope of the Project.

To define the overall extent and scope of rehabilitation work required to re-establish the MAOP of 7,355 kPa, the contractor was required to deliver, 30 days after the initiation of the Contract, a Certified Report specifying results of the Initial Fitness-for-Purpose assessment of all defect indications reported by the last in-line inspection.

The scope of work for each site identified by this initial assessment included exposing the pipe, performing required inspection, measurement and assessment of the reported defect, and performing required repairs of the injurious defects. Each activity was to be supported by QA documentation approved by the Certification Company.

Geo-positioning work was to start immediately and in parallel with the Rehabilitation segment of the Project. The contractor was required to perform accuracy verification of the geographical co-ordinate data produced by the geo-positioning tool for each pipeline segment. The accuracy verification process and results were to be witnessed by PGPB and independently documented by the Certifying Company.

The certification process was to continue with the second report evaluating the current condition of the specified pipeline system. This report was to be submitted by the Certifying Company sixty calendar days after the start of the field work. This report was to include recommendations of any upgrades required for the certification.

The next step in the scope of the certification process was to evaluate PGPB’s Preventive Maintenance Program. The resulting report was to provide a basis for

certifying that PGPB's preventive maintenance program, while the Integrity Certificate was in effect, was acceptable for maintaining the safe and reliable operation of each pipeline section and/or recommend required corrections.

Upon completion of the Project, the Certifying Company was to issue the Final Report and the Certificate of Mechanical Integrity for the specified 10 pipeline sections. The report was to outline the process and results of the certification and specify the conditions for granting to PGPB the Certificate of Mechanical Integrity, revalidation methodology, duration of and requirements for its validity.

MAJOR CHALLENGES.

In viewing the scope of the Project it was apparent that a number of practical scenarios could develop and cause major problems in delivering the expected results.

First of all, operator's ROWs typically contain number of lines of different or similar diameters running in parallel. This fact poses a real challenge for executing the field rehabilitation work in a timely manner. The only practical way to meet this challenge is to deliver pipeline geo-positioning results with the accuracy of about +/- 1 m.

It was also recognised that for the Project to be successful, a seamless integration of three different and not exactly compatible technologies was required. These technologies included pipeline mapping based on satellite geo-positioning, pipeline integrity assessment and rehabilitation, and the development of an intelligent data management system. This was seen as one of the major challenges of the Project. A failure to achieve a required level of quality consistently in each of these components of the Project would have a adverse effect on its overall prime objective.

The extent of the reported anomalies was considerable. In total, about 2,000 corrosion damage indications had to be evaluated and the inspection data was about two-and-a-half years old. Consequently, when performing the initial assessment of the severity of the reported corrosion, an appropriate allowance had to be made for potential corrosion growth since the time of the inspection. These kinds of corrections are known to be fraught with practical difficulties.

Operator's effort to maintain safe and reliable performance of the LPG System included performing the first in-line inspection of this system in 1994. The repairs performed in the subsequent rehabilitation program used, in most cases, a composite reinforcing sleeve. However, a limited number of pressure containing steel sleeves, welded to the carrier pipe, was installed as well.

Unfortunately, this work was not documented to the extent that would meet the requirements of the Certifying Company. There was a concern that the absence of this documentation might lead to extensive and costly "repairs of the existing repairs".

Last, but not least, in Tabasco and also in the first part of Veracruz, a prevailing swampy terrain combined with a possible heavy rainy season and notoriously difficult access permit conditions could conspire to make an orderly and timely execution of the field repair work exceedingly difficult.

ADOPTED APPROACH AND METHODOLOGY.

This section outlines the main features of the approach and methodology developed and implemented by the contractor in order to meet the challenges described above. It is important to stress that this outline is based on a detailed engineering analysis that was independently reviewed and approved by Germanischer Lloyd (GL), a member of the International Association of Classification Societies. The resulting engineering reports, methodologies and required procedures produced by the contractor were duly documented and after being approved by GL, they became an integral part of the overall documentation of this Project.

The independent audit provided assurance that all aspects of rehabilitation work were engineered and executed to meet internationally recognised quality standards. The function of independent quality assurance performed by GL throughout the Project proved to be equally effective in assuring that the other two components of the Project, geo-positioning and development of Intelligent Data Management System, were executed with the same consistent quality.

The concern related to achieving the required accuracy for the geo-positioning was alleviated early in the Project. The independent reports, prepared by GL, confirmed the results produced by the contractor's state-of-the-art GEOPIG™ tool had consistently met the specified required accuracy for all ten pipeline sections included in the scope of the Project.

The Initial Damage Assessment report specifying the scope of the rehabilitation program required for increasing the MAOP from the current 6,374 kPa to 7,355 kPa was completed and delivered within 30 days as required by the Contract. The following section outlines the process used in producing this Report within the context of the overall damage assessment methodology.

The existing repair issue was addressed early in the Project. Based on preliminary information provided by PGPB, a considerable number of composite reinforcing sleeve repairs appeared to be located at the sites where

the Initial Damage Assessment Report specified the Required Repairs. Since PGPB could not provide evidence confirming that these sleeves were installed in accordance with the requirements of the manufacturer's installation procedure, the Certifying Company required that their acceptability be determined independently. In responding to this challenge, the contractor solicited detailed engineering input directly from the manufacturer to develop the Field Evaluation Procedure for existing composite sleeve installations. Based on the best available technical information, the developed procedure included visual inspection, evaluation of sleeve compactness, measurement of sleeve thickness and hardness of epoxy material in specified locations around the circumference of a sleeve. A field Evaluation Report was required to be produced for each installation. Once approved by the Certifying Company, this procedure was used to evaluate the acceptability of over one hundred existing composite sleeve installations.

The existing steel sleeves that were welded to a carrier pipe presented similar problem. PGPB could not provide the evidence the Certifying Company required for determining the acceptability of these installations. The developed Field Evaluation procedure required the Grade and wall thickness of each sleeve to be determined in order to verify the acceptability of its design. In addition, Magnetic Particle Inspection was required to be performed to confirm the absence of any toe-cracks that might be located in the carrier pipe along the fillet weld. Again, a field Evaluation Report was required to be produced for each installation. Over fifty existing welded steel sleeves were evaluated after this procedure was approved by the Certifying Company.

Timely execution of field rehabilitation work in Tabasco and Veracruz proved to be as difficult as expected for the reasons indicated above. Although the contractor established a close co-ordination with PGPB management and a consistent weekly reporting of the progress, the access-permit-related delays were inevitable and as a result, one extension of the Contract time was required. However, once outside this difficult region, the field work was completed in a timely fashion before the end of the granted extension.

PROJECT EXECUTION AND RESULTS.

As much as practically achievable, execution of the four components of the Project was co-ordinated in parallel to ensure the seamless integration that was required for achieving the central objectives of the Project. In order to illustrate the unique nature of this integration process, some of the relevant aspects of the process are outlined in greater detail.

Damage Assessment Methodology.

The overall process of the adopted Damage Assessment Methodology included two separate steps; Initial Damage Assessment (IDA) of the available in-line inspection data, and the Field Damage Assessment (FDA) of the actual damage measured in the field.

The product of the Initial Damage Assessment of the in-line inspection data was the specifications of a cost-effective Rehabilitation Program required to meet the principal objective of the Project.

The deliverable of the second step (FDA) of the adopted Damage Assessment Methodology was a specification that determined the type of repair required to achieve the MAOP of 7,355 kPa at every site specified in the scope of the Rehabilitation Program for each pipeline segment. These repair decisions were based on a Field Fitness-for-purpose assessment of the severity of damage actually measured in the field at every specified site.

Initial Damage Assessment.

The overall scope of the Initial Damage Assessment included over two thousand (2,000) indications reported by the in-line inspection. Although the bulk of this data was reported to be external corrosion damage in the pipe body, there was also a limited number of indications of corrosion located in the immediate vicinity of both longitudinal and girth welds. In addition, there were several indications of combined damage, including corrosion on dents, and forty-nine (49) indications of laminations combined with possible internal corrosion. There were also over fifty indications of steel sleeves welded to the carrier pipe. Finally, detailed analysis of the corrosion indications in the pipe body suggested several locations where reported separate corrosion features could actually be interacting.

The first step in the overall damage assessment process essentially involved optimising a desired level of conservatism against the resulting cost. A process of evaluating two-and-a-half-year-old in-line inspection corrosion data involved addressing the uncertainties related to inspection tool accuracy, corrosion profile and possible corrosion growth. An appropriate degree of conservatism to account for these uncertainties was analysed and recommended by the contractor. Following a review process, its final level was approved by the Certifying Company and PGPB. After correcting the reported corrosion data accordingly, modified B31.G procedure was used to perform an equivalent of a hydrostatic test. The corrosion features that failed to meet the standard hydrostatic test acceptance criteria for

MAOP of 7,355 kPa were included in the scope of the specified Rehabilitation Program as Required Repairs.

In order to ensure that all significant defect indications reported by the in-line inspection were adequately addressed, the Initial Damage Assessment was designed to also produce the second category of the Rehabilitation Program; Required Verifications. These were the locations where the in-line inspection data indicated possible interactions of corrosion features, possible interaction of corrosion and longitudinal welds, damage caused by a combined effect of dents and corrosion, and laminations combined with internal corrosion. In addition, all welded steel sleeves were included in this category once it was established that no documentation was available to confirm the acceptable quality of the installation. This category of the Rehabilitation Program thus included all those features for which the available in-line inspection data was not sufficient for determining their effect on the integrity. Thus, they had to be exposed and evaluated directly in the field to determine whether a reinforcing repair was required at the specified MAOP of 7,355 kPa.

The results of the Initial Damage Assessment were integrated from the start of the Project directly into the original inspection database. Each Required Repair and Verification Feature was assigned a unique ID number identical with its chainage provided by the original inspection. This ensured a continued use of the established reference system and prevented any potential complications that the introduction of another database might cause.

In order to perform this initial assessment work within a given time frame, the pipe material data provided by PGPB at that time were used. However, the Report also specified the requirements for a full validation of the results of this analysis. PGPB was required to provide the evidence confirming engineering design and as-built parameters of each specified pipeline section. The minimum required for this validation was a confirmation that the pipe material was not brittle, and the hydrostatic test certificates confirming the pipe specification, nominal wall thickness, pipe Grade specification, test pressure, MAOP and the date of testing. The Report stressed that in the absence of such evidence, additional measures would have to be implemented before a certification at the targeted MAOP was considered.

Finally, in order to complete the repair decision and repair method selection process, the Initial Damage Assessment Report also specified the Repair Method Selection criteria and provided detailed Procedures for performing composite sleeve and compression steel

sleeve reinforcing repairs as well as acceptable coating repairs.

Field Damage Assessment.

In contrast to the Initial Damage Assessment, the second step of the overall damage assessment process was strictly deterministic. Actual severity of all specified Required Repair corrosion features, selected in the first step, was determined by the direct UT measurement in the field. This data was subsequently evaluated using the same Fitness-for-purpose assessment method. However, there were no speculative assumptions involved in this second step. Thus, the key result of the Field Fitness-for-purpose assessment was a reliable determination of the pressure at which the damaged section of pipe would fail. This calculated failure pressure was then used to determine whether a reinforcing repair was necessary to achieve the safety factor required in each inspected location.

The same Fitness-for-purpose assessment method, modified B31.G, was adopted to achieve the objectives in both steps of the overall damage assessment process. The method is based on the original NG-18 damage assessment equations that have provided a basis for the standard B31.G assessment method (Ref.1,2). The use of this Fitness-for-purpose assessment has been well established by the industry's leading companies, and in its present form, the method represents the industry-proven best practice (Ref. 3 to 7). Its main practical advantage is that it reduces the excess conservatism inherent in the B31.G method and it is therefore better suited for evaluation of extensive corrosion damage reported for the pipeline segments specified in the scope of this Project.

However, the acceptable application of this method requires that a detailed engineering analysis is performed and the limitations of the method are duly considered when making the repair decisions based on the assessment of the field-measured data. The Initial Damage Assessment Report therefore specified the background of the adopted Fitness-for-purpose assessment methodology together with the required conditions for its use. This report was reviewed and approved by the Certifying Company (8).

The Field Evaluation Procedure that was based on this document specified the requirements for the field evaluation process and the acceptance criteria for making repair decisions. Required UT measurements were performed to determine both maximum and average depth of the evaluated corrosion damage. Using the appropriate NG-18 parabolic and rectangular models, these values of corrosion depth were then used to

calculate two failure pressures: 'parabolic' (with max. depth) and 'rectangular' (with average depth).

The lower of these two calculated values was designated to be the Failure Pressure of the specified Feature. The repair decisions for Class Locations 1 and 2 were based on the acceptance criterion that exceeded the Hydrostatic Test Pressure requirement of 1.25 MAOP specified by ASME B31.4. The evaluated corrosion was determined to be acceptable if: Feature Failure Pressure > 1.39 MAOP. This level of conservatism, effectively removed all corrosion features that would fail at the Hydrostatic Test Pressure of 100% of SMYS.

The above assessment procedure is not applicable to combined damage and confirmed internal corrosion in the immediate vicinity of longitudinal ERW welds. A superficial internal corrosion in the vicinity of longitudinal weld was confirmed in few cases. The field inspection also confirmed a limited number of cases of combined damage involving corrosion on an otherwise acceptable dent. Finally, there were several cases where a superficial deformation of unknown origin ('bulge') was detected during the field inspection. In all of these cases, a reinforcing repair was executed by installing the compression steel sleeve.

Certification.

The Certification component of the Project was initiated immediately at its start. During the course of this work the Certifying Company established that the required evidence regarding the pipe material specification and hydrostatic test results were not available. In order to address this deficiency, PGPB implemented additional field testing programs designed to confirm pipe Grade and toughness met the requirements of API 5L specification.

Pipe Grade testing was implemented for all segments of the system. On average, each pipeline segment was tested every 15 km. In all but one location, the obtained results confirmed the measured pipe strength met the pipe Grade specification provided by PGPB. One pipe joint was identified on Line 8 where the Grade was found to be lower than the indicated value of API 5LX52. Detailed analysis, based on the actual wall thickness and lower Grade X42, determined this joint to be acceptable at the MAOP of 7,355 kPa.

The second part of this additional field testing program was designed to confirm whether pipe material

met the notch toughness requirements of the API 5L specification. In total, five hot-taps were performed to obtain pipe body samples for subsequent Charpy V-notch testing. Preliminary analysis of the results obtained from these tests indicated the pipe material met the API 5L requirements. However, the final confirmation of this preliminary conclusion was subject to the results of the final analysis that was being completed by GL at the time of writing this paper.

Apart from the extra work associated with pipe Grade and toughness confirmation, GL also reviewed and approved the required Quality Assurance documentation that was prepared by the contractor for every specified Required Repair and Required Verification site. Monitoring the Quality that was actually delivered by the geo-positioning tool runs and the Rehabilitation Program required most extensive involvement of GL. The next level of detail in executing these two components of the Project is briefly summarised in the following two sections.

Geopositioning.

The geo-positioning tool runs were performed for all ten (10) lines specified in the scope of the Project. Considering the complexity of scheduling this work for a fully loaded system, it was not surprising that some minor delays occurred during individual runs. In spite of this, all inspection work was completed as scheduled between June 17 and August 24/00.

Accuracy verification of the geo-positioning data was audited and documented by GL. The field accuracy verification for each line was performed by an independent GPS company. The process of locating designated features, based on GPS co-ordinates provided by the contractor, was witnessed by a PGPB Supervisor and GL representative, who also prepared an independent report specifying the results of each accuracy verification.

This report was then submitted by GL directly to PGPB Supervisor. These reports confirmed that data produced by the GEOPIG™ delivered the acceptable accuracy for each of the ten (10) pipeline segments. The tool used to perform this work is shown in Figure 1.



Figure 1: Geopig™ ready for launching.

Although this in-line inspection work produced a new three-dimensional reference system, it remained transparent to the user. The net result was that each feature, identified by the original in-line inspection chainage number, was cross-referenced and assigned a new set of co-ordinates that were then used by the GPS method to locate the feature in the field with the required accuracy.

The achieved accuracy of cross-referencing the results of the past in-line inspection and repairs to the new geographical co-ordinates, produced by this Project, provided a reliable basis for performing subsequent Rehabilitation work.

Rehabilitation Work.

The overall scope of the Rehabilitation Program is summarised in Table 2. In total, 383 features were field-inspected, assessed and repaired. Included in this total were 254 Required Repairs and 129 Verifications. The most extensive damage was identified on Lines 2 and 3 where the total number of Required Repairs identified by the Initial Damage Assessment was 161 (107 + 54). Most of this damage was reported as external corrosion. The largest number of Required Verifications was indicated on Lines 4 and 9 (49 and 57). In the case of Line 4, most of the Verifications included indications of possible combined damage caused by laminations and internal corrosion. The subsequent field work did not confirm the existence of any physical features that could generate

the reported indications. On Line 9, all of the 57 Verifications included existing steel sleeve repairs performed by PGPB in the past.



Figure 2: Compression Steel Sleeve Installation

The extent of the specified rehabilitation work, together with a broad range of identified integrity concerns that had to be addressed, required timely implementation of a comprehensive Quality Assurance process that included three major components: the development of required procedures, training of personnel designated to perform the repairs in the field, and documentation confirming the repair work was in full compliance with the approved procedures. Accordingly, the following procedures were developed by the contractor and submitted for a review and approval to GL: UT Inspection, Field Fitness-for-purpose Assessment, Composite Sleeve Installation, Compression Steel Sleeve Installation, Field Evaluation of Existing Steel Sleeve, Field Evaluation of Existing Composite Sleeve, Wax Tape and Duc-line Coating Repair Procedures.

Required training of personnel was witnessed by GL and the personnel qualified to perform the repair work received the Certificates that were registered with GL to ensure only the qualified personnel would be allowed to perform the work.



Figure 3: Composite Sleeve Installation

The documentation required to provide the evidence the work was performed in full compliance with the approved procedure was developed by the contractor in co-operation with GL and PGPB. This documentation included a Quality Assurance (QA) Report for each activity involved in a repair of a given Feature (Feature Field Report, UT Report, Field Fitness-for-purpose Assessment Report, Composite Sleeve Repair Report, Compression Steel Sleeve Repair Report, Wax Tape Repair Report, Duc-line Repair Report). In those cases where the existing repair was found to be present, two additional QA Reports would be included: Existing Steel Sleeve Evaluation Report and Existing Composite Sleeve Evaluation Report.

The key requirement of the Quality Assurance process was that the repair work of a given Feature was accepted as completed only after all related QA Reports were duly approved by the contractor, PGPB and GL. To provide the evidence GL required to issue the Certificate of Mechanical Integrity for each pipeline segment, all approved procedures, Certificates of qualified personnel, and fully approved QA Reports required for each Feature were integrated into the IDMS software.

Table 2 also shows (column of Existing repairs) a total of 64 existing composite sleeve repairs located on Line 2. As noted above, PGPB indicated that there would be some Composite Sleeve repairs on this line. However, their actual number was confirmed only during the field work when 107 Required Repair sites were located with the specified accuracy, using the GPS method. The accurate location of each corrosion Feature provided a reliable basis for determining whether each existing

composite sleeve repair was in the right location. Once this was confirmed, the acceptability of each sleeve repair installation was determined based on the requirements of the Field Evaluation Procedure. In the end, all existing composite sleeve repairs proved to be acceptable. There were only two cases where the existing repair sites needed to be extended by installing additional composite sleeves. Similarly, using the procedure developed and approved for this purpose, all fifty nine (59) existing steel sleeve repairs on Line 9 were evaluated and determined to be acceptable.

The field evaluations of the existing repairs generated the evidence and documentation that was required by the Certifying Company for accepting these installations as permanent reinforcing repairs. The results of this work prevented wasting resources and time on “repairing the past repairs”, and significantly contributed to timely and cost-effective completion of the Required Rehabilitation Program.

TABLE 2: SUMMARY OF THE INITIAL DAMAGE ASSESSMENT AND REPAIRS ACTUALLY EXECUTED BASED ON FIELD UT MEASUREMENTS									
LINE	INITIAL DAMAGE ASSESSMENT OF 2.5 YEAR OLD INSPECTION DATA			No. OF EXISTING REINFORCING REPAIRS		REPAIRS ACTUALLY EXECUTED BASED ON ASSESSMENT OF FIELD UT MEASUREMENTS			NOTE
	No. of Required reinforcing Repair sites	No. of Required Verifications	TOTAL to be Inspected and Assessed	CS	Welded SS	CS	Compression SS	Re-Coating Only	
1 (24")	22	0	22	7	1	3	3	8	
2 (24")	107	6	113	64	3	9	3	32	2-No Permit
3 (24")	54	2	56	6	0	4	10	36	
4 (24")	3	49	52	0	0	0	2	50	
5 (24")	26	0	26	0	0	6	1	19	
6 (24")	14	14	28	0	1	0	6	21	
7 (14")	3	0	3	0	0	0	2	1	
8 (14")	3	1	4	1	1	0	1	3	
9 (14")	21	57	78	5	59	0	2	12	
10 (14")	1	0	1	0	0	0	1	0	
TOTAL:	254	129	383	83	65	22	31	182	

Table 2: Summary of the Initial Damage Assessment

As Table 2 indicates, out of the total of 254 Features identified as Required Repairs by the Initial Damage Assessment Report, a full 148 Features had acceptable existing repair in the right location (65 welded steel sleeves and 83 composite sleeves).

From the remaining 106 “bare” Required Repair Features (254 –148 =106), only fifty-three (53) actually required reinforcing repair in order to meet the hydrostatic test acceptance criterion: Failure pressure > 1.39 MAOP. The reinforcing repairs actually performed included twenty-two (22) composite sleeves (Figure 2) and thirty-one (31) compression steel sleeves (Figure 3).

These results demonstrate that the objective of re-establishing the integrity of this system at the MAOP of 7,355 kPa was achieved with a high degree of confidence confirmed by adequate redundancy of the completed Rehabilitation Program. The number of inspected and assessed “bare” Required Repair Features (106) was 50% higher than the number of the reinforcing repairs actually required to meet the specified hydrostatic test acceptance criterion.

Intelligent Data Management System (IDMS).

It is our experience that reliability of documentation pertaining to executed repair work presents a challenge that is often difficult to meet under the conditions of everyday operation. Without actually dwelling on it, the work described here makes this point clear. Before starting this Project this pipeline system had a good record of safe and reliable operation achieved by performing in-line inspections and repairs. However, the past repairs were not documented to the extent that would meet the requirements of the Certifying Company. The absence of the reliable repair documentation also increased uncertainty about the integrity of the system.



Figure 4: Screen Capture of the IDMS software

The use of the geo-positioning technology removed this uncertainty. Moreover, the established new co-ordinates have provided the added benefit of having in place a backbone for managing the pipeline integrity data.

The Intelligent Data Management System (IDMS) software, developed and implemented as part of this Project, organized all documentation produced during the Rehabilitation Program in a way that is user-friendly and, at the same time, meets the requirements of the

Certification process. As example, a high-level view screen is shown in Figure 4 to indicate how the IDMS is structured. The user starts with a geographical view of a particular pipeline segment that provides an overview of the line’s geographical location and also indicates all points where integrity concerns have been identified and repairs need to be, or have been executed.

The next levels of detail provide all required documentation for each Feature. This includes applicable procedures and visual evidence, together with the approved QA Reports produced in the field (UT, Fitness-for-purpose, Compression steel sleeve, Composite sleeve and Coating repairs, as well Existing repair evaluation reports, if applicable). Moreover, any future repairs can be documented in the same comprehensive manner to meet the specified quality level.

The implementation of the IDMS software rectified the deficiency of not having the correlation between past repairs and inspection data reliably documented. With the IDMS in place, all required documentation is now stored in one logical place: in the location of each specified Feature, indicated in the geographical view of the entire pipeline segment. So completed, the IDMS also provides a solid basis for cost-effective integrity maintenance of the entire system in the future.

CONCLUSIONS.

Measuring the results delivered in the Project against the objectives specified at its onset allows to draw the following conclusions:

1.The executed Rehabilitation Program, involving a total of 383 repair sites, re-established the integrity of the Cactus–Guadalajara LPG system at the targeted MAOP of 7,355 kPa. This was performed with a high degree of confidence, confirmed by a 50% redundancy in meeting the specified acceptance criterion (1.39 MAOP).

2.In order to meet the requirements of full Certification, extra work to provide missing data on pipe material toughness needs to be completed together with two repairs where the access has been denied.

3.GEOPIG™ tool runs produced a new and accurate three-dimensional GPS-based reference system for all 10 specified pipeline segments. All features, identified by the original in-line inspection chainage number, now have a new set of GPS co-ordinates that can be used to locate the feature in the field with the confirmed acceptable accuracy.

4.Procedures developed and implemented for the field evaluation of the existing composite and welded steel sleeve repairs produced the result that

avoided “repairing the past repairs” and contributed to timely and cost-effective completion of the Required Rehabilitation Program.

5. The accuracy actually achieved in cross-referencing the new geographical co-ordinates to the last in-line inspection data, was the single most important factor responsible for timely completion of the required Rehabilitation work.

6. The established GPS-based reference system also provided a backbone for the Intelligent Data Management System (IDMS) that integrated all documentation required for the Certificates of Mechanical Integrity of all ten (10) pipeline segments.

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