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Interaction of corrosion defects in pipelines – Part 1: Fundamentals

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ABSTRACT

Corrosion defects, also called metal loss due to corrosion, are frequently found in carbon steel pipelines. Corrosion defects may occur singly or in colonies. Usually the failure pressure of a colony of closely spaced corrosion defects is smaller than the failure pressures that the defects would attain if they were isolated. This reduction in the corroded pipe pressure strength is due to the interaction between adjacent defects. The interaction of corrosion defects in pipelines is the subject of two companion papers. In the present paper (the Part 1 paper) a literature review and the fundamentals of interaction of corrosion defects in pipelines are presented. In the subsequent paper (the Part 2 paper) initially the database of corroded pipe tests generated during the MTI JIP is described. Then the failure pressures contained in the MTI JIP database of corroded pipe tests are compared with those predicted by six of the currently available assessment methods. MTI JIP is the acronym for Mixed Type Interaction Joint Industry Project.

1. Introduction

Carbon steel pipelines have been used to transport hydrocarbons since the 1930s [1]. Almost always carbon steel is the best choice for pipeline material because it has low cost and good mechanical properties.

Due to carbon steel susceptibility to corrosion [2], sooner or later a carbon steel pipeline will be corroded. External corrosion typically occurs where, due to a coating defect (holiday or disbondment) or due to the coating degradation, the wet soil enters in contact with the pipe external surface [3]. Internal corrosion occurs due to the presence of water in the transported fluid [4].

Corrosion represents a threat to the pipeline strength because it produces a reduction in the pipe wall thickness. The most common morphology of corrosion defects on pipelines is uneven metal loss over a localized area [3].

Colonies of corrosion defects are frequently found in pipelines. Usually the failure pressure of a colony of closely spaced corrosion defects is smaller than the failure pressures that the defects would attain if they were isolated. This reduction in the corroded pipe pressure strength is due to the interaction between adjacent defects.

The interaction of corrosion defects in pipelines is the subject of two companion papers.

In the present paper (the Part 1 paper) a literature review and the fundamentals of interaction of corrosion defects in pipelines are presented.

In the subsequent paper [5] (the Part 2 paper) initially the database of corroded pipe tests generated during the MTI JIP is described. Then the failure pressures contained in the MTI JIP database of corroded pipe tests are compared with those predicted by six of the currently available assessment methods. MTI JIP is the acronym for Mixed Type Interaction Joint Industry Project.

2. Literature review

The literature on the failure behavior and assessment of pipelines containing interacting corrosion defects is extensive [6–49]. However many of the published documents address more than one topic related to corroded pipelines and usually the topic dealing with interaction of corrosion defects is not the most important one [6–11,14,16–18,20,21,23,26,37,39,41,42,46].

Many research projects were carried over the past 45 years in which the failure behavior and assessment of pipelines containing interacting corrosion defects was addressed. A majority of these projects adopt one of two approaches to the problem. The first approach is the one in which the center of interest is an interaction rule (see subsections 3.5 and 3.6), while the second approach is the one in which the center of interest is a Level-2 assessment method

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(see subsections 3.4 and 3.6).

In order to develop interaction rules or assessment methods and even with the purpose of proving the accuracy of already existing interaction rules or assessment methods, several of those research projects have generated databases which contain only the results of burst tests of corroded pipes, only the results of Finite Element (FE) analyses of corroded pipes only or both type of results.

Brief descriptions of some research projects, which were deemed to be the most relevant among those carried out over the last 45 years, are presented below.

In the late 1960s the Battelle Memorial Institute carried out a research project [6] which, among others subjects, addressed the problem of the interaction of multiple corrosion defects. In this work the failure behavior of single-path colonies (see definition in subsection 3.3) was investigated using full scale burst tests. Full scale burst tests of four machined single corrosion defects were performed: two longitudinal grooves and two pits. Twelve full scale burst tests of single-path colonies (see definition in subsection 3.3) were performed. Three colonies were composed of longitudinally aligned grooves, three colonies were composed of circumferentially spaced grooves that overlap when projected onto the longitudinal plane and six colonies were composed of longitudinally aligned pits. This work has laid the foundations for a majority of the experimental programs into the failure behavior of colonies of corrosion defects that would be performed in the next 45 years.

In the late 1980s the Nova Corporation of Alberta carried out a research project [7b] which, among others subjects, addressed the problem of the interaction of multiple corrosion defects. Full scale burst test of two single defects and six single-path colonies (see definition in subsection 3.3) were performed. Based on these burst test Coulson and Worthingham proposed an interaction rule, hereinafter called CW rule. This interaction rule states that “defects separated by more than the length of the shortest defect in the longitudinal direction are not expected to interact and defects separated by more than the width of the narrowest defect in the circumferential direction are not expected to interact”.

In the early 1990s the University of Waterloo carried out a comprehensive study on the interaction of corrosion pits [11–13,15]. In this work the failure behavior of single-path colonies (see definition in subsection 3.3) composed of pits was investigated using full scale burst tests and Finite Element analyses. The main conclusions of the study were: corrosion pits do not interact in the circumferential direction, the failure pressure of longitudinally aligned corrosion pits that do not touch will only be slightly lower than that of the deepest individual pit within the colony and failure of corrosion pits lying along a spiral will be due to longitudinal cracking through the deepest pit ligament.

In the early 1990s, a cooperative research project [17], named Linepipe Corrosion Group Sponsored Project (LPC GSP), was conducted by British Gas Technology with the sponsorship of eight companies (BP, British Gas, Exxon/Esso, Phillips Petroleum, Saudi AramCo, Shell, Statoil and Total) and two European regulatory authorities (UK HSE and Norwegian Petroleum Directorate). In this work the failure behavior of single defects, complex shaped defects and interacting defects was investigated using full scale burst tests and Finite Element analyses. Among others high quality products this project has developed an interaction rule and the first Level-2 method specific for the assessment of interacting corrosion defects. The guidelines developed during this project have been merged with the guidelines developed during the Reliability of Corroded Pipes Joint Industry Project, carried out by DNV in the 1990s, to generate a document called Unified Guideline BG-DNV, which was published in 1999, as the recommended practice DNV RP-F101 (the DNV RP-F101 1999). Unfortunately the database developed during the LPC GSP, which contains the results of 81 full scale burst tests and the results of 477 Finite Element analyses, was never published in the open literature.

In the early 2000s Advantica carried out a comprehensive study on the interaction of pits and grooves [22,24,25,39] with the sponsorship of PRCI (Pipeline Research Council International). In this work the failure behavior of single-path colonies (see definition in subsection 3.3) was investigated using full scale burst tests and Finite Element (FE) analyses. The size of the corrosion defects (pits and grooves) and the spacing between them were chosen as multiple of the pipe wall thickness (t). Based on the study of colonies composed of pits only the following conclusions were drawn: interaction of small diameter (2 t) axially separated pit-pit combinations is negligible, even when defects are spaced as close as 1 t from each other while interaction of larger diameter (8 t) axially separated pit-pit combinations is more significant. Based on the study of colonies composed of pits and grooves the following conclusions were drawn: interaction of small diameter (2 t) pit and groove defects, separated either axially, circumferentially or a combination of both, is negligible, even when the defects are spaced as close as 1 t from each other; interaction only occurs when larger diameter pits are spaced close to deep groove like defects. Based on the study of colonies composed of grooves only the following conclusions were drawn: interaction of groove-groove defects separated axially can be significant; a reduction in predicted failure pressure of approximately 26% is obtained as the defect spacing reduces from 6 t to 1 t (for 80% deep defects). It was also concluded that interaction of circumferentially spaced defects is negligible.

In the early 2000s, a research project, named IDDC project, was carried out by PETROBRAS together with the Pontifical Catholic University of Rio de Janeiro (PUC-Rio), the Federal University of Rio de Janeiro (COPPE/UFRJ) and the Brazilian National Laboratory for Scientific Computing (LNCC). IDDC is the acronym for Interação de Defeitos em Dutos Corroídos, the title of the project in Portuguese. In this work the failure behavior of interacting corrosion patches was investigated using full scale burst tests and Finite Element (FE) analyses. Part of the results of the IDDC project has already been published [28–31]. One of the characteristics that distinguished the experimental program performed during the IDDC project from other experimental programs previously performed was the inclusion of multiple-path colonies (see definition in subsection 3.3) in the test matrix. Among 12 tubular specimens that were tested one was a defect-free specimen, two contained a single defect, four contained single-path colonies and five contained multiple-path colonies. Another characteristic of this experimental program was that eight among the nine colonies of corrosion patches tested were composed of defects whose individual profiles overlap when projected onto the longitudinal plane. The main conclusion of the IDDC project was that the assessment methods available at that time (early 2000s) are overly conservative when applied in the assessment of colony of corrosion defects whose individual profiles overlap when projected onto the longitudinal plane.

In the late 2000s, a cooperative research project [50–53], named Mixed Type Interaction Joint Industry Project (MTI JIP), was carried out by Pontifical Catholic University of Rio de Janeiro (PUC-Rio) with the sponsorship of six companies (PETROBRAS, Tenaris-Confab, DNV, Shell, Statoil and TransCanada). In this work the failure behavior of interacting corrosion patches was investigated using full scale burst tests. One of the characteristics that distinguished the experimental program performed during the MTI JIP from other experimental programs previously performed was the inclusion of multiple-path colonies (see definition in subsection 3.3) in the test matrix. Among 18 tubular specimens that were tested two contained a single defect, six contained single-path colonies and ten contained multiple-path colonies. Another