

# Use of Experimental Methods to Quantify the Effects of Crack-Like Flaws in Pipelines

by Atul Ganpatye, Ryan Holloman, and Chris Alexander  
ADV Integrity, Inc



## Pipeline Pigging and Integrity Management Conference

Virtual  
February 24-25, 2021



*Organized by*  
Clarion Technical Conferences *and* Great Southern Press

*Proceedings of the 2021 Pipeline Pigging and Integrity Management conference. Copyright ©2021 by Clarion Technical Conferences,  
Great Southern Press and the author(s).*

*All rights reserved. This document may not be reproduced in any form without permission from the copyright owners.*

## Abstract

Traditional code-based approaches for assessing crack-like flaws in pipelines rely on two key aspects: 1) flaw detection and sizing, and 2) an analytical approach for estimating the stress intensity of a flaw. The estimated stress intensity is then used to predict pipe performance in terms of burst pressure (static loading consideration) or cycles to failure (cyclic loading consideration) under a set of loading parameters. In following a traditional approach, several idealizations/assumptions are made regarding flaw shape and orientation, material properties, and applicability of the analytical framework used to estimate pipe performance. The uncertainties in these assumptions can, and often do, result in overestimation or underestimation of pipe performance. This paper outlines an experimental approach to quantify the “effective” stress intensity for crack-like flaws as it correlates to the results from full-scale testing. The proposed full-scale testing approach bridges several levels of assumptions and idealizations to provide a more systemic, direct, and robust method for predicting pipeline performance that better integrate with real-world observations.

## Introduction

The traditional approach for evaluating the effects of crack-like flaws on pipeline performance subject to static loading conditions typically follows four steps that include the following:

1. Detection and sizing of crack-like features using ILI and/or NDE techniques,
2. Calculation of the stress intensity based on the sizing of the features (incorporating the geometry-related parameters),
3. Use of material-specific data such as fracture toughness and yield stress (incorporating material parameters), and
4. Construction of a failure assessment diagram (FAD) using the above information.

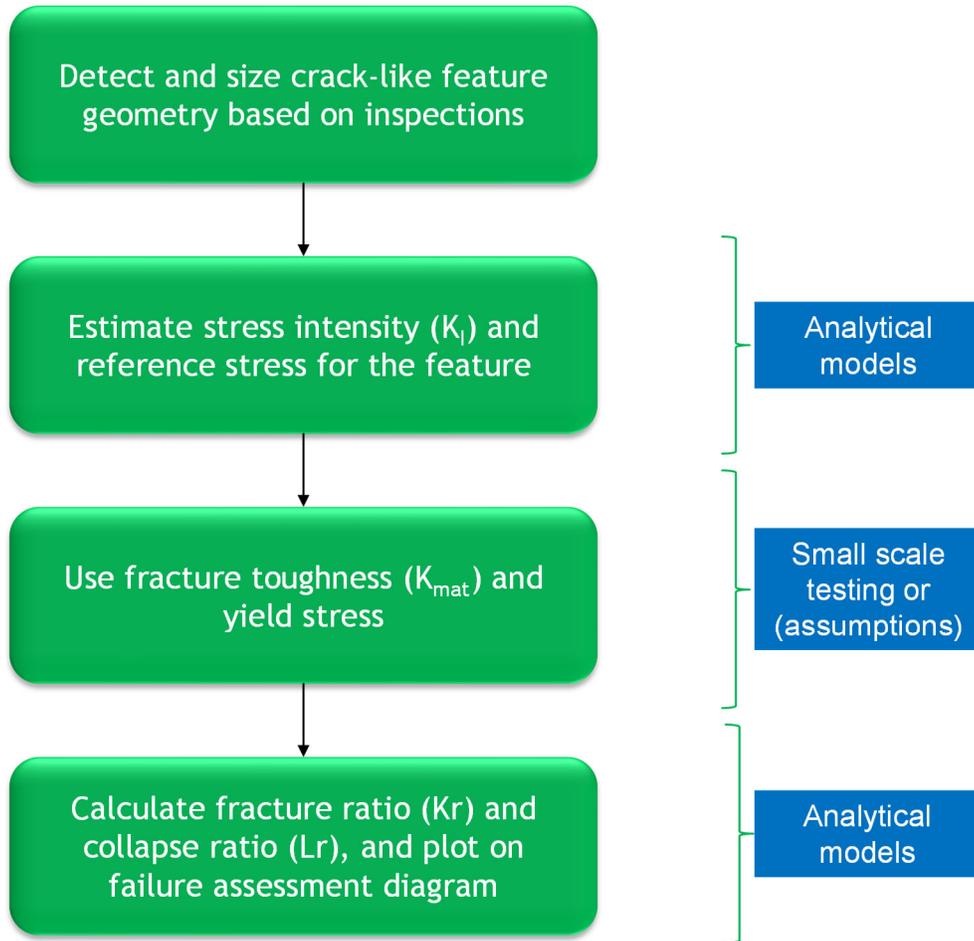
This approach is shown in Figure 1. Of these elements, the calculation of stress intensity due to the feature and the eventual construction of the FAD rely on analytical models that may or may not rely on fully-validated data sets. As with most analytical approaches, assumptions are required in the development of the framework. Such assumptions, while possibly broadly applicable, may not rigorously reflect specific evaluation conditions (e.g., material properties, plasticity, etc.). Moreover, the fracture toughness data used for such calculations is either a result of sub-scale tests performed on relatively small samples cut out from a representative pipe, or at times acquired from published references (e.g., assumption of specified minimum yield stress based on material grade).

Results of several full-scale burst tests with known crack-like features (containing a mix of artificially-introduced and “naturally” existing features), performed at ADV, indicate that significant difference can exist between the predicted burst pressures using the traditional approach outlined above compared to the actual burst pressures observed during full-scale burst tests. The test burst pressure typically exceeds the corresponding predicted pressure. This better-than-expected performance of pipes with crack-like features can be attributed to any (or all) of the four assessment elements shown in Figure 1. Refinement of the individual elements in the traditional approach will require careful multi-parameter studies - although such refinements, without appropriate calibration, cannot be fully validated and will nevertheless be associated with significant uncertainties.

In the proposed, idealized approach, full-scale pipe performance data are used to interpret an “effective” stress intensity for the features of interest and the results are used to construct an adjusted FAD that accommodates the gap in predicted burst pressures (using traditional approach) and the

observed burst pressures from full-scale tests. The benefits for the pipeline industry include the following:

- Reduced uncertainty in predicting the performance of pipelines having crack-like features.
- Significant improvement in managing dig programs on account of relying on tangible, observed, experimental data.
- Greater utilization of material performance capabilities and integration of available inspection data.



**Figure 1: Flowchart Showing Traditional Crack Assessment Method**

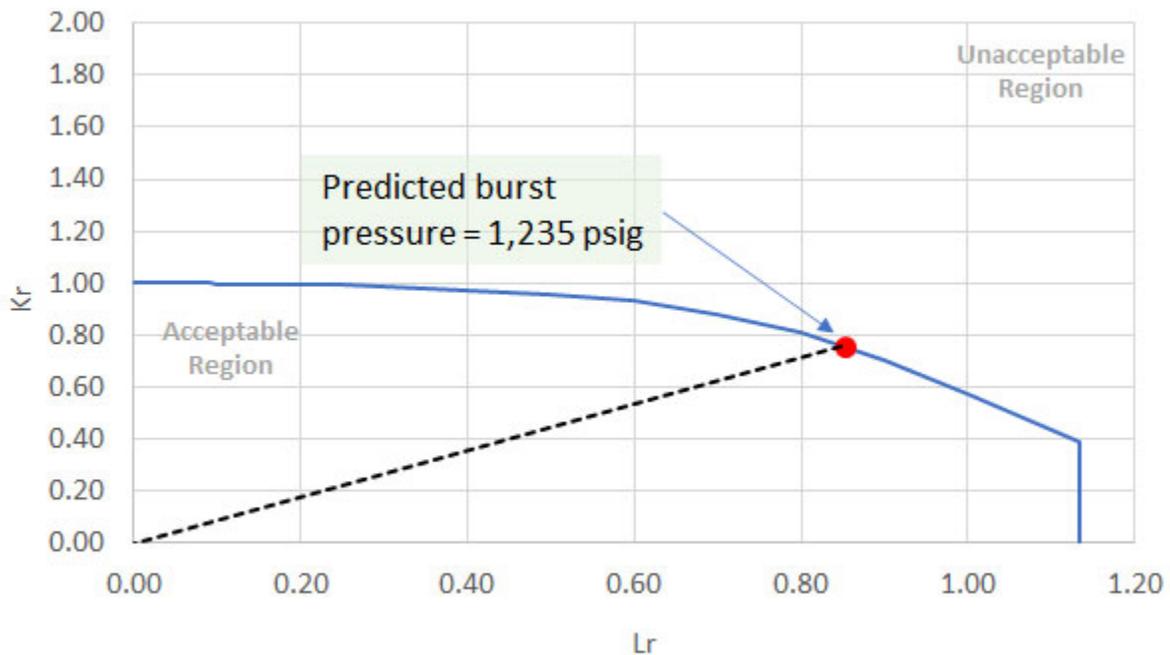
## Materials and Methods

To convey the concept of the “effective” stress intensity, a Level II FAD was generated for an example pipe using procedures outlined in API 579/ASME FFS-1, Fitness for Service, Part 9 [1]. The pipe properties used are listed below:

- Pipe OD: 18-inch
- Wall thickness: 0.275-inch
- Yield stress: 52,000 psi
- Tensile strength: 66,000 psi
- Fracture toughness: 40,000 psi√inch

The example OD-originating flaw (crack-like feature) for demonstrating the proposed approach was assumed to be 3 inches long, along the axis of the pipe, and 0.0825 inch deep (30% of the wall thickness). The resulting FAD is shown in Figure 2; with the fracture ratio ( $K_r$ ) on the y-axis, and the load ratio ( $L_r$ ) on the x-axis. The failure curve of the assessment diagram represents material resistance to fracture-dominated or tearing (plastic collapse) dominated failure. For the current pipe and feature combination, the burst pressure was calculated to be 1,235 psig. This is shown as an assessment point on the failure curve in Figure 2. In this case, the stress intensity ( $K_I$ ) for the feature was calculated to be = 30,366 psi√inch; and  $K_r$  corresponding to this predicted burst pressure is calculated as:

$$K_r = \frac{K_I}{K_{mat}} = 0.76 \dots \text{Equation (1)}$$



**Figure 2: Initial FAD constructed using traditional analytical approach showing predicted burst pressure**

Commensurate with the continuing observations from full-scale tests, a hypothetical “observed” burst pressure for this pipe is assigned to be 300 psig higher than the predicted burst pressure (1,235 psig + 300 psig = 1,535 psig). For this pressure, the assessment point on the FAD will be as shown in Figure 3. This assessment point corresponds to a fracture ratio of 0.94 and a load ratio of 1.06. However, for this assessment point to be interpreted as the failure point (corresponding to the observed burst pressure), it should be interpreted as a point on the failure curve of the FAD

achieved by reducing the fracture ratio (while keeping the load ratio constant = 1.06). The resulting fracture ratio ( $K_{r\_new}$ ) was calculated to be 0.49. This is illustrated in Figure 4.

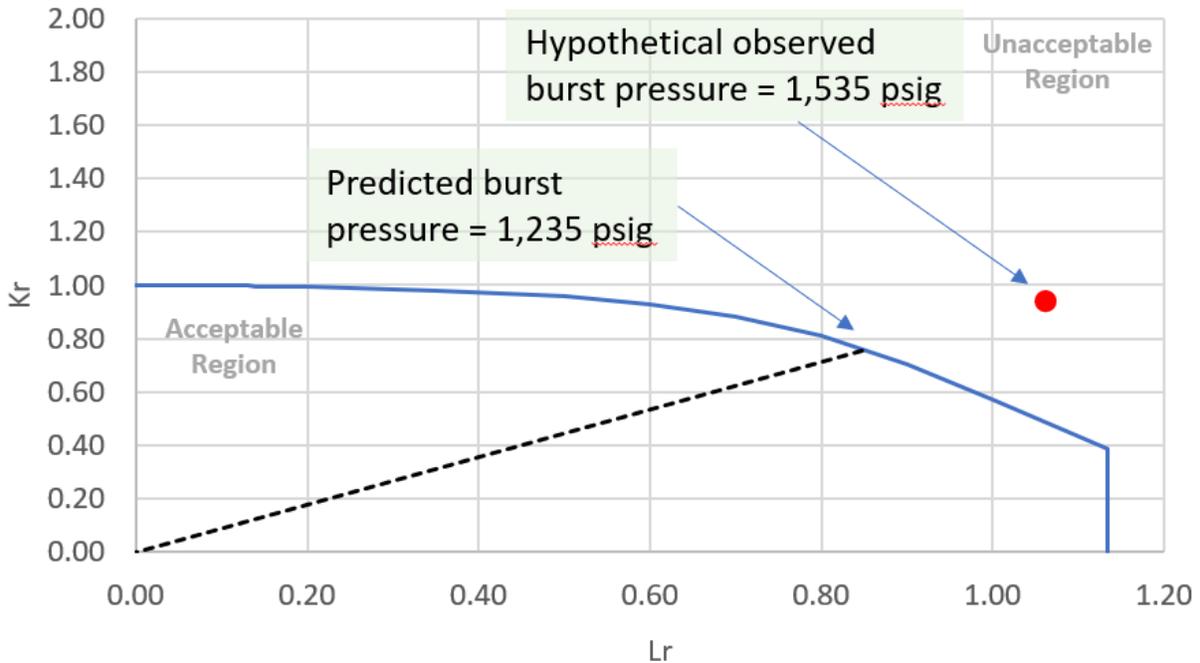
This new (lower) fracture ratio can be interpreted as a result of either decreased stress intensity (“effective” stress intensity) associated with the feature, or higher fracture toughness associated with the material. In reality, the reduction is likely a combination of both factors to some extent; however, with the current approach, it is not necessary to specify which factor needs adjustment. For ease of communication and interpretation, let us assume that the fracture toughness ( $K_{mat}$ ) is constant; then, the “effective” stress intensity can be expressed as:

$$K_{r\_new} = \frac{K_{I\_effective}}{K_{mat}} = 0.49 \dots \text{Equation (2)}$$

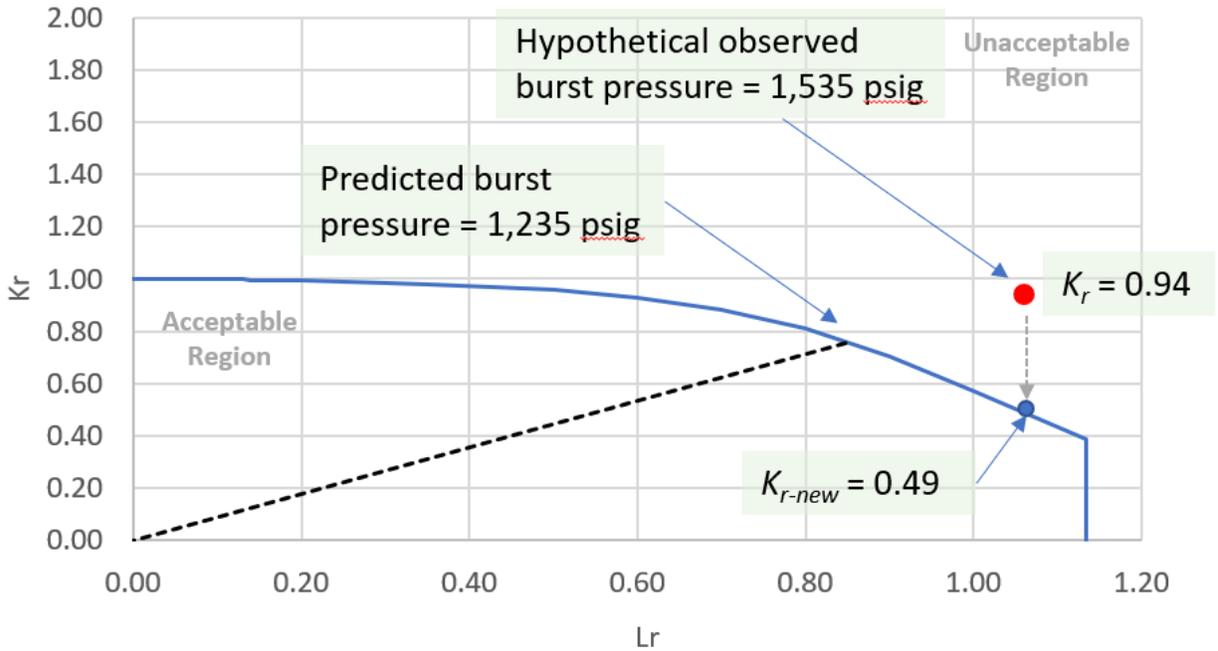
Using Equation (1), this expression can be rearranged as:

$$K_{I\_effective} = K_I * \left(\frac{0.49}{0.76}\right) = K_I * 0.52 \dots \text{Equation (3)}$$

Equation (2) indicates that the effective stress intensity in the present case is almost half of the initially calculated stress intensity. In terms of fracture toughness, this result can also be interpreted as the “effective” fracture toughness to be almost twice as high as initially assumed.

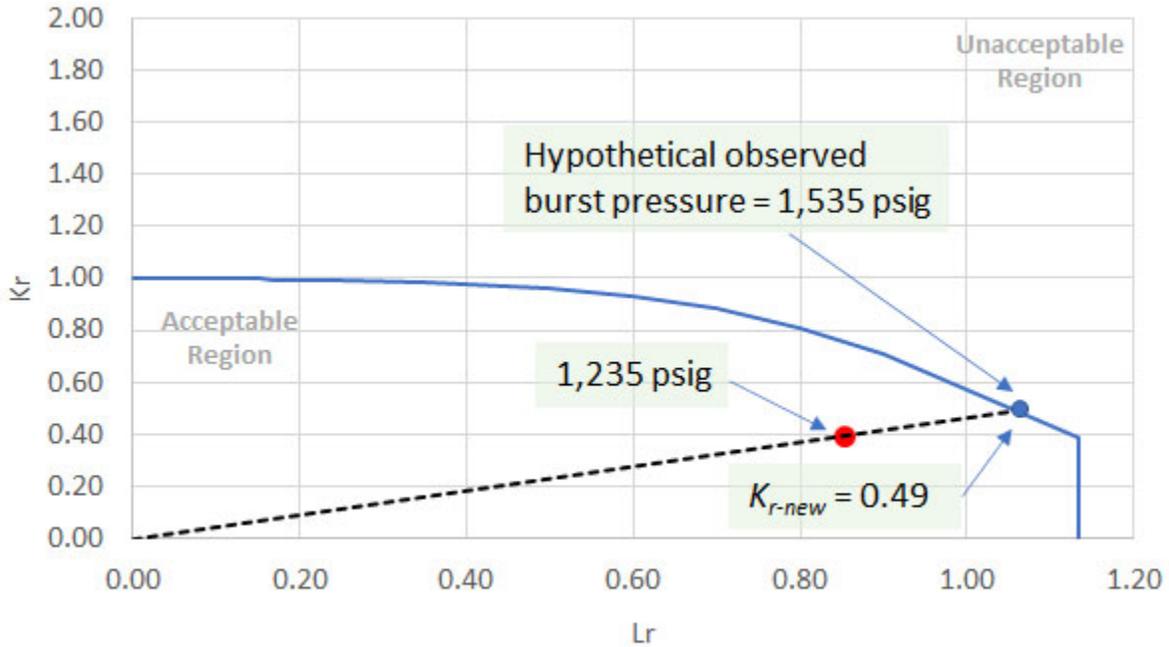


**Figure 3: Assessment point corresponding to the observed burst pressure**



**Figure 4: Interpretation of fracture ratio for observed burst pressure on FAD failure curve**

Using the “effective” stress intensity calculated according to Equation (3), a new, adjusted FAD is constructed. This FAD is shown in Figure 5. This adjusted FAD better represents the observed pipe performance compared to the originally constructed FAD that under-predicted burst pressure at 1,235 psig (refer to Figure 2). The assessment point for 1,235 psig pressure now falls within the FAD failure curve and has a factor of safety of approximately 1.25 – making the FAD results commensurate with the experimental observations.



**Figure 5: Adjusted FAD constructed using “effective” stress intensity**

Only one data point has been used in the present example for demonstration purposes. However, using additional test data points from a comprehensive full-scale testing program, this approach can be refined to be statistically robust, leading to better confidence in the predicted burst pressures. Depending on the intent of the calculations, mean, maximum, and minimum “effective” stress intensities can be calculated using results from multiple burst tests. To ensure that the non-linearities in the full-scale responses are adequately accommodated, multiple notch lengths and depths should be tested for generating the “effective” stress intensity data.

What has been presented for the static pressure condition is ideally-suited for gas pipeline operators. It is possible to employ a similar approach for liquid pipelines that will involve cyclic pressure fatigue considerations. Additionally, it is possible to construct a performance-based safety factor as a function of the number of test samples – reflecting higher confidence in the performance prediction with greater number of samples.

## CONCLUSIONS

A full-scale, testing-based approach is presented in this paper. This approach has the potential to provide a more robust predictive capability for estimating burst pressures of pipes containing crack-like flaws. Using actual test data allows a systemic incorporation of almost every single detail in the pipe performance “system” – in this context, the “system” is the collection of all parameters/factors that directly or indirectly influence the pipe performance, such as: pipe properties, feature morphology, stress intensity due to the presence of the feature, pipe ovality, presence/absence of welds, and many more. This kind of systemic evaluation allows the circumvention of the need to isolate and accurately identify individual factors affecting the pipe performance. Moreover, the results are more tangible and more readily implementable compared to the traditional analytical approach.

Along the lines of the approach discussed for burst pressure prediction, a similar approach can be designed for fatigue life/failure prediction in the presence of crack-like flaws. In the interest of brevity, fatigue issues will be addressed in a future publication.

Improved confidence in the predicted pipe performance using full-scale test data, has the potential to meaningfully impact integrity management approaches by reducing the number of digs that may be flagged when using the traditional approach.

## REFERENCES

1. API 579/ASME FFS-1, Fitness for Service, Part 9 Assessment of Crack-Like Flaws, June 2016. ASME-PCC-2-2018, Repair of Pressure Equipment and Piping, American Society of Mechanical Engineers, New York, NY, 2018