Engineering Critical Analysis

Paresh Haribhakti
MD and Principal Metallurgist

Engineering Critical Analysis (ECA): *what is it?*

Performing analysis based on the principles of fitness-for-purpose is alternatively termed as engineering critical assessment, or ECA

- **Engineering Critical Analysis (ECA)** is a procedure that uses **Fracture Mechanics** principles to evaluate flaws to determine their tolerance (size).
- **Flaw tolerances** in pressure equipment are analysed to determine whether they can **continue in service** or **require repairs** or **replacement.**
- **Fracture mechanics** is the study on behaviour of materials under stress for Flaw propagation rate based on **Fracture toughness.**
- **CTOD (crack tip opening displacement)** test can be used for the assessment of **fracture toughness**

Engineering Critical Analysis (ECA) - Codes

Some of the recognized international codes / standards

- **API579 ASME-FFS 1:** is a standard / code on "Fitness for Service" that establishes the flaw acceptance criteria for different types of damages in pressure system
- **BS 7910:** Guide to methods for assessing the acceptability of flaws in metallic structures
- **ASME Sec VIII:** Rules for design and acceptable flaws for new fabrications, Pressure vessels
- **API 1104 Annex A:** Alternative Acceptance Standards for Girth Welds, Welding of Pipelines and Related Facilities

Importance of Engineering Critical Analysis

- **Safety**: Pipelines functional in steam and chemical services may lead to leaks, explosions, or fires, posing significant risks to public safety and the environment. Ensuring pipeline integrity helps prevent such catastrophic events.
- **Reliability**: Continuous supply of energy resources and raw materials to various industries is essential for reliable operations of plants and industries.
- **Economic Impact**: Pipeline failures can disrupt supply chains, leading to significant economic losses.
- **Regulatory Compliance**: Pipelines require the compliance with government regulations to avoid legal penalties and maintain a good reputation.
- **Environmental Protection**: Pipeline failures can result in spills that cause severe environmental damage and cleanup costs.

Applications of Engineering Critical Analysis

- **Design stage:** Standards like ASME Sec VIII provide essential guidelines for the design, construction, and inspection of pressure vessels, ECA offers a more in-depth and tailored approach, particularly when dealing with complex geometries, unique loading conditions, or materials with specific properties through FEA and Fracture Mechanics.
- **Fabrication stage:** ECA can be used to assess the significance of defects that are found during the fabrication process and their acceptance beforehand.
- **Operation / in-service stage:** ECA can be used to evaluate flaws that are discovered during in-service inspections and to determine whether they can safely remain in service or if repairs or replacements are necessary.

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ECA Applicability for Piping Girth Welds:

Acceptance standards (Section IX) are based on empirical criteria for workmanship and place primary importance on imperfection length however they are very stringent. The use of fracture mechanics analysis and fitness-for-purpose criteria for determining acceptance criteria are alternative methods for evaluation of both imperfection height and imperfection length.

- Earlier, CTOD values of 0.13 or 0.25 mm were acceptable regardless of fracture toughness.
- New welding techniques, mechanized welding have resulted in higher fracture toughness and CTOD 0.13mm or lower have also shown to perform adequately.
- **ECA provides tolerable defect / flaw size before the first inspection of welding.**

TCR's Confidence in ECA:

The **knowledge and expertise** TCR gained through extensive FFS work using **API579/ASME FFS-1** translates directly to the specific requirements of API 1104 Annex A. **We are confident in our ability to**:

- Identify and characterize weld imperfections
- Conduct CTOD (crack tip opening displacement) and other physical tests
- Apply fracture mechanics principles
- Perform engineering calculations to assess flaw severity
- Recommend the acceptance strategies as per API 1104 Annexure A, Method 1 OR Method 2

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Steps for Piping Girth Weld ECA:

- Prepare coupon as per WPS (welding procedure specification)
- Draw specimens for finding actual fracture toughness through CTOD
- Apply obtained values of CTOD to determine tolerable defect (flaw) size

Steps for Piping Girth Weld ECA:

1. **Component Identification and data study**: Provide definition of component or structure under analysis with description, identification numbers, drawing numbers, detailed engineering drawing / piping layout, MDMT, soil loading, hydro test requirement etc.

2. **Define loadings** (internal pressure/temperature/ sustained and dynamic mechanical forces /cyclic/soil), operational variations, environmental factors etc.

3. **Material properties:** Compilation of material of construction properties such as YS, UTS, Charpy V-notch strength, hardness etc.

4. **NDT inspection** (coupon sent to TCR): Visual inspection, DP, UT/ radiography for flaw detection. The specimen (e.g. impact, CTOD, tensile) to be selected from flaw-less area. It is assumed that the production weld shall follow the same WPS and PQR as per the coupon.

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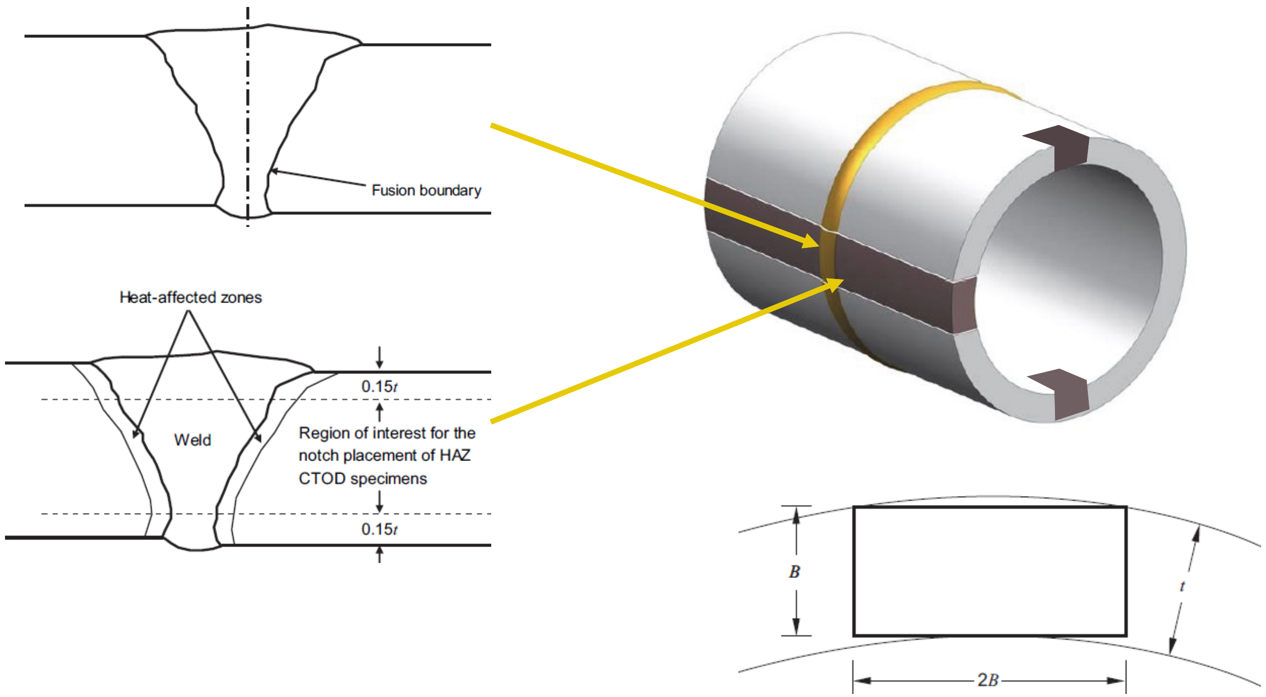
Steps for Piping Girth Weld ECA:

5. **Destructive test on coupons**: CTOD (12, 6, 3/9 o'clock, weld/HAZ), impact test, tensile test as per API 1104 Annexure A requirement. *[Total 6 samples]*



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API 1104, Annex B, Method 2, (Failure Assessment Diagram)

Step

6. **Use CTOD results** for calculations as per API 1104 Annex A. Perform fracture mechanic analysis as per API 1104 methodology.

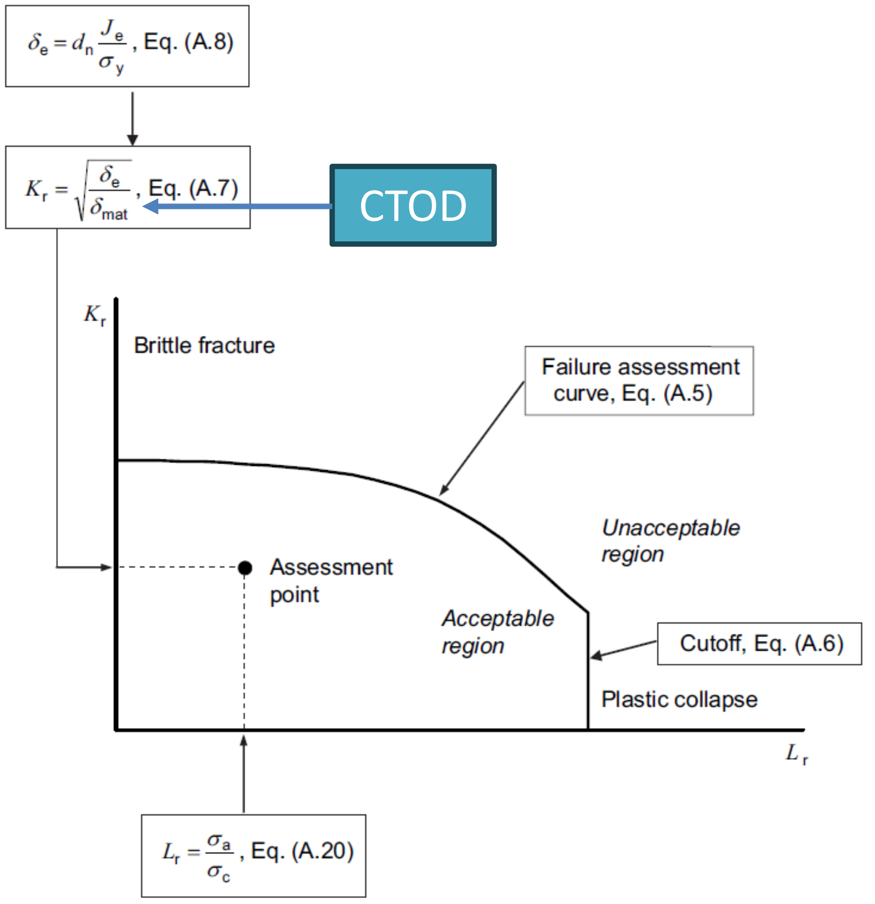

Figure A.10—Schematic Overview of the Option 2 Procedure

Steps for Piping Girth Weld ECA:

7. **Perform FEA** to determine axial stresses in the pipeline considering actual line layout e.g. sub-surface (buried) line with soil load, internal pressure / hydro test pressure / ambient temperature.

8. **Prepare Flaw Table** for acceptable flaw size as per API 1104 (e.g. 42" diameter, 36mm thick girth weld).

$\frac{Allowed\ height}{Thickness}$	Allowed height	$\frac{Allowed\ circumference}{Circumference}$	Allowed length
%	mm	%	mm
0.5	18.0	0.025	26.7
0.2	7.2	0.063	67.3
0.1	3.6	0.128	134.6

ILLUSTRATIVE NUMBERS (NOT TRUE)

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Credentials

Experts' Profiles:

Paresh Haribhakti, (M.D.)

Paresh Haribhakti leads TCR Advanced Engineering Services (a TCR Engineering Services partner company) as a pioneer in in-situ metallography and Engineering Critical Analysis (ECA). With a proven record of solving over 8,000 industrial problems, he is a recognized expert in failure investigations across refinery, petrochemical, power, and chemical industries.

Paresh developed AiOM™, a software tool for Asset Integrity Management, incorporating lessons from extensive failure case studies. His ECA expertise drives predictive maintenance strategies, enhancing plant life and preventing industrial disasters.

Ketan Upadhyay (G.M.)

Mr. Ketan Upadhyaya leads reliability engineering, undertaking projects on remaining life assessment, fitness for service and failure investigations. He is a metallurgical engineer and has more than 34 years of experience in the fertilizers and petrochemical field with non-destructive examinations by UT, PT, MT, Cobalt60 radiography, acoustic emission testing, metallography and vibration analysis of rotating machinery. He has successfully developed and implemented the projects of quantitative microstructural examinations and automated ultrasonic reformer tube inspection system.

Experts’ Profiles:

Gopul Patel, RBI Expert

Mr. Gopul Patel, a postgraduate from Sardar Patel University and an API-certified professional in Risk-Based Inspection (RBI) methodology (API 580), serves as an ECA expert at TCR Advanced. His role encompasses establishing and implementing robust management systems, ensuring their effectiveness, and optimizing engineering practices. He has played a key role in the development of the Asset Integrity Optimization Management (AiOM) system, focusing on modules related to risk analysis (API 581), refurbishment strategies, Integrity Operating Window (IOW) management, and seamless integration with intelligent plant interfaces for comprehensive asset optimization

Mr. Nikhil Sabhaya – NDT Expert

Mr. Nikhil Sabhaya is an experienced professional with a Master’s degree in Industrial Metallurgy and over 10 years in Engineering Critical Analysis (ECA). His expertise includes Non-Destructive Testing (NDT), Remaining Life Assessment (RLA), and structural integrity evaluation, particularly in boiler and reformer tube inspections. Nikhil is certified as ASNT NDT Level-III (PT & MT), API 510 - Pressure Vessel Inspector, and CSWIP 3.1 - Welding Inspector. He has led multiple projects focused on tank condition assessments and high-pressure vessel inspections, adhering to industry standards such as AWS, API, and ASME. His research on reformer tubes in Hydrogen Generation Units emphasizes his analytical capabilities and commitment to enhancing safety protocols.

Experts' Profiles:

Hemant Pradhan, Design Expert

Mr. Hemant Pradhan is a Mechanical Engineer with about 38 years of experience in design, detail engineering services, projects, inspection, mechanical construction, procurement, estimation. Major experience field has been design, detailed engineering, troubleshooting of fertilizer plants like ammonia, urea, DAP, ASP, AS, phosphoric acid, sulphuric acid etc; petrochemical plants like Caprolactam, Melamine, Nylon-6, and utility/co-generation/ boiler, water treatment plants. Participation in design with process licensors/ detail engineering firms like M/s Enco, at Chur, Switzerland; M/s INCRO SA, at Madrid, Spain; Tunisian Joint Venture, at Tunis, Tunisia; M/s Schmidt & Clemens, at Lindlar, Germany M/s Davy Power gas, India; M/s Uhde India; M/s Linde, India.

Mr. MY Joshi – Advisor, Reliability Engineering

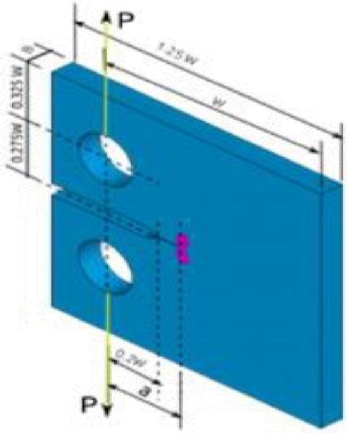
Mr. MY Joshi holds bachelor's Degrees in Metallurgy & he has professional experience of 38+ years. He has worked in Gujarat Narmada Valley Fertilizers Co. Ltd. (GNFC), Bharuch, He has hands on experience for handling & inspecting the below plants Ammonia, Linde, GE (Texaco), Haldor Topsoe (4,45,500 MTPA), Urea, Snamprogetti, Italy (6,36,000 MTPA), ANP, BASF, Germany (1,42,5000 MTPA), Formic Acid, Kemira OY, Finland (5000 MTPA, Country's largest capacity), Acetic Acid, British Petroleum, UK (1,00,000 MTPA Country's largest capacity), Methanol, ICI, UK (1.20.000 MTPA, Country's largest capacity), Weak Nitric Acid, UHDE, Germany (2,47,500 MTPA)-2 plants, Concentrated Nitric Acid, Plinke, Germany (66,000 MTPA)-3 plants, TDI 1 & TDI 2, Chematur, By-products - Ammonia, ANP melt, Nitrogen etc. and BHEL & Thermax make boilers..

Material Test Facilities:

Material Test Facilities:

Fatigue & Creep Testing Facilities

- Tensile Testing
- Compression Testing
- Fatigue Testing
- Creep testing
- Load Unload Testing
- 3 Point Bending Testing
- High Temperature Tensile, LCF, HCF Testing [up to 1000 Degree C]
- Spring Fatigue Testing



Material Test Facilities [CTOD]:

TEST REPORT

ULR - TC690523000024234F

Page 1 of 2
Date: 21-08-2023

T.C. No.	:	CM7829
Issued To.	:	M/s TCR ADVANCED ENGG. PVT. LTD. 250-252/9, GIDC Estate, Makarpura, Naren Hardware Lane, Vadodara-390010. (Gujarat) INDIA. Contact No.:8000090242,Email Id:testing@tcradvanced.com

Party Ref.	: SR No. 3587	Condition of Sample	:	Test Piece
Ref. Date	: 04-08-2023	Sample Received on	:	07-08-2023
Description of Sample	: Test Piece			
Specification	: BS EN 10088-3 Steel Designation X2CrNiMoN22-5-3	Testing Started on	:	18-08-2023
Sample Drawn By	: Party	Date of Completion	:	20-08-2023
Test Location	: TCR Navi Mumbai	Enclosure	:	Annex: A & B
Test	: CTOD			

Lab No.	V25262
Challan No.	3587
Size	50 x 160 x 16mm Thk

I. Discipline : Mechanical Testing
1. Group : Mechanical Properties of Metals

CTOD TEST — Test Method : ASTM E1820 - 20b
Equipment : 50KN UTM ; Calibration Due Dt:01-12-2023 — Test performed on : 20-08-2023

Specimen ID: 01

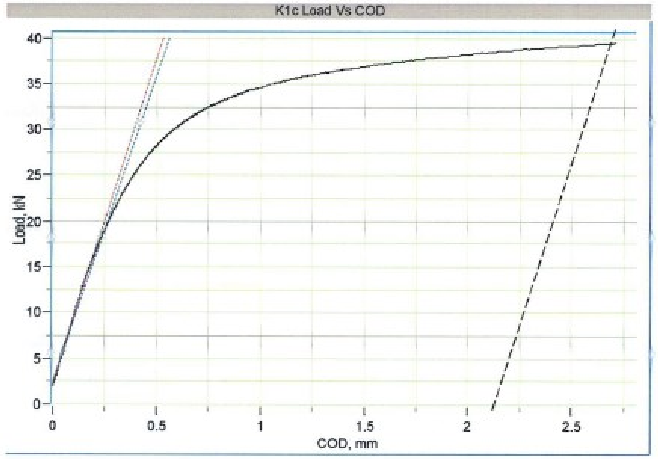
1. MECHANICAL PROPERTIES (As specified by customer)		
Ultimate tensile strength (σTS)	:	728.85 Mpa
Yield strength (σYS)	:	501.98 Mpa
Young's modulus of elasticity (E)	:	210 Gpa
Poisson's ratio (ν)	:	0.30

2. SPECIMEN DIMENSIONS		
Geometry	:	CT (LLD)
Crack plane orientation	:	LC
Specimen thickness (B)	:	16.45 mm
Specimen width (W)	:	32.90 mm
Nominal crack length (a)	:	14.14 mm
Knife edge thickness (z)	:	0 mm

PRABHAKAR SINGH
(HEAD - Corrosion)

LOAD V/S COD GRAPH

TC. No: CM7829 — Date: 21-08-2023



CTOD value (δ)	0.554	mm
Maximum force (Pmax)	39.474	kN
Plastic Component (Vp)	2.1255	mm

Checked by

Accreditations:

National Accreditation Board for Testing and Calibration Laboratories

NABL

CERTIFICATE OF ACCREDITATION

TCR ENGINEERING SERVICES PVT. LTD.

has been assessed and accredited in accordance with the standard

ISO/IEC 17025:2017

"General Requirements for the Competence of Testing & Calibration Laboratories"

for its facilities at

VKB HOUSE, PLOT NO. EL 182, MIDC TTC, INDUSTRIAL AREA, ELECTRONIC ZONE, MAHAPE, NAVI MUMBAI, MAHARASHTRA, INDIA

in the field of

TESTING

Certificate Number: TC-6905

Issue Date: 03/03/2022 Valid Until: 02/03/2024

This certificate remains valid for the Scope of Accreditation as specified in the annexure subject to continued satisfactory compliance to the above standard & the relevant requirements of NABL.
(To see the scope of accreditation of this laboratory, you may also visit NABL website www.nabl-india.org)

Name of Legal Identity : TCR ENGINEERING SERVICES PVT. LTD.

Signed for and on behalf of NABL

N. Venkateswaran
Chief Executive Officer

API INDIVIDUAL CERTIFICATION PROGRAMS

verifies that

Gopul Patel

HAS MET THE ESTABLISHED AND PUBLISHED REQUIREMENTS FOR API CERTIFICATION AS AN

API 580 RISK BASED INSPECTION

IN ACCORDANCE WITH THE KNOWLEDGE DEFINED IN THE API Recommended Practice 580

CERTIFICATION NUMBER 96800

ORIGINAL CERTIFICATION DATE October 31, 2020
CURRENT CERTIFICATION DATE October 31, 2023
EXPIRATION DATE October 31, 2026

Director, Individual Certification Programs

API ICP

TCR ADVANCED

Case study

ECA / FFS TCR Case study:

REPORT ON FITNESS FOR SERVICE ASSESSMENT OF PSA VESSELS A-0401 A-L

REPORT NO: TXXXX

CLIENT: XXXXXX

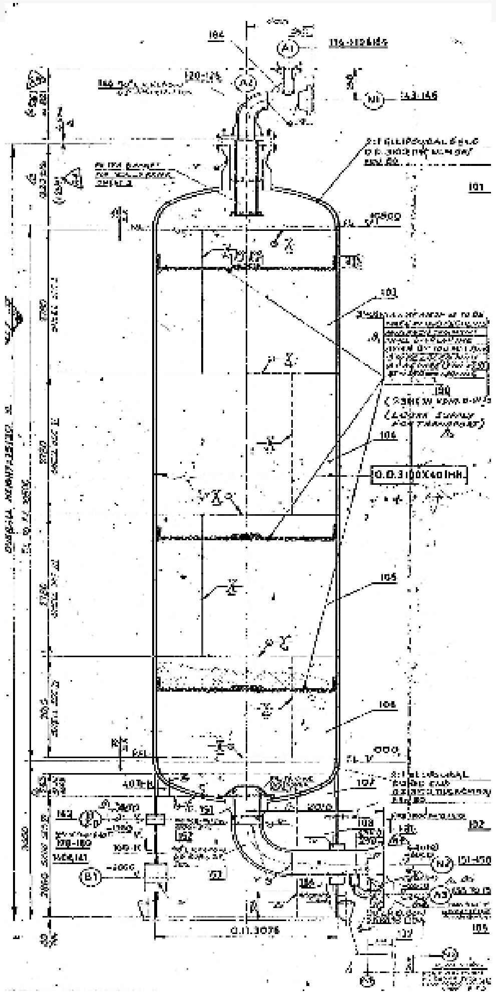
ECA / FFS TCR Case study:

PSA vessels offered for Fitness for Service (FFS) assessment as per API 579/ASME FFS-1.

NDT Inspection

Inspection done in TAR April 19 2021 by Visual examination, thickness measurement, MPI, PAUT, ToFD and metallography with hardness measurements.

Parameter	Unit	Value
Design Code	--	ASME Sec. VIII Div. 1 - 1992 Incl. A-93 ASME Sec. VIII Div. 2 For Fatigue Analysis
Design pressure	kg/cm^2g	28.56
Design temperature	°C	5 (Min.) / 75 (Max.)
Operating pressure	kg/cm^2g	0.306 (Min.) / 24.99 (Max.)
Operating temperature	°C	45
Corrosion allowance	mm	3.0
Service fluid	--	Reformed process gas
Hydrostatic test pressure	kg/cm^2g	42.84 Vertical at top/ 44.4 Horizontal at top
Joint Efficiency	--	1.0
PWHT	--	Yes (Complete vessel)
Radiography	--	Full
Insulation	mm	Nil
Fire proofing	--	Yes (at skirt area)
Min. Design Metal Temperature	°C	0
Number of pressure cycles	--	43500/ year
Fatigue design life	Years	10

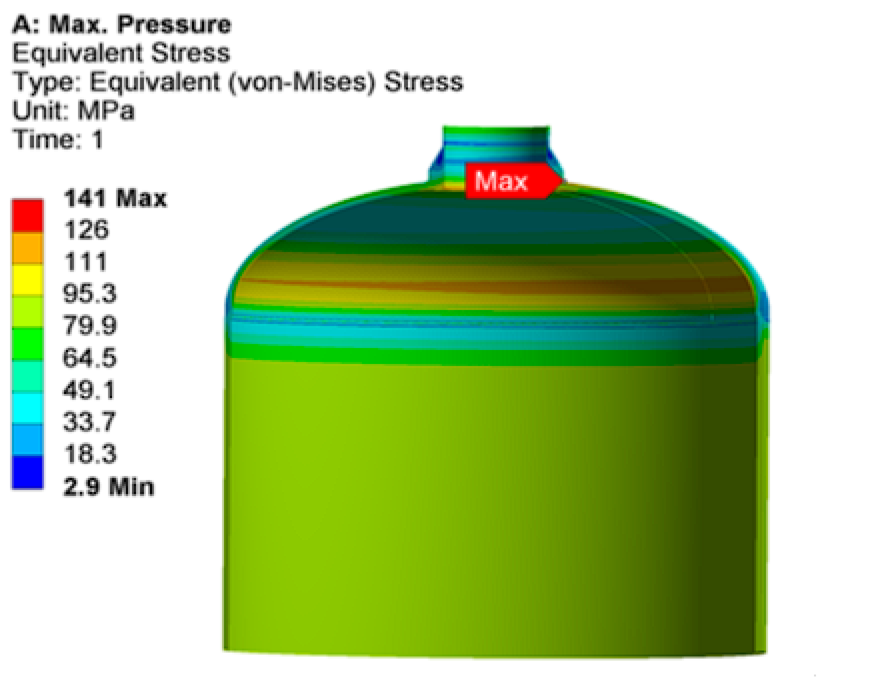
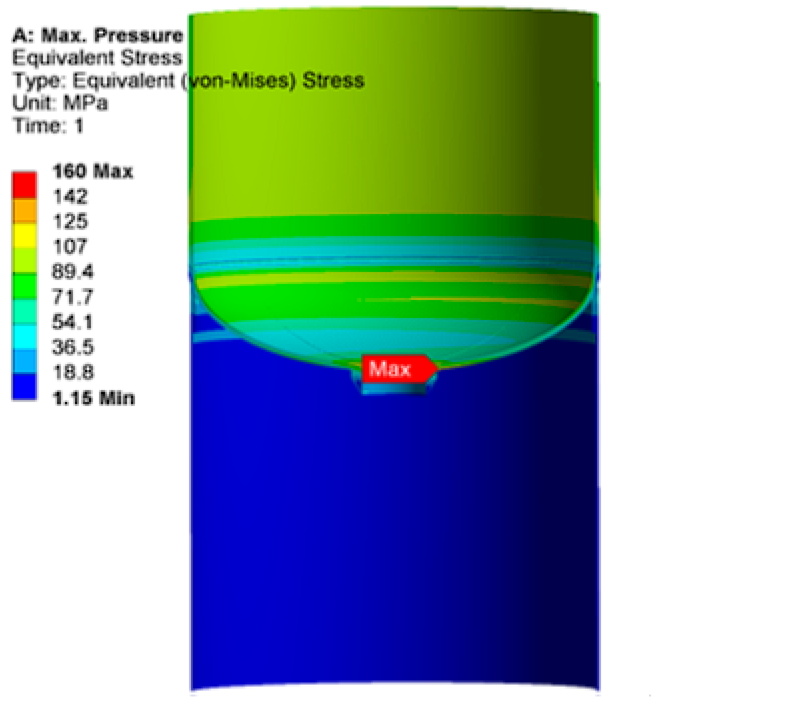


ECA / FFS TCR Case study:

Multiple flaws detected on different vessels by PAUT / TOFD

Sr No.	PSA Vessel	Location	Length-2c (mm)	Depth d mm	Height-2a (mm)
1	A	Bottom Nozzle	32	23	9
2	A	Top Nozzle	32	36	5
3	A	Top Nozzle (surface breaking)	18	49	6
4	D	CS5	146	18	4.2
5	D	LS 1	58	16.7	6.7
6	D	LS 1	56	14	5
7	D	Bottom Nozzle	57	37	12
8	E	CS5	51	14.8	3
9	E	Bottom Nozzle	22	37	5
10	E	Bottom Nozzle (surface breaking)	61	50	5

ECA / FFS TCR Case study:

	
Von-mises stress distribution at top portion of the vessel	*Von-mises stress distribution at bottom portion of the vessel*

ECA / FFS TCR Case study:

Fitness for service assessment for crack-like flaws detected in PAUT/TOFD

Sr No.	PSA Vessel	Location	2c	D	2a	FEA Path	Stress	Lr	Kr	a_{cr}	Result
			mm	mm	mm	-	MPa	-	-	mm	
1	A	Bottom Nozzle	32	23	9	6B	129.6	0.8	0.45	41.42	Acc
2	A	Top Nozzle	32	36	5	6T	106.7	0.7	0.31	49.71	Acc
3	A	Top Nozzle (Surf. Breaking)	18	49	6	6T	106.7	0.7	0.40	50.00	Acc
4	D	CS5	146	18	4.2	1T	49.8	0.47	0.21	115.91	Acc
7	D	Bottom Nozzle	57	37	12	6B	129.6	0.8	0.53	38.93	Acc
8	E	CS5	51	14.8	3	1T	49.8	0.47	0.18	40.00	Acc
9	E	Bottom Nozzle	22	37	5	6B	129.6	0.8	0.34	39.76	Acc
10	E	Bottom Nozzle (Surf. Breaking)	61	50	5	6B	129.6	0.8	0.42	35.62	Acc

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ECA / FFS TCR Case study:

Conclusions:

- The flaws are evaluated as per FFS assessment (API579/ASME FFS-1) for all 12 PSA vessels and found acceptable.
- PSA vessels A0401-A, D and E shows limited fatigue life as per Table below. These vessels require repair for a long-term reliability / safe service.

PSA Vessel	Restricting location	Predicted time for safe operation (months)
A0401-A	Bottom Nozzle	26
A0401-D	Bottom Nozzle	12
A0401-E	Bottom Nozzle	27

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ECA / FFS TCR Case study:

If it is decided to continue the vessels in operation without repair, a safe operating period in terms of months is calculated based on growth model as given in the standard API579/ASME FFS-1, that can be considered to evaluate **critical flaw height** with respect to **monthly monitoring** program.

Tolerable defect size with time (critical height)	Vessel A	Vessel - D	Vessel - E
	mm	mm	mm
Present value	9.0	12.0	5.0
After 1 month	9.9	13.6	5.8
After 2 months	10.9	15.2	6.6
After 3 months	11.8	16.7	7.4
After 4 months	12.7	18.3	8.2
After 5 months	13.7	19.9	9.0
After 6 months	14.6	21.5	9.8

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ECA / FFS TCR Case study:

OUTCOME

- PSA vessels successfully continued in the service until April 2024 until the 3-equipment replaced.
- Other equipment are successfully continued in service as on today.

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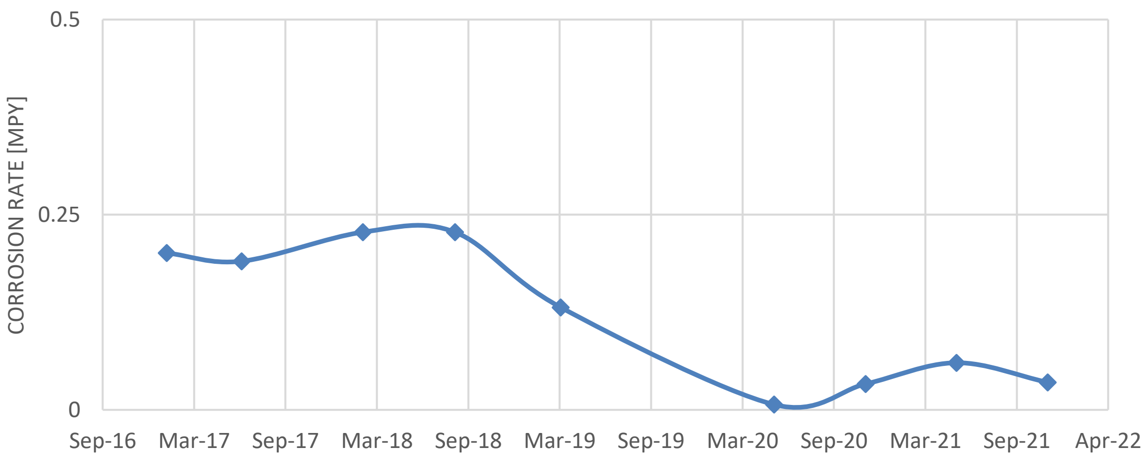
NDE Tools

NDEs for Pipeline Integrity Management

- **Visual Inspection:** Visual inspection of line pipes is most important NDE methodology with respect to detect overall condition of pipe, support system, leaks as oozing, paint / coating condition, open insulation pockets, vibrations etc.

NDEs for Pipeline Integrity Management

- **Thickness monitoring**: Repeated thickness measurements on fixed locations of pipeline provides data with trend of wall thickness condition.
- **Trends**: Corrosion trends provide rate of metal loss to alert with an early warning on thickness approaching minimum required value.



NDEs for Pipeline Integrity Management

- **Weld joint integrity**: Pipelines are subject to thermal swings and vibrations. Weld joint integrity may get affected due to such situation. It is necessary to inspect the weld joints.
- **LPT/ WFMPI**: Liquid penetration test (LPT) or wet fluorescent magnetic particle inspection (WFMPI) are the techniques for surface flaw detection, essentially useful for branched connections / small-bore openings.

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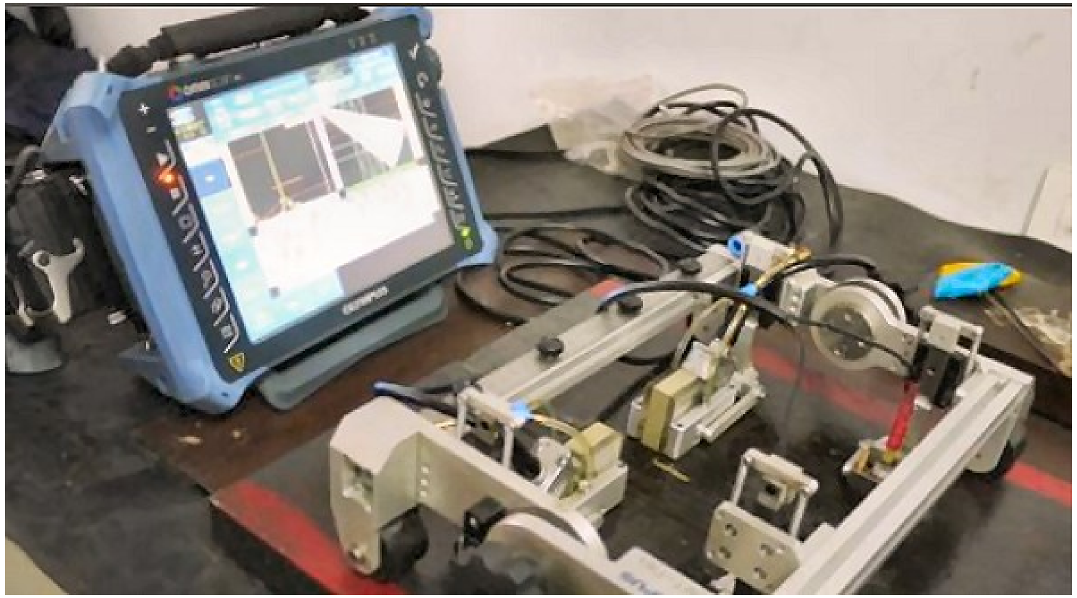
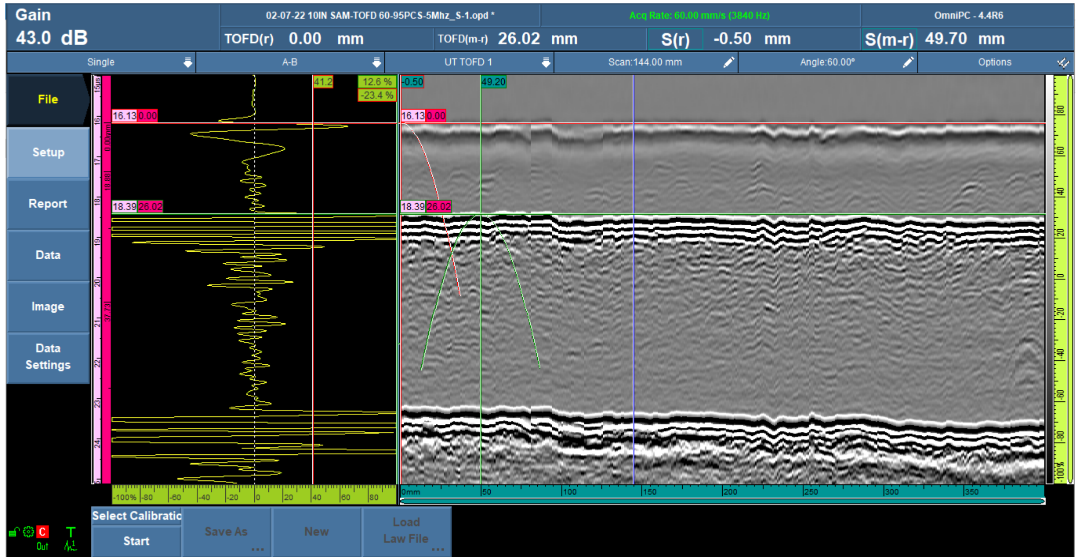
NDEs for Pipeline Integrity Management

- **Weld joint integrity**: On occasions when flaws detected by LPT / MPI, extent of repair estimate becomes crucial.
- **PAUT**: Conventional ultrasound flaw detection or phased array ultrasonic test (PAUT) are important tools on judgement for ID initiation or OD initiation as well as flaw depth assessment.



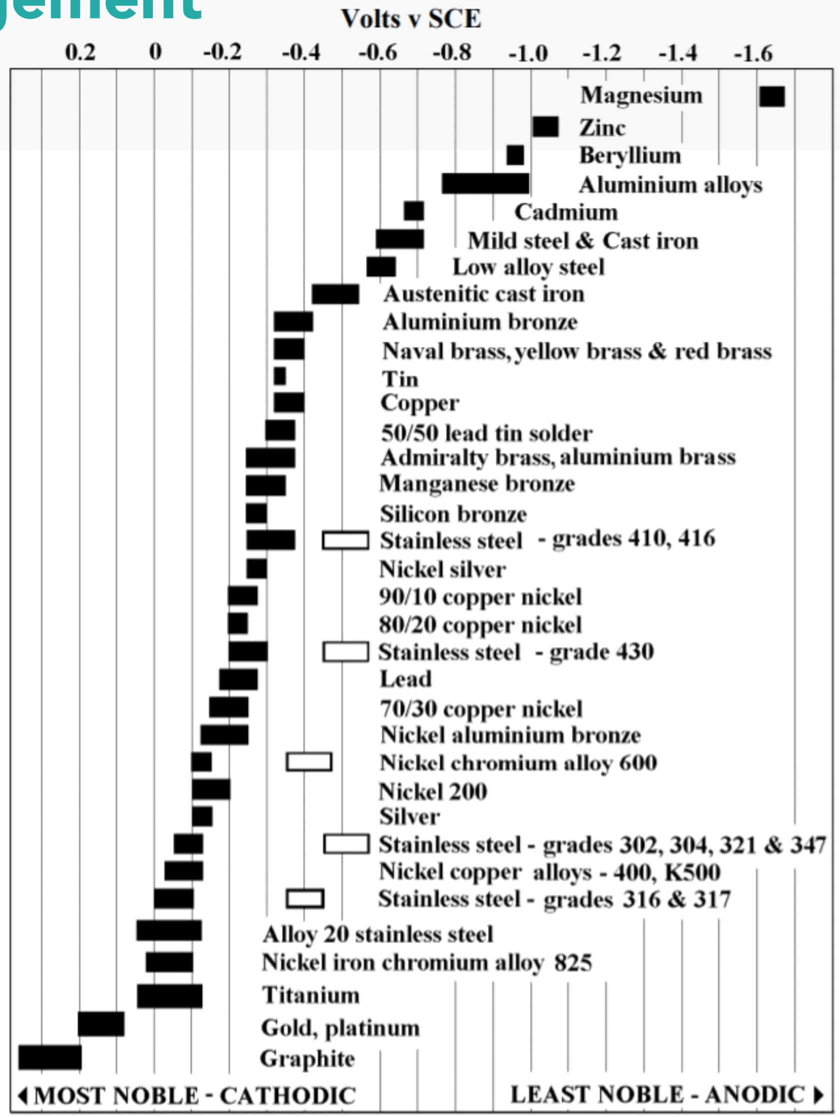
NDEs for Pipeline Integrity Management

- **Weld joint integrity**: Pipelines are subject to internal stresses and occasional pressure surges / water hammer etc. Weld joint integrity may get affected due to such situation, essentially from ID side of pipes.
- **TOFD**: Time of flight diffraction (TOFD) is one of the ultrasound inspection methods for weld joint integrity inspection, especially internal flaws.



NDEs for Pipeline Integrity Management

- **Bi-metallic joints**: Pipelines are subject to different methodologies of welding. There are dual metal joints or buttering layers on bimetallic joints. The dilution effect of elements becomes crucial for integrity assessment.
- **PMI**: Positive Metal Identification (PMI) is one of the portable chemical composition analysis techniques to check the segregation or dilution effects on bimetallic joints, to understand galvanic corrosion susceptibility.



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NDEs for Pipeline Integrity Management

- **Check for brittleness**: The forged fittings (e.g. studs, flanges) are often inadequately heat treated causing their microstructural properties in poor impact strength (brittleness). This may trigger during wintertime or during thermal shock conditions.
- **Microstructural examinations**: In-situ microstructural examination can reveal metallurgical properties including susceptibility to brittle fractures of such components.

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TCR ADVANCED

MEET US
250-252/9, GIDC Estate,
Makarpura,
Vadodara-390010 Gujarat,
India

Optimizing
Asset Integrity
www.tcradvanced.com

THANK YOU

For questions, mail us at testing@tcradvanced.com
or call us at +91. 7574805594 to get a quote

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