Structural Integrity Assessment of a Sour Service Low Pressure Production Trap Using Fitness-for-Service Methodology

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Publication Date: 2025/08/01

Abstract: This paper presents a real case study of a structural integrity assessment of a Low-Pressure Production Trap (LPPT) at a Gas Oil Separation Plant using Fitness-for-Service methodology. The equipment, constructed from carbon steel (CS A-516 Gr. 65) with a nominal wall thickness of 18.0 mm, operates in a sour environment prone to hydrogen-induced cracking (HIC) and step-wise cracking. Automated ultrasonic testing revealed HIC and inclusions at depths ranging from 7.3 mm to 14.8 mm, with step-wise cracks up to 2.2 mm in height. Fitness-for-Service assessments, using API-579 Level 1 and 2, confirmed the equipment's fitness for continued service, provided regular monitoring and protective measures are implemented. This study underscores the utility of Fitness-for-Service in extending the lifecycle of aging infrastructure while ensuring operational safety.

Keywords: *Corrosion; Fitness-For-Service; Hydrogen-Induced Cracking; Sour Service.*

How to Cite: Mohammed S. Al-Robai; Abdulrahman A. Alkhateeb (2025) Structural Integrity Assessment of a Sour Service Low Pressure Production Trap Using Fitness-for-Service Methodology. *International Journal of Innovative Science and Research Technology*, 10(7), 2491-2495. https://doi.org/10.38124/ijisrt/25jul1697

I. INTRODUCTION

Structural integrity management of oil and gas infrastructure operating in corrosive and sour environments is critical to ensuring operational safety, minimizing environmental risks, and optimizing lifecycle costs. Hydrogen-induced cracking (HIC) and step-wise cracking are pervasive degradation mechanisms in carbon steel equipment exposed to wet H_2S environments, where hydrogen atoms generated by corrosion diffuse into the material, leading to microstructural damage and crack initiation [1, 2]. These defects, if left unmonitored, can propagate rapidly, compromising the mechanical integrity of pressure-containing equipment such as pressure vessels (LPPT), heat exchangers, and pipelines [3, 4].

A Low-Pressure Production Trap (LPPT) at a Gas Oil Separation Plant (GOSP) exemplifies the challenges of managing aging infrastructure. Constructed from carbon steel (CS A-516 Gr. 65) with a nominal wall thickness of 18.0 mm, the LPPT has operated for over five decades in a sour service environment. Periodic inspections since 2022 have identified HIC, inclusions, and step-wise cracks, necessitating rigorous fitness-for-service (FFS) evaluations to determine its continued operability.

A. Hydrogen-Induced Cracking (HIC)

Hydrogen induced cracking (HIC) is characterized by laminar (in-plane) cracking with some associated through-thickness crack linkage. This is sometimes referred to as step-wise cracking, due to its morphology. HIC is a well-documented failure mechanism in sour service equipment, driven by the ingress of hydrogen atoms into the steel which combine to form H_2 molecules at non-metallic inclusions or other imperfections, that may lead to microcrack initiation and propagation [1, 5]. Step-wise cracking, manifests as stair-step cracks. These defects are particularly challenging to detect and manage due to their subsurface nature and potential for rapid growth under cyclic loading [6].

B. Fitness-for-Service (FFS) Methodology

FFS assessments, codified in standards such as API-579-1/ASME FFS-1, provide systematic frameworks to evaluate the structural integrity of damaged equipment. These methodologies prioritize safety while enabling cost-effective decisions on repair, replacement, or continued operation [7]. Level 1 assessments use simplified screening criteria to quickly determine if flaws exceed conservative thresholds, while Level 2 employs detailed analysis to evaluate remaining strength factor [8]. Level 3 assessments, involving finite element analysis (FEA), are reserved for complex geometries.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25jul1697

Prior studies have demonstrated the efficiency of FFS in extending the lifecycle of aging assets. For instance, Al-Otaibi et al. (2024) applied API-579 Level 2 assessments to a 50-year-old HIC-defected reboiler, concluding that protective coatings and regular inspections could safely prolong its service life [2]. Similarly, Anderson et al. (2005) highlighted the importance of integrating FFS with material property data and operational history to mitigate risks in high-stress environments [3].

C. Gaps and Research Objectives

Despite advancements in FFS methodologies, limited studies have focused on damaged mechanisms related to low-pressure production traps (PPT), which often operate under pressures and corrosive conditions (wet H2S). This study addresses this gap by applying FFS principles to the Low PPT experiencing HIC damage mechanism, leveraging recent automated ultrasonic testing (AUT) data. The objectives are:

- To evaluate the structural integrity of the LPPT using API-579 Level 1 and 2 criteria.
- To propose a monitoring strategy aligned with circular economy principles, emphasizing asset longevity and reduced environmental footprint.
- To provide a template for FFS assessments in similar aging infrastructure.

By bridging the knowledge gap in production trap integrity management, this work contributes to safer, more sustainable operations in the oil and gas sector.

II. METHODOLOGY

A. Automated Ultrasonic Testing (AUT)

The inspection of the LPPT was conducted using an automated ultrasonic testing (AUT) system (Equipment ID: SCNR-1116) to evaluate subsurface defects in critical shell courses (Courses #04, #05, and #07). Key parameters included:

- Material: CS A-516 Gr. 65
- Nominal Wall Thickness: 18.0 mm
- Scans: 300 mm × 300 mm grids across critical zones (Courses #04, #05, #07) as shown in Fig. 1.

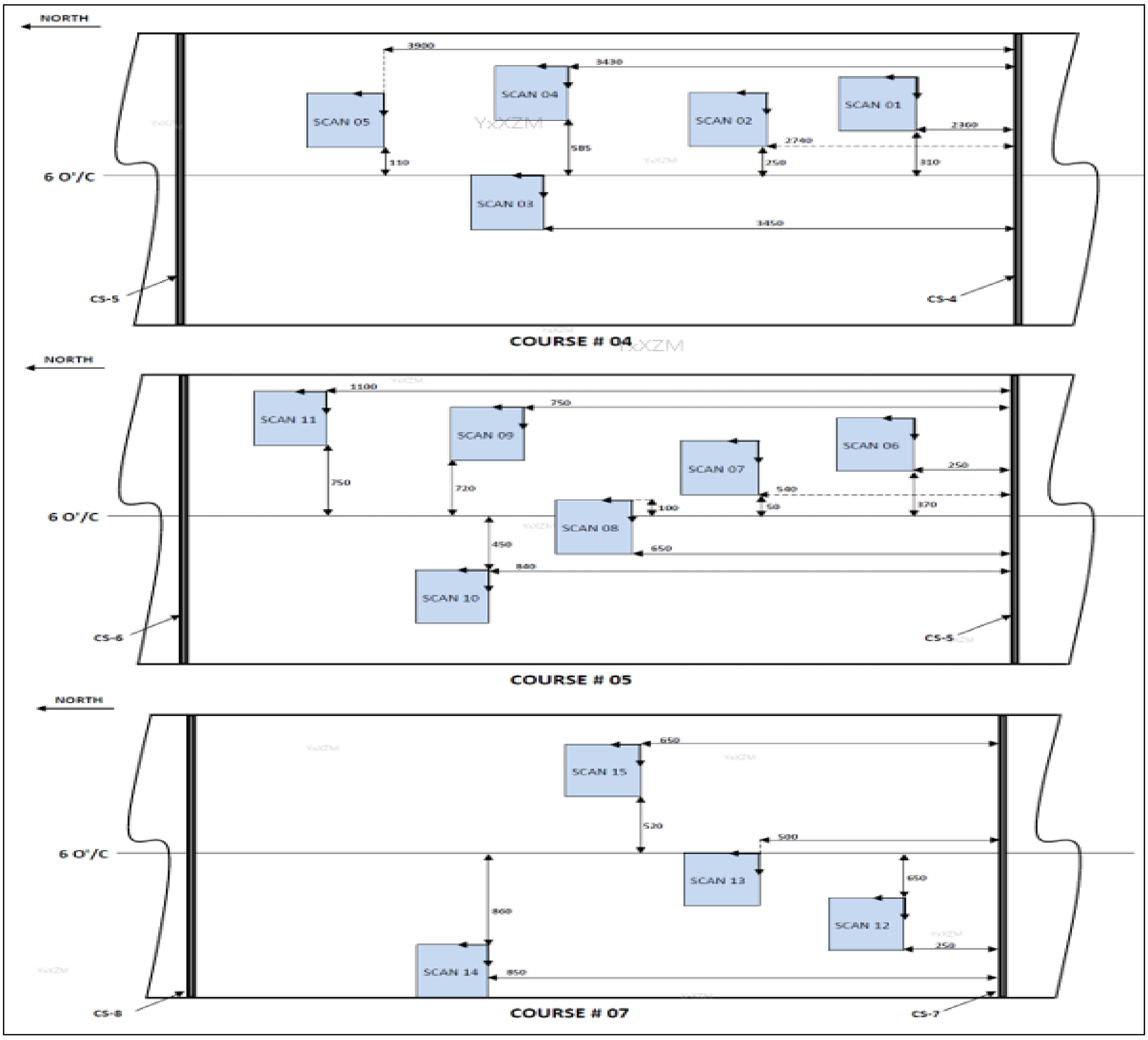

Fig 1. Course 4, 5, and 7 Including Scans Location.

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25jul1697

B. Fitness-for-Service (FFS) Assessment

FFS evaluations were performed using the methodology of API-579-1/ASME FFS-1 and focusing on HIC with step wise cracking damage. The FFS assessment included:

- Screening criteria for crack height and depth relative to wall thickness.
- Conducting detailed analysis of remaining wall thickness.

III. RESULTS

A. AUT Inspection Findings

Key observations from the inspection results revealed that the largest step-wise crack had a height of 2.2 mm, located in Course #07, Scan 13, and notably, no growth was detected in these cracks since the 2022 inspections. Additionally, the inspection identified hydrogen-induced cracking (HIC) and inclusions, with the deepest defect measuring 14.8 mm in Course #07, Scan 15, and the shallowest defect measuring 7.3 mm in Course #07, Scan 13. Figures 2-6 and Table 1 show the advance ultrasonic inspection readings across the critical zones.

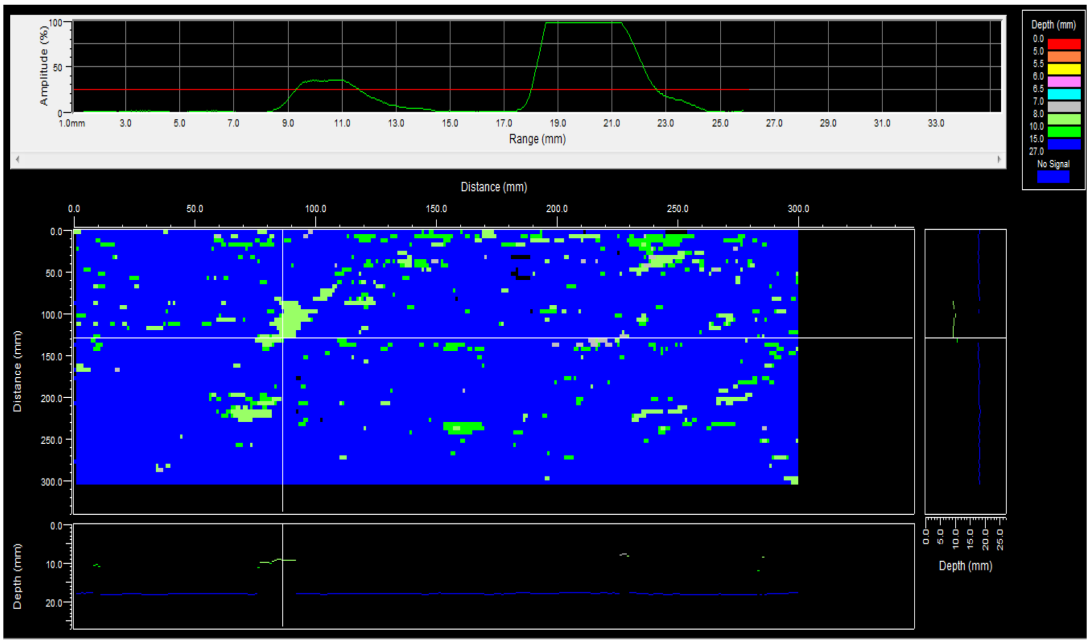

Fig 2. Course 4, 5, and 7 Including Scans Location.

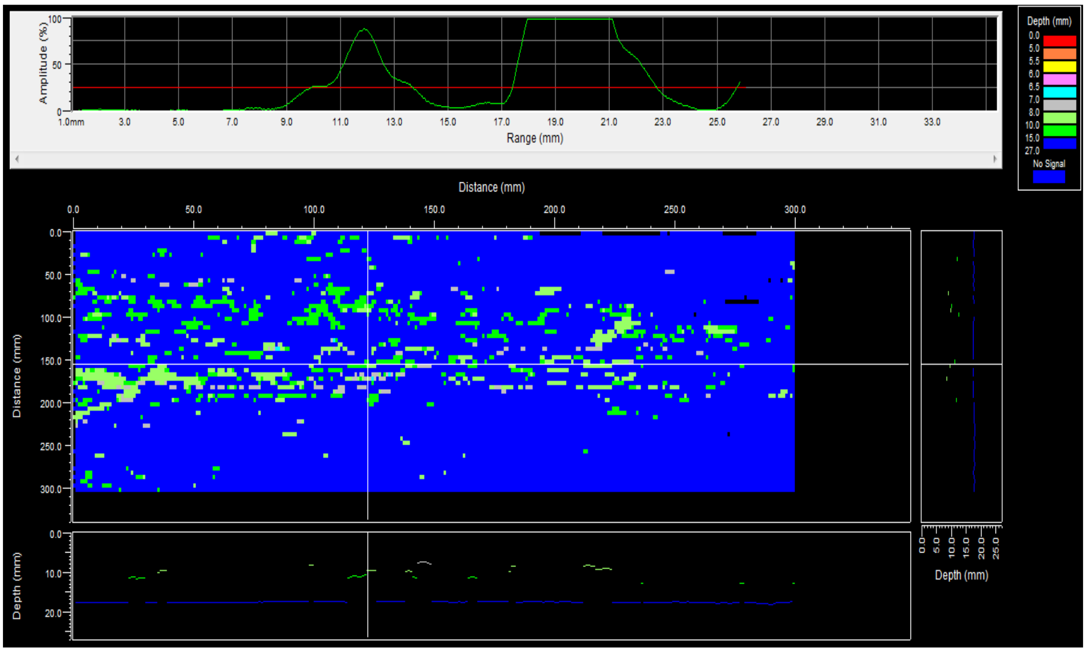

Fig 3. Shell Course #4 Scan 03

ISSN No:-2456-2165

https://doi.org/10.38124/ijisrt/25jul1697

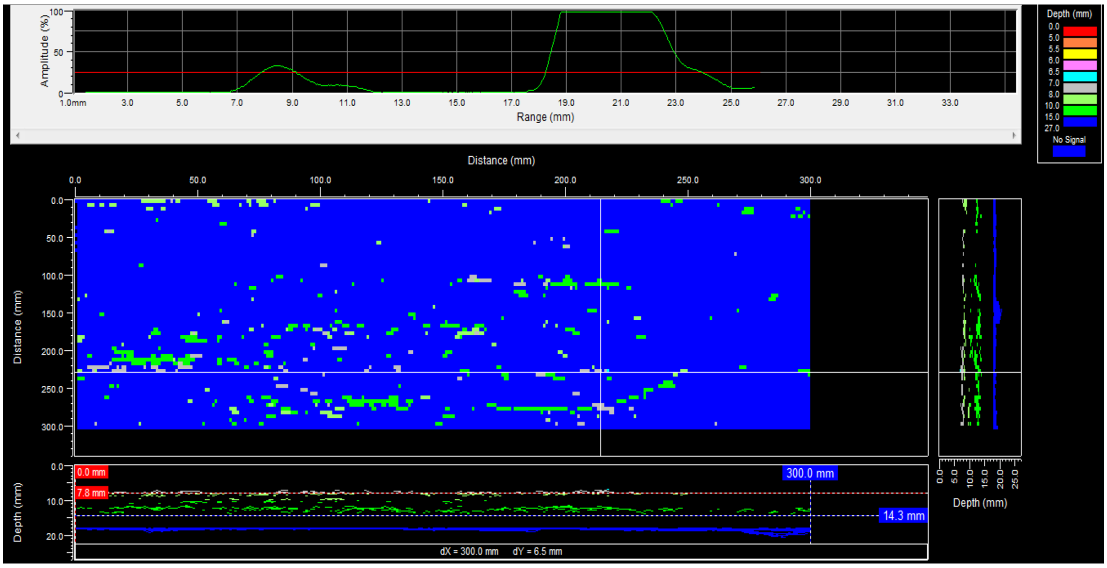

Fig 4. Shell Course #5 Scan 10

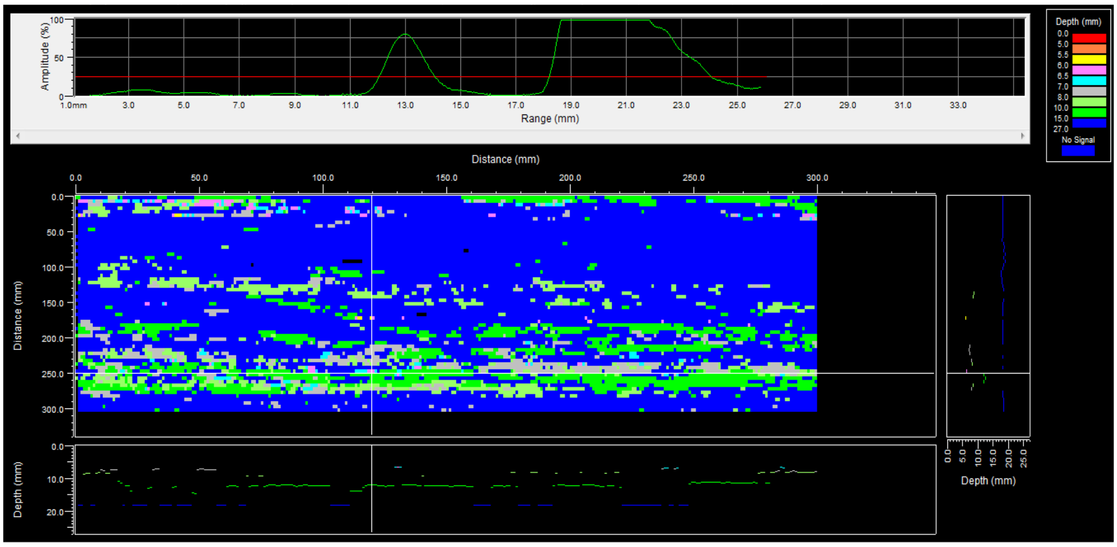

Fig 5. Shell Course #7 Scan 13

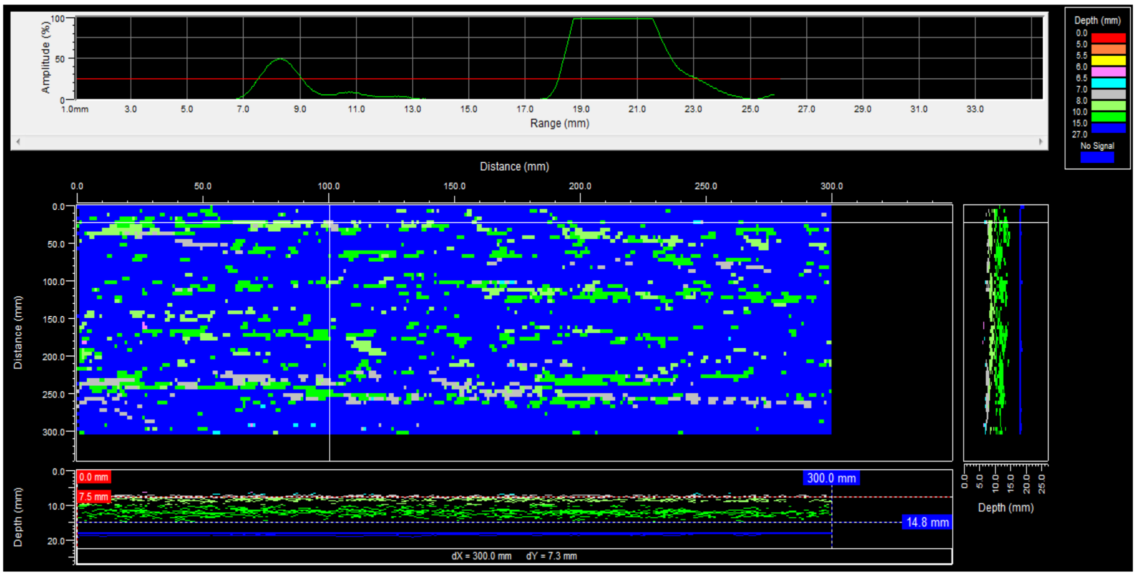

Fig 6. Shell Course #7 Scan 15

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/25jul1697

Table 1. Defect Measurements from Scan Locations

Scan Location	Defect Type	Max Crack Height (mm)	Depth Range (mm)	Crack Growth vs. 2022
Course 04, Scan 02	Step-wise cracks	2.2	12.8–14.8	No growth
Course 04, Scan 03	Step-wise cracks	1.9	9.2–14.0	No growth
Course 05, Scan 10	HIC/Inclusions	N/A	7.7–14.4	N/A
Course 07, Scan 13	Step-wise cracks	2.2	7.3–14.7	No growth
All Scans	HIC/ Inclusions	N/A	7.3–14.8 (ave. 11.2)	N/A

B. FFS Assessment Outcomes

The Fitness-for-Service assessment outcomes revealed that the crack heights and depths were within acceptable limits, with crack maximum heights of 2.2 mm which satisfying through-thickness extent of the damage less than 4.9 mm, and subsurface requirement (depths of 12.8 mm), thereby satisfying the API-579 screening criteria for Level 1 compliance and therefore no need to conduct Level 2 assessment.

IV. DISCUSSION

The structural integrity assessment of the LPPT confirms its capacity to operate safely under current conditions and monitoring program, supported by robust safety margins derived from FFS analysis.

The stability of step-wise cracks since the 2022 inspection reflects effective mitigation strategies, such as protective coatings and controlled H_2S levels, which have likely slowed hydrogen ingress and crack growth. However, the shallowest HIC defect (7.3 mm depth) warrants attention, as corrosion could reduce remaining wall thickness over time. Assuming a conservative corrosion rate of 0.1 mm/year, the remaining life based on nominal thickness (18.0 mm) would exceed 100 years, far surpassing the equipment's operational lifespan. This emphasizes the critical role of coatings in limiting hydrogen diffusion and corrosion progression.

Comparisons with literature reinforce these findings. Similar to Al-Otaibi et al.'s (2024) reboilers case study, Level 2 FFS assessments provided sufficient confidence for continued operation without re-rating, demonstrating the methodology's versatility across asset types [2]. Koh et al.'s (2008) findings on microstructural influences on HIC susceptibility align with the uniform defect distribution observed in the LPPT, suggesting consistent material quality and reduced failure risk [5]. The assessment also aligns with circular economy principles by avoiding premature replacement, thereby reducing material waste and carbon footprint.

To ensure sustained safety, biennial AUT inspections should prioritize monitoring Courses #04 and #07, where defects were most severe. Proactive measures, such as applying corrosion-resistant coatings (e.g., epoxy) and maintaining strict H_2S partial pressure control, are recommended to further mitigate risks. A reassessment every five years or following operational changes (e.g., pressure adjustments) will ensure ongoing compliance with integrity standards.

Limitations of this study include reliance on inferred historical corrosion rates and assumptions about environmental stability. While finite element analysis (FEA) was unnecessary due to the simplicity of the defects, it could be considered if complex flaws emerge in future inspections. Overall, this case study demonstrates the efficacy of FFS in extending the lifecycle of aging infrastructure while balancing safety, cost, and sustainability objectives.

V. CONCLUSION

The LPPT is deemed fit for continued service under current operating conditions. FFS methodology provided a robust framework to justify asset retention, avoiding premature replacement costs. This case study highlights the value of integrating FFS with advanced NDT techniques for managing aging infrastructure in sour service environments. Future work should explore predictive modeling to forecast defect evolution and optimize inspection intervals.

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