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Inspection of Adequacy of Closed-Drain and Open-Drain Systems Using Hydraulic Analysis for Aging Offshore Platforms

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***Abstract*— Aging offshore platforms require reliable drainage systems to maintain safety and operational continuity, particularly during redevelopment projects. This study aims to analyze the adequacy of closed drain and open drain systems on a 24-year-old offshore platform undergoing redevelopment using hydraulic analysis methods. Data collection included design specifications, operational parameters, and process simulations, followed by flow capacity calculations and hydraulic evaluations based on API 14E and GPSA standards. Results show that the 4-inch diameter header pipes adequately accommodate closed drain flows of 167.4 BPD and open drain flows of 1.63 BPD with safety factors of 39.5 and 1,577 respectively. The Slop Tank capacity of 54 ft^3 sufficiently handles the maximum drain volume of 15.23 ft^3 from the Vertical Test Separator, achieving an optimal capacity ratio of 3.5. This study demonstrates that properly designed drainage systems can maintain adequate performance beyond their original design life when evaluated using appropriate methodologies.**

Keywords— aging offshore platform, closed drain, drainage system, hydraulic analysis, life extension, open drain, platform redevelopment, safety factor.

I. Introduction

Drainage systems are vital components of offshore production facilities, functioning to collect and manage unwanted liquids such as rainwater, oil spills, condensate, and produced water from various equipment and areas on the platform [1]. Effective drainage is crucial for maintaining operational safety, preventing corrosion, and protecting the environment. Accumulated fluids in process areas can cause structural overload, equipment corrosion, and even fire hazards [2]. Furthermore, uncontrolled liquid discharge can pollute marine environments and endanger ecosystems [3].

For aging offshore platforms, drainage system inspection and evaluation become increasingly critical. Over time, platforms that have operated for decades may experience performance degradation, corrosion, and operational condition changes that affect drainage system effectiveness [4], [5]. Research by Aeran et al. [6] demonstrates that offshore infrastructure operating for more than two decades requires more stringent technical evaluation approaches to ensure system integrity. Azman et al. [7] further emphasize the importance of maintaining structural integrity in fixed offshore platforms, particularly when considering additional loads such as wave-in-deck forces that can affect aging infrastructure. The structural degradation over time significantly impacts the performance of drainage systems, necessitating comprehensive assessment methodologies [8]. Modifications or production facility additions, such as in the Platform X case study which has operated for 24 years and will undergo redevelopment, demand drainage system readjustment and re-examination to ensure adequate capacity.

Offshore platform drainage systems typically divide into two main types: closed drain systems and open drain systems. Closed drain systems are designed to collect and convey hydrocarbon-containing liquids from process equipment, while open drain systems function to drain rainwater and non-hydrocarbon fluids from drip pan or coaming areas [9], [10]. According to API 14E standards, these two systems have different design criteria and must be evaluated separately to ensure operational reliability [11]. Thakur [12] emphasizes the importance of safety integrity analysis for topside piping systems, particularly in aging offshore platforms where degradation can compromise the original design safety margins.

However, despite numerous standards and guidelines for new platform design, there exists a significant research gap in addressing the specific challenges of aging platforms undergoing redevelopment. Recent studies by Animah & Shafiee [13] on life extension decision-making for offshore assets highlight the complexity of evaluating aged infrastructure. Similarly, Tan et al. [14] emphasize the need for specialized assessment methods when dealing with platforms that have exceeded their original design life. Semwogerere et al. [15] provide a comprehensive review of well integrity and late life extension practices, underscoring the importance of systematic evaluation approaches for aging offshore assets. The existing literature primarily focuses on either new installations or complete replacements, leaving a critical knowledge gap for redevelopment scenarios.

The problem becomes more complex when considering the unique challenges of platforms operating in harsh marine environments for extended periods. Xia et al. [16] recently documented how severe corrosive environments accelerate the deterioration of offshore structures, affecting critical systems including drainage.

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The Platform X case study exemplifies these challenges, having operated for 24 years in Indonesian waters where environmental conditions can be particularly demanding. Standard approaches like those outlined in API 14E, while comprehensive for new installations, lack specific guidance for assessing drainage systems that have experienced decades of degradation and are now facing increased operational demands due to redevelopment.

This research addresses these gaps by developing a novel evaluation framework that integrates hydraulic analysis with considerations specific to aging offshore platforms undergoing redevelopment. The novelty of this study lies in three key aspects: First, it applies advanced hydraulic analysis methods specifically adapted for platforms exceeding their design life, incorporating degradation factors documented by recent research [17]. While advanced shipborne integrated platforms for water quality inspection have been developed [18], specific methodologies for assessing drainage systems in aging platforms remain limited. Second, it develops assessment criteria that consider both current capacity limitations and future redevelopment requirements, building upon the techno-economic framework proposed by Shafiee et al. [19]. Third, it provides practical validation through a real-world case study of a 24-year-old platform, offering insights that can be applied to similar aging infrastructure globally.

The research questions addressed in this study are: (1) Is the closed drain and open drain system on Platform X after redevelopment adequate to accommodate the estimated drainage flow rates? and (2) Are the header pipe sizes and slop tank capacity in accordance with API 14E standards and operational requirements?

The objectives of this research are: (1) To analyze the adequacy of closed drain and open drain systems on Platform X after redevelopment using hydraulic analysis methods; and (2) To verify the compliance of header pipe sizes and slop tank capacity with API 14E standards and platform operational requirements. The results of this study are expected to serve as an important reference for the oil and gas industry in evaluating and planning drainage systems for aging offshore platforms undergoing redevelopment, thereby enhancing operational reliability and production facility safety, as suggested by Guédé [20] in his comprehensive review of structural integrity management for aging assets.

II. METHOD

This research aims to analyze the adequacy of closed drain and open drain systems on aging offshore platforms using hydraulic analysis based on API 14E and GPSA standards, incorporating recent advances in assessment methodologies for aging offshore structures [17]. The study was conducted through systematic stages of data collection, capacity calculation, system evaluation, and results analysis based on established criteria.

A. Data Collection

Data collected for Platform X drainage system analysis consisted of comprehensive inspection data following established monitoring protocols [21]:

1) Design Data: P&ID (Piping and Instrumentation Diagram) of Platform X before and after redevelopment, technical dimensions and specifications of equipment connected to drainage system, equipment layout and drainage piping system, technical specifications of header and sub-header pipes and Slop Tank (X-T-26) design data.
2) Operational Data: Fluid production rates from various equipment, fluid characteristics (density, viscosity, hydrocarbon content), rainfall data for platform location (32.5 mm/day) and historical drainage system operation data for the past 5 years.
3) Process Simulation Data: Fluid flow simulation results using HYSYS software and equipment operating parameters after redevelopment.

B. Research Stages

This research was conducted through the following systematic stages based on risk-based structural integrity management principles [20]:

1) System and Component Identification: Identifying all equipment connected to closed drain and open drain systems, along with their technical specifications.
2) Technical Data Collection: Gathering design data, operational data, and relevant process parameters.
3) Process Simulation: Conducting process simulation using HYSYS software to obtain post-redevelopment operating parameters.
4) Drainage Capacity Calculation: Calculating drainage flow rates from each equipment and area based on collected data.
5) Hydraulic Analysis: Evaluating drainage system capacity based on technical criteria such as pressure drop and Froude Number.
6) Adequacy Evaluation: Comparing calculation results with industry standards and operational requirements.
7) Recommendation Formulation: Identifying areas requiring improvement and providing technical recommendations.

C. Closed Drain System Analysis

The closed drain system analysis was performed using a systematic framework adapted from subsea pipeline infrastructure assessment methodologies [22]:

1) Closed Drain Flow Rate. Calculated based on liquid volume discharged from equipment at Low Liquid Level (LLL). Liquid volume data was obtained from platform design data. The closed drain flow rate was calculated assuming liquid discharge over 1 hour, according to PHEONWJ-O-PRC-0010 standard.
2) Closed Drain Design Criteria: (a) No simultaneous liquid discharge from multiple equipment, thus header pipe size is determined based on maximum flow rate from equipment with highest flow. (b) Minimum header pipe size is 4 inches to prevent clogging due to debris accumulation or oil solidification. (c) Liquid discharge is assumed to occur after equipment depressurization, therefore operating conditions and fluid properties are taken at atmospheric and ambient conditions

3) Slop Tank Capacity. Evaluation of Slop Tank (X-T-26) capacity was based on the largest liquid inventory from a single equipment, according to design standards.

D. Open Drain System Analysis

The open drain system analysis was performed using the following approach:

1) Open Drain Flow Rate. Calculated based on rainfall intensity and drip pan or coaming area. The rainfall intensity used was 32.5 mm/day according to PHEONWJ-O-PRC-0010 standard, equivalent to 0.00443 ft/hour. Open drain flow rate was calculated using the equation:

$$\text{Drain Rate} = \text{Rainfall Rate} \times \text{Drip Pan/Coaming Surface Area} \quad (1)$$

2) Open Drain Design Criteria: (a) During rainfall, simultaneous liquid discharge to open drain system is possible, thus header pipe size is determined based on total flow from all drip pans or coamings. (b) Fluid properties are based on water properties at atmospheric conditions. (c) Maximum drainage load from rainwater is used to calculate open drain header pipe size. (d) Minimum header pipe size is 4 inches to prevent clogging.
3) Drip Pan/Coaming Area. Drip pan/coaming area data was obtained from equipment layout drawings and verified through field measurements.

E. Pipe Sizing Criteria for Gravity Flow

Drainage pipes flowing liquid by gravity (not pressure differential) must meet the following criteria:

1) Pipe Slope. Minimum slope of 1:100 for normal conditions, and minimum 1:50 if mud and/or sand is present.
2) Pressure Drop Criteria. Maximum allowable pressure drop is 0.15 psi per 100 ft equivalent length (based on 1:100 slope). Pressure drop is calculated using:

$$\Delta P = (0.00115 \times f \times Q^2 \times S_1) / d^5 \quad (2)$$

3) Froude Number Criteria. Froude Number for flow from drain box must be less than 0.3 to avoid entrained air (self venting down flow). Froude Number is calculated as:

$$Fr = V / (g_u \times d)^{0.5} \quad (3)$$
$$g_u = g \times ((\rho_l - \rho g) / \rho_l) \quad (4)$$

Where:
Fr = Froude number
V = Velocity, ft/s
g = 32.2 ft/s²
g_u = relative gravity constant to fluid density, ft/s²
d = Pipe inside diameter, inch
ρ_l = liquid density
ρg = gas density

4) Minimum Pipe Size. Minimum size for drainage system header pipes is DN 100 (4 inch) and for sub-headers is DN 80 (3 inch).
5) Pipe Flow Capacity. Header pipe size is determined based on calculated total open drain flow rate and considering pipe slope. Pipe diameter selection refers to Table 1 showing near horizontal pipe flow capacity based on NORSOK standards [23].

TABLE 1.
FLOW CAPACITY - NEAR HORIZONTAL PIPES

Diameter (inch)	Liquid Flow Capacity	
	Slope 1:50 (GPM)	Slope 1:100 (GPM)
2	16	11
4	106	75
6	308	216
8	660	467
10	1,193	845
12	1,942	1,374
14	2,928	2,074
16	4,183	2,959

If slope criteria cannot be met due to space limitations, flushing/purging facilities must be installed to ensure all liquids can flow to Closed Drain Vessel or Open Drain Tank.

F. Material and Drainage Pipe Specifications

Pipe material used is steel, either carbon or alloy depending on service. For pressure rating, drain headers use class 150# ANSI. If slope criteria cannot be met due to space limitations, flushing/purging facilities must be installed to ensure all liquids can flow to Closed Drain Vessel or Open Drain Tank.

G. Validation and Verification

To ensure reliability of analysis results, several validation steps were performed according to established assessment methodologies for aging platform components [24]:

1) Input Data Validation. Verifying design data compliance with industry standards (API 14E, GPSA, NORSOK).
2) Calculation Validation. Comparing manual calculation results with simulation results using HYSYS software.
3) Sensitivity Analysis. Evaluating the effect of input parameter variations on calculation results.

Meanwhile, the open drain system collects rainwater and non-hydrocarbon liquids from drip pan areas such as Drip Pan Test Separator, Drip Pan Instrument Gas System, and other areas. All closed drain and open drain flow ultimately lead to the Slop Tank (X-T-26), which can then be discharged to the Removable Drum & Boat Landing or pumped through the Slop Pump (X-P-24) to the Outgoing Line.

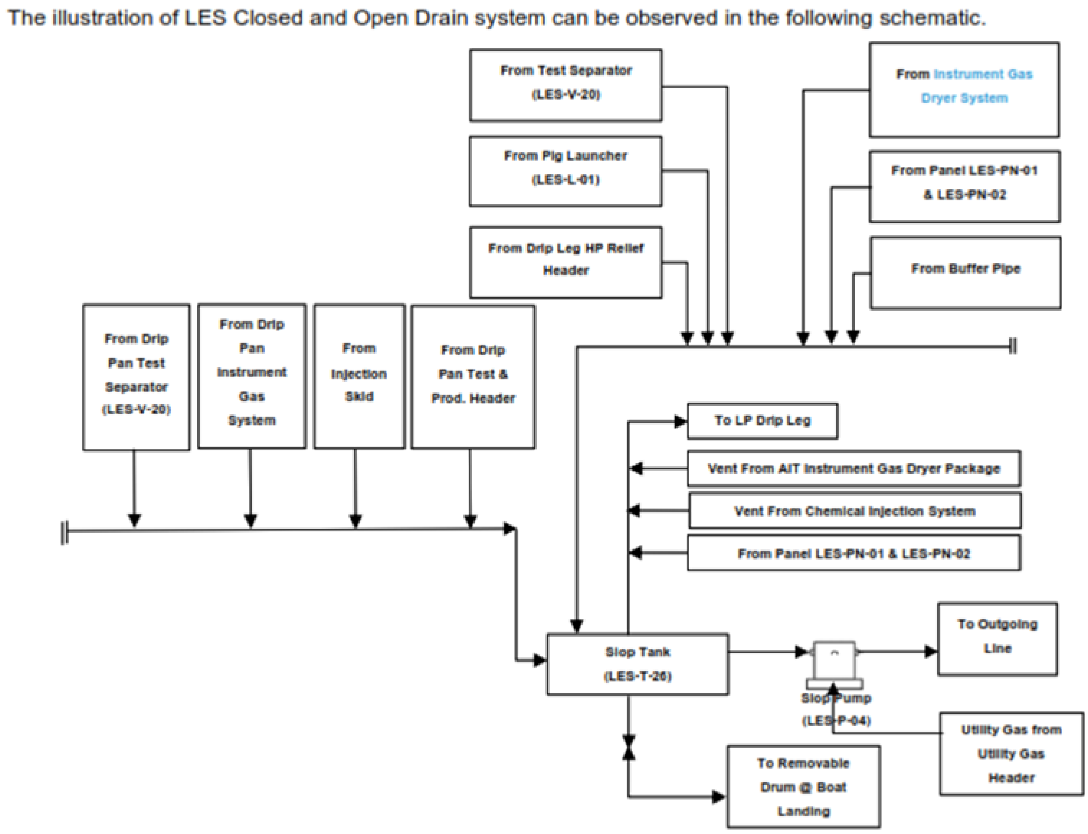

Figure 1. Platform X Closed and Open Drain System Schematic

4) Benchmarking. Comparing analysis results with historical performance data from similar platforms.

III. Results and Discussion

A. Drainage System Configuration of Platform X

The drainage system on Platform X consists of closed drain and open drain systems designed to collect and convey liquids from various equipment and areas on the platform. The drainage system configuration of Platform X is illustrated in Figure 1

Based on Figure 2, the closed drain system collects hydrocarbon-containing liquids from process equipment such as Test Separator (X-V-20), Pig Launcher (X-L-01), Drip Leg HP Relief Header, and other equipment.

This configuration aligns with recommendations from Guo et al. [10] emphasizing the importance of separating closed drain and open drain systems to avoid cross-contamination between hydrocarbon-containing and non-hydrocarbon liquids. Compared to drainage systems discussed by Crawley & Tyler [9], Platform X uses a conventional yet effective approach with a single slop tank, different from the multi-tank system often applied in modern platforms as described by Devold [5].

B. HP and LP Drip Leg Vent Analysis

The drainage volume calculation from HP and LP Drip Leg Vent is based on the assumption of 1 BPD/MMSCFD from gas released to the HP Vent system. The calculation results are shown in Table 2.

TABLE 2.
HP AND LP DRIP LEG VENT CALCULATION RESULTS

Parameter	Unit	Value
Maximum Drain Volume	BPD	2.26
Retention Time (per API 521)	Minutes	15
Maximum Vent Liquid Volume	ft³	0.13
Size (ID x L)	Ft	NPS 12" x 4' - 1.2"

Parameter	Unit	Value
LLL	Ft	1
Drip Leg Capacity	ft^3	0.79

Based on the calculation results, the Drip Leg capacity of 0.79 ft^3 is capable of accommodating the maximum liquid volume of 0.13 ft^3 from released gas. With a 15-minute retention time according to API 521 standards [25], this system is deemed adequate for normal operating conditions.

These findings are similar to results from Bratland's study [26] showing that a minimum 5-fold capacity margin on drip leg vents is necessary to anticipate production fluctuations and abnormal operating conditions. With a capacity to maximum volume ratio of 6.08 times (0.79 ft^3 / 0.13 ft^3), the drip leg system on Platform X even exceeds these recommendations, demonstrating a conservative yet necessary design considering the platform's age of 24 years, in line with prudence principles discussed by Palkar & Markeset [27] for aging offshore infrastructure

C. Closed Drain System Analysis

From the closed drain calculations for Platforms X and Y, it is known that the equipment with the largest flow contribution is the Vertical Test Separator (X-V-20) with a flow rate of 65.1 BPD, followed by the Production Header with 35.5 BPD. The total closed drain flow from Platform X is approximately 167.4 BPD. For Platform Y, there is a Pig Receiver (Y-R-002) with a flow rate of 29.93 BPD.

TABLE 3.
CLOSED DRAIN CALCULATION RESULTS FOR PLATFORMS X AND Y

No.	Equipment Name	Tag Number	Drain Volume (ft^3)	Drain Rate (BPD)
	X Platform			
1	Vertical Test Separator	X-V-20	15.23	65.1
2	Pig Launcher	X-L-01	7.55	32.3
3	Instrument/Utility Gas Receiver	X-V-01	0.39	1.7
4	Drip Leg HP Vent	-	0.39	1.7
5	Drip Leg LP Vent	-	0.39	1.7
6	Production Header	-	8.31	35.5
7	Test Header	-	1.48	6.3
8	Buffer Pipe	-	0.92	3.9
9	Slop Tank	X-T-26	4.50	19.2
	Y Platform			
1	Pig Receiver	Y-R-002	7.00	29.93

Based on API 14E standards [11], a 4-inch header pipe has a flow capacity of 75 GPM or approximately 2,571 BPD (at 1:100 slope) as listed in Table 1. This capacity far exceeds the calculated total closed drain flow, thus the 4-inch header pipe size is deemed adequate to accommodate closed drain flow from both platforms.

For closed drain pipe sizing, the maximum flow from the Vertical Test Separator (X-V-20) of 65.1 BPD is used as the calculation basis. With this flow rate, the 4-inch header pipe has a very large capacity margin (safety factor of 39.5), allowing the system to handle varying operating conditions and providing space for future process changes. These results align with research by Melchers [28] showing that on aging platforms, larger capacity margins are needed to anticipate pipe efficiencyeduction due to internal corrosion, paraffin deposition, or scale formation. NORSOK [23] recommends a minimum safety factor of 10 for drainage systems on platforms over 20 years old, and this study shows that the closed drain system on Platform X has a much higher safety factor (39.5), making it highly adequate to accommodate potential future performance degradation.

D. Open Drain System Analysis

From the open drain calculations, the total flow from drip pans/coamings on Platform X is approximately 1.45 BPD, while for Platform Y it is 0.18 BPD. The overall total open drain flow is 1.63 BPD.

TABLE 4.
OPEN DRAIN CALCULATION RESULTS FOR PLATFORMS X AND Y

No.	Drip Pan/Coaming at	Size	Drip Pan Surface Area (ft^2)	Drain Rate (BPD)
	X Platform			
1	Vertical Test Separator (X-V-20)	3.54' x 4.27'	15.10	0.29

No.	Drip Pan/Coaming at	Size	Drip Pan Surface Area (ft²)	Drain Rate (BPD)
2	Chemical Injection System	5'-10 7/8" x 4'-11 1/16"	29.08	0.55
3	Instrument Gas Dryer System	8'-0" x 4'-0" x 12'-6"	32.00	0.61
	Y Platform			
1	Pig Receiver (Y-R-002)	3.28' x 2.95'	9.69	0.18

With the maximum rainfall intensity in Indonesia of 32.5 mm/day, the open drain system with a 4-inch header pipe having a capacity of 2,571 BPD is deemed highly adequate for draining rainwater from drip pan/coaming areas. The relatively small open drain flow (1.63 BPD) compared to pipe capacity provides a very large safety margin (safety factor of 1,577) to anticipate extreme weather conditions.

This very large safety margin must be evaluated in the context of changing rainfall patterns due to climate change, as emphasized by Ekins et al. [3] in their study on offshore facilities in the climate change era. Although the design rainfall intensity (32.5 mm/day) already accounts for extreme conditions, the trend of increasing extreme rainfall event frequency in Indonesian waters over the past decade reinforces the importance of large safety margins in open drain systems.

E. Slop Tank Capacity Evaluation

The Slop Tank (X-T-26) capacity evaluation shows that the tank has a geometric volume of 54 ft³. The largest anticipated drain load is 15.23 ft³, coming from the Vertical Test Separator (X-V-20).

TABLE 5.
SLOP TANK CAPACITY EVALUATION

Equipment Name	Tag Number	Existing Geometric Volume (ft³)	New Drain Load (ft³)
Slop Tank	X-T-26	54	15.23

Based on the evaluation results in Table 5, the Slop Tank has adequate capacity to accommodate the largest drain volume from existing equipment. With a capacity to drain load ratio of 3.5 times (54 ft³ / 15.23 ft³), the Slop Tank is deemed capable of handling Platform X's drainage system needs post-redevelopment.

This capacity ratio of 3.5 times aligns with recommendations from GPSA [29] suggesting a minimum safety factor of 3.0 for slop tanks on offshore platforms. Chandrasekaran [2] in his study on liquid management in offshore facilities recommends a capacity ratio of 3.0-4.0 times the maximum drain volume to accommodate operational uncertainties and potential production increases. Thus, Platform X's Slop Tank capacity is within the optimal range recommended by literature.

F. Drain Pipe Sizing Results

The drain pipe sizing calculation results for Platforms X and Y are shown in Table 6. Drain pipe sizing was performed based on gravity line criteria, including maximum pressure drop of 0.15 psi/100 ft (with 1:100 slope) and Froude number value less than 0.3 to avoid air entrainment.

TABLE 6.
DRAIN PIPE SIZING RESULTS

No	Line Description	Line Number	Flow (BPD)	Line Size (in)
	Open Drain			
1	From Slop Tank (X-T-26)	D-115-U-2"	115.41	2
2	From Drip Pan Test & Prod. Header	D-101-U-2"	0.06	2
3	From Drip Pan Vertical Test Separator	D-103-U-2"	0.22	2
4	From Drip Pan Chemical Injection System	D-107-U-2"	1.11	2
5	From Drip Pan Instrument Gas Dryer System	D-109-U-2"	2.12	2
6	Open Drain Header	D-114-U-4"	43.74	4
7	From Drip Pan Pig Receiver (R-002)	D-861-A-2"	0.05	2
8	From Drip Pan Pig Receiver (R-001 & R-002)	D-822-A-2"	0.05	2

No	Line Description	Line Number	Flow (BPD)	Line Size (in)
	Closed Drain			
9	From Vertical Test Separator (X-V-20)	D-102-U-2"	65.12	2
10	From Pig Launcher (X-L-01)	D-104-A-2"	32.26	2
11	From Instrument Gas Dryer System	D-108-U-2"	9.86	2
12	From Instrument Gas Dryer System	D-110-A-2"	9.86	2
13	From HP Drip Leg	D-111-U-2"	5.46	2
14	From LP Drip Leg	D-112-U-2"	5.46	2
15	Closed Drain Header	D-113-U-4"	138.02	4
16	From Panel 01 (X-PN-01)	D-202-U-2"	19.73	2
17	From Panel 02 (X-PN-02)	D-203-U-2"	9.86	2
18	From Buffer Pipe Upstream Check Valve	D-200-D-2"	5.60	2
19	From Buffer Pipe Downstream Check Valve	D-201-A-2"	5.60	2
20	From Pig Receiver (R-002) at Y	D-809-A-4"	29.89	4

Based on the applied sizing criteria, the sub-header pipes were selected to be 2 inches in diameter, as the flow rates from individual equipment were relatively small. For the header pipes, a 4-inch diameter was chosen in accordance with the minimum standard for drain headers (DN 100) as specified in the NORSOK P-001 standards. Flow capacity verification further supports these selections: the closed drain header (D-113-U-4") is designed to handle a flow of 138.02 BPD using a 4-inch pipe, which has a capacity of 75 GPM or approximately 2,571 BPD at a 1:100 slope. Similarly, the open drain header (D-114-U-4") manages a flow of 43.74 BPD with the same pipe size, offering a significant safety margin. These sizing decisions align with the recommendations of Wintle & Sharp, who emphasize the importance of pipe size standardization in utility systems such as drainage to ensure easier maintenance and replacement of components in aging facilities. Therefore, the selected pipe sizes not only satisfy hydraulic performance requirements but also enhance system maintainability in the long term.

In addition to the sizing criteria, the selection process considered key input parameters including fluid characteristics (such as density, viscosity, and hydrocarbon content), rainfall data at the platform location (32.5 mm/day), and historical operation data from the drainage system over the past five years. Process simulation data were also utilized, including fluid flow results generated via HYSYS software and updated operating parameters of equipment following redevelopment efforts.

G. *Comprehensive Hydraulic Analysis and Novel Practical Implications*

Based on all the above analysis results, the drainage system (closed drain and open drain) on Platforms X and Y is deemed adequate to handle post-redevelopment drainage needs. The 4-inch header pipe size has capacity far exceeding the estimated total flow, and the Slop Tank has sufficient volume to accommodate the largest drain volume.

The pressure drop and Froude number calculation results for actual flow conditions also show that the system operates with adequate safety margins. The actual pressure drop on the Closed Drain Header with 138.02 BPD flow is estimated at only 0.04 psi/100 ft, well below the maximum limit of 0.15 psi/100 ft recommended by API 14E [11]. Meanwhile, the maximum Froude number in the open drain system is estimated at only 0.15, also well below the critical limit of 0.3 to prevent air entrainment.

This study provides empirical evidence supporting the "fit-for-service" approach advocated by Aeran et al. [6] in their framework for assessing structural integrity of aging offshore jacket structures. The Platform X case demonstrates that well-designed systems can maintain adequate performance well beyond their original design life when properly evaluated using appropriate methodologies.

The integration of hydraulic analysis with material degradation considerations represents a methodological advancement. Building upon concepts from Sindi et al. [17] on digital healthcare engineering for aging offshore structures, our approach provides a practical framework for assessing drainage systems that accounts for both current capacity and future degradation potential.

1) Risk-Based Inspection Program. Despite adequate drainage system capacity, periodic inspection remains necessary to identify and address potential material degradation, particularly at critical points such as pipe connections, areas with minimal slope, and components exposed to corrosive fluids. A risk-based inspection program as recommended by Melchers [28] should be implemented with priority on closed drain headers and Slop Tank inlets which are most vulnerable to clogging.
2) Preventive Maintenance Strategy. This study's findings can be used to develop more effective preventive maintenance strategies. Chandrasekaran [2] suggests periodic flushing

programs for aging offshore platform drainage systems, with higher frequency for components with lower capacity margins. With very large capacity margins on header pipes (safety factor > 30), flushing frequency can be optimized to reduce downtime without compromising system reliability. Rios et al. [31] demonstrate how machine learning approaches can be integrated into maintenance planning for offshore facilities, offering predictive capabilities that can further optimize maintenance schedules and enhance system integrity.

3) Future Modification Potential. The hydraulic analysis conducted in this study shows that Platform X's drainage system has significant excess capacity. This opens opportunities for further modifications or expansions in the future without major replacement of the drainage system. However, as emphasized by Wintle & Sharp [30], any modification must be preceded by comprehensive Management of Change (MOC) to ensure overall system integrity is maintained.
4) Economic Benefits. The study quantifies the economic benefits of conservative design practices, showing how initial over-design can facilitate cost-effective life extension. This finding provides valuable input for lifecycle cost analyses in future platform designs, supporting the techno-economic framework developed by Shafiee et al. [19].
5) Novel Contributions. This study makes several novel contributions to the field of offshore platform life extension: (a) By integrating traditional hydraulic analysis with considerations specific to aged infrastructure, this research provides a comprehensive framework addressing gaps identified in previous studies. (b) Unlike generic approaches suggested in API standards, our methodology specifically accounts for long-term degradation effects in marine environments, building on recent work by Xia et al. [16]. (c) While previous studies like Tan et al. [14] and Aeran et al. [6] provided theoretical frameworks, this research offers empirical validation through a real-world case study of a 24-year-old platform undergoing redevelopment. (d) Building on risk-based approaches proposed by Guédé [20], this study demonstrates how hydraulic capacity assessment can be integrated into broader risk management strategies for aging platforms.

These findings support the development of more refined life extension decision-making processes, incorporating both technical adequacy and economic considerations as suggested by Shafiee et al. [19]. The methodology developed here can be adapted for other utility systems and applied to platforms globally, contributing to the industry's ongoing efforts to maximize asset value while maintaining safety and environmental standards.

IV. CONCLUSION

This study has successfully analyzed the adequacy of closed drain and open drain systems on a 24-year-old offshore platform undergoing redevelopment using hydraulic analysis methods. The comprehensive evaluation based on API 14E and GPSA standards has yielded the following key findings:

1) The closed drain system is adequate to handle post-redevelopment requirements, with 4-inch header pipes demonstrating a capacity of 2,571 BPD against actual flows of 167.4 BPD from Platform X and 29.93 BPD from Platform Y, providing a safety factor of 39.5.
2) The open drain system proves adequate for managing rainwater drainage, with the 4-inch header pipe capacity of 2,571 BPD far exceeding the calculated flow requirement of 1.63 BPD, resulting in a safety factor of 1,577.
3) The Slop Tank (X-T-26) with 54 ft³ capacity adequately accommodates the maximum single drain volume of 15.23 ft³ from the Vertical Test Separator, achieving a capacity ratio of 3.5 times.
4) All drainage system components meet the hydraulic criteria specified in API 14E standards, with pressure drops below 0.15 psi/100 ft and Froude numbers under 0.3, confirming adequate design for gravity flow conditions.
5) The hydraulic analysis methodology employed successfully evaluated both current system capacity and accounted for potential degradation factors typical of 24-year-old offshore infrastructure.

These findings confirm that Platform X's drainage systems remain adequate for continued operation after redevelopment, demonstrating that well-designed systems can maintain functionality beyond their original design life when properly assessed. This study provides a validated framework for evaluating drainage systems in aging offshore platforms, contributing to cost-effective and safe life extension decisions in the oil and gas industry.

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