For Action

Work Car Hydraulic Leak Incidents Update

Date: December 3, 2024
To: TTC Board
From: Executive Director – Innovation and Sustainability

Summary

On May 13, 2024, a hydraulic oil leak from a work car resulted in a 12-hour service suspension on Line 2. At its meeting on May 16, 2024, the TTC Board received a summary of the events leading up to the incident, the results of the initial investigation, immediate corrective actions, and the next steps, which included a third-party analysis of the failures and audit of maintenance policies and procedures.

Subsequently, staff engaged rail industry experts Hatch to conduct a forensic technical root cause analysis of the failures and the American Public Transit Association (APTA) to conduct an independent peer review of how the incident was handled. Both parties were also asked to comment on the relatively high frequency of hydraulic leaks and whether the frequency or cause(s) were evidence of a willful act.

The full and final reports from Hatch and APTA were submitted to the TTC in November and are attached to this report. Both reports identified common root causes, and while they found that the TTC's practices are typical of the industry, they recommend implementing a more robust preventative maintenance program of procedures, training, and quality control modeled after what the TTC has in place for revenue service vehicles.

The scope of both reports focused on the eight hydraulic leak incidents on the work cars between January and May 2024. It should be noted that hydraulic equipment often operates in harsh and challenging working environments. As a result, hydraulic leaks are not uncommon. The scope of these reports does not include incidents that have occurred during vehicle maintenance inspections, nor does it include leaks that may have happened on non-vehicle-related equipment, such as way-side equipment failures.

Both reports conclude that there was no evidence that the subject hydraulic leaks were intentional or the result of sabotage. The TTC has accepted all recommendations provided by both Hatch and APTA.

This report summarizes the findings, recommendations, management action plans, and their owner and target completion dates. All priority management actions have been completed or will be by the end this year.

Recommendations

It is recommended that the TTC Board:

1. Receive this report for information.

Financial Summary

This report has no direct capital financial impact beyond what has been approved in the 2024-2033 Capital Budget and Plan. The TTC's 2024-2033 Capital Budget and Plan includes $34.0 million of approved funding for work car overhauls and $63.4 million toward work car procurements.

TTC staff will include a funding request in its 2025 Operating Budget submission to establish a more robust work car preventative maintenance program.

The Chief Financial Officer has reviewed this report and agrees with the financial impact information.

Equity/Accessibility Matters

The TTC recognizes that hydraulic leaks can significantly impact the customer and employee experience. Service disruptions caused by hydraulic leaks may negatively impact customers who rely on the TTC's services, particularly customers without access to a car, those who live with low incomes, customers who require accessibility support, and those who are commuting from Toronto's Neighbourhood Improvement Areas, where access to transit faces a range of challenges. Service disruptions, such as the incident that occurred on May 13, 2024, may impact customers' mental well-being, job security, and access to important activities, such as attending medical appointments, and may lead to challenges when navigating through crowded subway station areas.

Access to information and related transparency is also an important part of equity-based approaches. Transparency around the hydraulic leak incidents and the subsequent work to understand the root causes and the performance of other transit agencies in this respect is essential in building and maintaining trust with the public. The TTC will continue providing key information to the public in transparent and accessible ways.

In response to understanding how hydraulic leak incidents have and can impact customers, the TTC will also continue to consider how the customer experience can be improved during major service disruptions. This work will help to mitigate challenges to equitable access to transit that can emerge during major service disruptions and will support equity-seeking groups when accessing the TTC's services.

In addition, the TTC recognizes that hydraulic leak incidents may impact employees in different ways, including negative impacts. In response to this, the TTC has accepted all recommendations provided by Hatch and APTA.

Innovation and Sustainability Matters

The TTC is committed to reducing the environmental impact associated with its operations and complying with all applicable legal and regulatory requirements. The TTC's internal corporate program on spills details prevention and response measures, including reporting requirements. To successfully implement this program, applicable staff are required to complete an online spills training module every two years. Supervisors are required to conduct a Safety Talk on spill management with unionized workers every six months.

The TTC has a very robust Spill Response Procedure, which includes clean-up and reporting. Following each incident, TTC workers completed a thorough clean-up to mitigate potential adverse effects on the natural environment. As required, the incidents and clean-up efforts are to be reported to the Ministry of Environment, Conservation and Parks (MECP) Spills Action Centre.

The Safety and Environment Department confirms that all internal and regulatory measures were taken during the subject hydraulic leak incidents. To date, there has been no follow-up from the MECP.

Following the incidents, the TTC broadcasted the Spill Response Procedure on TTC-TV at all work locations and reassigned the online Spills training module to all Track and Structure and Rail Cars and Shops employees.

Decision History

At its meeting on April 11, 2024, the Board was informed by a deputant representing Amalgamated Transit Union (ATU) Local 113 of a hydraulic fluid spill along the mainline track on January 17, 2024. At this time, the Board requested that TTC staff return to the next scheduled meeting with more information on the spill.

At its meeting on May 16, 2024, the Board received a presentation by TTC staff summarizing the hydraulic leak incidents in 2024 and the associated corrective actions taken. The Board requested staff to report back at subsequent meetings with updates on the investigation of the hydraulic leaks. In addition, it was requested that the final Hatch and APTA reports be shared, once finalized.

Report: Chief Executive Officer's Report – May 2024 (For Information)
Presentation: Service Impacts Due to Hydraulic Spills Summary of Recent Events

At each subsequent meeting of the Board, the TTC CEO's Report included an update on the progress of the Hatch and APTA investigations, targeting a final report in Q4 2024.

On November 15, 2024, at the Board's request, staff issued a briefing note transmitting the third-party reports.

Issue Background

The TTC maintains a fleet of 848 revenue subway cars for passenger service and 75 non-revenue cars for infrastructure maintenance. The work car fleet is highly varied, and each car's configuration and operating environment are largely unique. Work cars are generally and broadly classified by their main propulsion technology – electric, diesel, and trailer (no self-propulsion).

Historically, only four hydraulic leak incidents were reported between 2019 and 2023. From January to May 2024, there were a total of eight hydraulic leak incidents in the work car fleet.

Comments

Hatch Root Cause Assessment of Hydraulic Leaks

On May 15, 2024, two days after a hydraulic hose failure on RT-56 caused a 730-minute shutdown of Line 2, the TTC contacted Hatch to perform an independent root cause assessment of the May 13, 2024 incident and the four less disruptive leaks that had occurred earlier in the year. After engaging Hatch, there were three additional leaks that occurred. Hatch investigated all eight hydraulic leak incidents between January 14, 2024, and May 26, 2024.

The Hatch evaluation of incidents that had occurred on and after May 13, 2024 included physical inspection of the work cars and failed components, interviews with TTC staff, and the review of available documentation, including maintenance history for the work cars and internal TTC reports on hydraulic leak incidents. Hatch's review of the four early hydraulic leak incidents was limited to the available TTC documentation.

Hatch's investigation found that each failure had an identifiable technical root cause. There was no evidence of a nefarious or deliberate act, despite the unusually high number of occurrences over a short period of time. Hatch reported that the incidents appeared to be isolated failures, however, there were common findings that informed their recommendations to improve management practices as follows:

1. **Maintenance Records**: The level of information recorded in TTC's maintenance reporting system does not provide sufficient detail to trace the repair or replacement history of some components.
2. **Maintenance Program**: Recommended maintenance intervals and inspection criteria are not available or sufficient for the maintenance of hydraulic subsystem components.
3. **Configuration Management**: The limited availability of reference documentation and inadequate configuration control is impacting millwrights', coach technicians', and other tradespersons' ability to perform effective component repairs and replacements.

To effectively reduce the risk of future hydraulic leak issues, Hatch developed recommendations that can be found in Attachment 2, which includes the TTC's Management Action Plan. For the full report prepared by Hatch, please refer to Attachment 2 of this report.

APTA Peer Review of Hydraulic Leak Incident Management

The APTA Peer Review process is well-established as a valuable resource to the public transit industry. Highly experienced and respected transit professionals voluntarily provide their time and support to address the scope requested by the transit agency.

Following the hydraulic leak incidents, the TTC engaged APTA for a comprehensive peer review on the recent increase in service disruptions and failure modes that have impacted operations. These incidents were varying in nature and included the eight hydraulic leaks on the work cars. Additional incidents that occurred over the review period, including streetcar derailments and HVAC failures on buses, were also reviewed.

The panel conducted the peer review from July 22 to July 26, 2024, through documentation reviews, field observations, and a series of interviews with TTC staff. The observations and recommendations provided through this peer review were offered as an industry resource to be considered by the TTC in support of ongoing efforts to align and minimize service disruptions with industry standards.

Attachment 1 summarizes the recommendations from this peer review and includes the TTC's Management Action Plan. For the full APTA report, please refer to Attachment 3 of this report.

APTA's findings were consistent with Hatch's conclusion that, while the hydraulic leaks had common root causes, there was no evidence that the leaks, or any other incident they investigated, were the result of intentional acts or sabotage.

The TTC has accepted all recommendations put forth by Hatch and APTA and all are currently in a completed or in progress state. With this commitment, the TTC aims to implement effective strategies that will minimize the risks associated with hydraulic fluid spills and improve overall maintenance practices and vehicle reliability.

Next Steps

Staff will track implementation and provide an update to the Board upon closure of all recommendations from Hatch and APTA. The Audit, Risk, and Compliance Department will validate the completion of recommendations before the closeout report to the Board.

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Signature

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Attachments

Attachment 1 – TTC's Management Action Plan
Attachment 2 – Hatch Root Cause Assessment of Hydraulic Leaks
Attachment 3 – APTA Peer Review of Hydraulic Leak Incident Management

Table 1: Hatch Recommendations with TTC's Management Action Plan

Item	Recommendation	Owner	Management Action Plan	Status	Target / Completion Date
1 *(1i)*	Update work car recovery procedure to incorporate guidance to address hydraulic fluid leaks	• Rail Cars and Shops • Transit Control	**Implement 24/7 on-call work car technical support.**	Complete	Q4 2024
			Update Transit Control Work Instruction to require consultation with the 24/7 on-call work car technical support for all movement of disabled vehicles (revenue and non-revenue).	Complete	Q4 2024
			Develop recovery guidelines for work cars with hydraulic systems.	In progress	2025
2 *(1ii)*	Develop guidelines for coordination between TTC departments in response to spill incidents	• Operational Safety and Planning • Rail Cars and Shops • Track and Structure • Transit Control	**Develop guidelines for coordination between TTC departments.**	In progress	Q4 2024
3 *(2i)*	Improve [efficiency of] cleaning protocol for hydraulic fluid spills	• Track and Structure • Safety and Environment	**Review and update Spill Prevention and Spill Response Management Procedures.**	Complete	Q4 2024

Item	Recommendation	Owner	Management Action Plan	Status	Target / Completion Date
4 *(3i)*	Improve standard maintenance practices and procedures for work car maintenance tasks	• Rail Cars and Shops	**Develop work car inspection check sheets.**	Complete	Q4 2024
			Develop maintenance procedures for each vehicle type in the work car fleet.	In progress	2025: 5 cars 2026-2029: 18 cars/year
5 *(3ii)*	Quality assurance resources to oversee work car maintenance	• Rail Cars and Shops	**Assign resources to conduct quality assurance to oversee work car maintenance.**	Complete	Q3 2024
			Evaluate if additional configuration control resources are required to support this initiative long-term.	In progress	2025
6 *(4i)*	Establish a more detailed inspection regimen	• Rail Cars and Shops	**Develop detailed inspection points to address the failure modes identified in this report.**	In progress	Q4 2024
			Develop a detailed inspection regimen for each vehicle type in the work car fleet.	In progress	2025

Item	Recommendation	Owner	Management Action Plan	Status	Target / Completion Date
7 *(4ii)*	Determine an appropriate inspection interval for work car system components	• Rail Cars and Shops	**Develop maintenance intervals for work cars with hydraulic systems to address the failure modes identified in this report.**	Complete	Q2 2024
			Develop maintenance intervals for each vehicle type in the work car fleet.	In progress	2026
8 *(5i)*	Implement stronger quality assurance and control processes	• Rail Cars and Shops	**Implement independent quality control checks.**	Complete	Q4 2024
9 *(6i)*	Update maintenance reference documentation	• Rail Cars and Shops	**Engage with vehicle OEMs to update maintenance documentation where available.** **Update specifications for future procurements to require more comprehensive maintenance documentation as a contract option.**	Complete	Q4 2024
10 *(6ii)*	Improve inventory management protocols and configuration control guidelines	• Rail Cars and Shops	**Re-organize the inventory management to improve configuration control within the work car repair shop.**	Complete	Q4 2024

Item	Recommendation	Owner	Management Action Plan	Status	Target / Completion Date
11 *(7i)*	Provide On-call Work Car Technical Expert to support Transit Control Center during non-revenue service shifts	• Rail Cars and Shops	**Implement 24/7on-call work car technical support.**	Complete	Q4 2024
12 *(8i)*	Develop training materials and provide formal training	• Operations and Training Centre	**Develop and deliver refresher training.**	In progress	Q4 2024
13 *(9i)*	Update the SMS system in a timely fashion and improve the level of information in the reporting system	• Rail Cars and Shops	**Develop and implement a quality control process requiring timely updates on SMS system.**	Complete	Q4 2024
14 *(10i)*	Consider automatically shutting down hydraulic systems on low fluid level alarm activation	• Rail Cars and Shops	**Evaluate the cost, risks, and benefits of this recommendation.**	In progress	Q4 2024
			Implement auto shutdown of the hydraulic system.	Pending analysis	2025
15 *(10ii)*	Consider coupling the above new functionality with the implementation of a data logger to record activation of the low hydraulic fluid level alarm	• Rail Cars and Shops	**Evaluate the cost, risks, and benefits of this recommendation.**	In progress	Q4 2024
			Implement data logger.	Pending analysis	2025
16 *(11i)*	Perform audit to evaluate the condition and labeling of the [hose crimping] tooling	• Rail Cars and Shops	**Develop a plan and initiate audits for the condition and labeling of the hose crimping tool**	Complete	Q4 2024

Legend:

High Priority	
Medium Priority	
Low Priority	

Table 2: APTA Recommendations

Item	Recommendation	Owner	Management Action Plan	Status	Target / Completion Date
1	Develop maintenance instructions for work cars that are specific to the systems of the work car design.	• Rail Cars and Shops	**Develop work car inspection check sheets.**	Complete	Q4 2024
			Revise maintenance procedures for each vehicle type in the work car fleet.	In progress	2025: 5 cars 2026-2029: 18 cars/year
2	Include the proper cleaning of work cars prior to all periodic maintenance intervals.	• Rail Cars and Shops	**Require work car cleaning as part of the maintenance program.**	Complete	Q4 2024
3	Develop procedures for the fabrication of hydraulic hoses that are in line with industry standards that include proper training and qualifications for personnel who fabricate hydraulic hoses.	• Rail Cars and Shops • Operations and Training Centre	**Develop hose fabrication procedures and train staff.**	Complete	Q4 2024
			Update training curriculum and records in the Learning Management System.	In progress	Q4 2024
4	Evaluate usage of work car maintenance personnel to be available to assist when track and structure work cars are operating on the main line in case they become disabled.	• Rail Cars and Shops	**Implement 24/7 on-call work car technical support.**	Complete	Q4 2024
			Request additional resources to support this initiative long-term.	In progress	2025
5	Conduct exercises/drills on work car recovery from the main line with both operators and maintenance personnel to re-enforce procedures.	• Operations and Training Centre • Rail Cars and Shops	**Develop a strategy to implement regular exercises/drills on work car recovery.**	Complete	Q4 2024

Item	Recommendation	Owner	Management Action Plan	Status	Target / Completion Date
		• Track and Structure • Transit Control • Operational Safety and Planning	**Conduct the first recovery drill.**	In progress	2025
6	Review or revise after action review process/investigation to ensure that key facts of the incident are captured.	• Rail Cars and Shops • Track and Structure • Transit Control • Operational Safety and Planning	**Expand the scope of Quarterly Table Top workshop to include an after-action review.**	Complete	Q3 2024
			Develop an after-action review process for work car-related incidents.	In progress	2025
7	Consider developing a policy for who can authorize the movement of a disabled work car to ensure that it can moved safely.	• Transit Control	**Update Transit Control Work Instruction to require consultation with the 24/7 on-call work car technical support for all movement of disabled vehicles (revenue and non-revenue).**	Complete	Q4 2024
8	Re-emphasize the scope of the track and structure work car operator training to students so they know what mechanical systems they are qualified to assess upon completion of the training and when to escalate mechanical problems to work car maintenance personnel.	• Operations and Training Centre • Track and Structure	**Develop and deliver refresher training.**	In progress	Q4 2024

Item	Recommendation	Owner	Management Action Plan	Status	Target / Completion Date
9	Continue current practices of revenue vehicle incident management and that policies and procedures for incident management of non-revenue vehicles be aligned with that of revenue vehicles as both present the same level of risk to service disruptions.	• Transit Control	**Consistent with existing revenue vehicle incident management process, update Transit Control Work Instruction to require consultation with the 24/7 on-call work car technical support.**	Complete	Q4 2024
10	Develop established communication expectations and protocols for incident notification and post incident updates.	• Corporate Communications • Legal	**Update policy 1.3.4 Correspondence with Elected Officials and TTC Board Members.**	In progress	2025
11	Consider additional resources and/or personnel to manage public communication expectations.	• Corporate Communications • Strategy and Customer Experience • Transit Control	**Develop a customer communications standard to ensure timely and frequent customer updates through all channels.**	In progress	2025

Legend:

High Priority	
Medium Priority	
Low Priority	

– RESTRICTED –

Toronto Transit Commission

Subway Work Car Hydraulic Fluid Leak Investigation Report

			Mable Bakali			
2024-11-14	A	FINAL	Chris Petersen, P.Eng. Mable Bakali	Danny Ly, P.Eng. Gunneet Singh, P.Eng.	Sulaiman Janjua	
Date	**Rev.**	**Status**	**Prepared By**	**Checked By**	**Approved By**	**Approved By**

Version History

Revision	Date	Description of Change
Rev. 1	2024-07-19	Initial draft
Rev. 2	2024-09-06	Revised draft based on client inputs.
Rev. 3	2024-10-31	Revised draft based on client inputs.
Rev. A	2024-11-14	Finalized version

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List of Acronyms

EB	Eastbound
SOGR	Infrastructure State of Good Repair
NB	Northbound
OEM	Original Equipment Manufacturer
OSP	Operational Safety & Planning
PIC	Person in Charge
RCS	Rail Cars & Shops
RVE	Rail Vehicle Engineering
TCC	Transit Control Centre
TTC	Toronto Transit Commission
WAC	Work Area Coordinator
WB	Westbound

Scope

TTC contacted Hatch on May 15, 2024 to perform an independent assessment of eight work car incidents that occurred between January 14, 2024 and May 26, 2024, after a hydraulic hose failure on RT56 caused a 730-minute shutdown of Line 2. Hatch was not onsite to conduct an in-depth investigation and interview TTC stakeholders for the four incidents that occurred prior to Hatch's contract. Hatch's review of the four early work car incidents is limited to available TTC documentation. As such, the details for the four incidents that occurred prior to Hatch's contract date do not provide enough information for a detailed analysis but are included in this report for information only.

The evaluation of the May 13, RT56 spill event and subsequent work car incidents was conducted through the physical inspection of the work cars and failed components (where possible), interviews with TTC staff, and the review of available documentation (including maintenance history for the work cars and internal TTC reports on work car incidents). Staff interviews were limited to TTC vehicle maintenance and track maintenance personnel. Hatch acknowledges the reduction of future hydraulic fluid spill events and related service disruptions will require system-wide improvements. However, information and interviews regarding the involvement of stakeholders from other departments were not extensively evaluated, given the scope of this report primarily focuses on specific technical contributing factors rather than TTC's operational practices.

1. Executive Summary

The Toronto Transit Commission (TTC) operates 20-25 work cars a night to maintain 300 km of subway infrastructure as part of the agency's Infrastructure State of Good Repair (SOGR) Program. The work car fleet is composed of 75 cars, including 47 work cars that have hydraulic systems or equipment.[1]

Over a short period (January 14, 2024, to May 26, 2024), TTC has experienced issues with 8 subway work cars causing a hydraulic fluid leak: four O-ring failures, three hydraulic hose failures, and one vacuum clutch failure. A brief description of all 8 incidents is provided below:

1. **On Jan. 14, the RT56 work car** spilled 10L of hydraulic fluid between Sherbourne and Donlands stations, due to a hydraulic hose failure. Operators were instructed to operate at reduced speed within the areas affected by the spill, resulting in minimal impacts to revenue service.
2. **On Jan. 17, the RT17 work car** spilled 120L of hydraulic fluid on the southbound tracks between Eglinton West and St. Clair West stations on Line 1, due to a hydraulic filter O-ring failure. Operators were instructed to operate at reduced speed within the areas affected by the spill, resulting in minimal impacts to revenue service.

[1] 1_Service_Impacts_Due_to_ Hydraulic_Spills_Presentation.pdf, page 21, TTC, 2024.05.16

3. **On Feb. 10, the RT7 work car** spilled 5L of hydraulic fluid during a pre-departure inspection, due to a hydraulic filter O-ring failure. The spill did not impact revenue service, as the hydraulic fluid leak was discovered during a pre-departure inspection.
4. **On April 22, an RT41 work car** spilled 50L of hydraulic fluid while shunting north to the WYE at the Greenwood Yard, due to the failure of an unspecified O-ring. The spill did not impact revenue service.
5. **On May 13, the RT56 work car** spilled approximately 100L to 140L of hydraulic fluid on the rail infrastructure between Spadina and Dupont stations and between Yonge Station and the Greenwood Yard, due to a hydraulic hose failure. The incident caused a 730-minute shutdown of Line 2 and a reduced speed zone on Line 1, prompting TTC to contact Hatch to investigate the agency's recent rash of subway work car hydraulic fluid leaks.
6. **On May 15, the RT84 work car** spilled approximately 200L of hydraulic fluid onto the rail bed on the northbound track near Eglinton Station on Line 1, due to a clutch failure that consequently compromised a hydraulic hose. The RT84 incident did not cause a service disruption, given the hydraulic fluid spill and cleaning to address the spill occurred prior to revenue service hours.
7. **On May 16, the RT41 work car** leaked 0.25L of hydraulic fluid as the work crew was tamping ballast on the eastbound track near Keele Station, due to a pressure sensor O-ring failure. The RT41 incident did not cause a service disruption, given the hydraulic fluid leak and cleaning to address the leak occurred prior to revenue service hours.
8. **On May 26, the RT18 work car** spilled 30L of hydraulic fluid on the westbound track of Line 2, between Warden and Victoria Park stations, due to a hydraulic hose failure. The spill incident did not cause a service disruption as service was already suspended through the area for the weekend under a shared Impassable Work Zone.

This report documents Hatch's review of all 8 work car incidents including a summary of the provided information regarding the spill event, work car recovery, and spill site clean up efforts as well as the determination of root causes to make recommendations to reduce the risk of future hydraulic fluid leak issues.

Hatch's investigation established there is no evidence to support the notion that the eight incidents were caused by nefarious actions, despite the unusually high number of occurrences over a short period of time. The incidents appear to be isolated failures caused by the following common contributing factors:

1. The level of information recorded in TTC's SMS maintenance reporting system does not provide sufficient detail to trace the repair or replacement history of some components.
   a. The faulty hydraulic filter O-rings that caused the Jan. 17, RT17 and Feb. 10, RT7 incidents may have been past their service life. The service descriptions for the filters

did not provide specific information to determine when the filters are due for replacement (i.e., part numbers for old filters and replacement filters).

2. Recommended maintenance intervals and inspection criteria are not available or sufficient for the maintenance of hydraulic subsystem components.
    a. The vacuum clutch that prompted the May 15, RT84 hydraulic fluid spill has failed 3 times in the last 12 years, although the component is expected to have a much longer service life. Until recently, there was no inspection regimen for the vacuum clutch.
    b. TTC advised the last recorded maintenance for the pressure sensor assembly, including the O-ring that caused the May 16, RT41 hydraulic fluid leak was in 2015. Over 9 years, the O-ring could have easily hardened over time, becoming more brittle resulting in a minor leak.
3. The limited availability of reference documentation and inadequate configuration control is impacting millwrights', coach technicians' and other tradespersons' ability to perform effective component repairs and replacements.
    a. The lack of OEM documentation has challenged TTC's ability to maintain configuration control of the hose assembly and routing, which may have contributed to the hose failure that caused the May 13, RT56 incident.
    b. The use of an incorrect fitting and improper hose rating type caused the hose failure that led to the May 26, RT18 hydraulic fluid spill.

2. Work Car Incidents

2.1 Jan. 14, RT56 Hose Failure

The details about the Jan. 14, RT56 incident were derived from a TTC presentation on service impacts due to hydraulic fluid spills and are included in this report to demonstrate the scale of work car failures TTC has experienced within a short time span and to provide additional context for Hatch's recommendations. The limited information available for this incident is provided below.

2.1.1 Spill Event

On Jan. 14, the RT56 work car spilled a reported 10L of hydraulic fluid eastbound between Sherbourne and Donlands stations. At 8:29 am, train run 212 operating eastbound reported slippery rails at Castle Frank station. Three red signal violations due to positional uncertainty (E28s) were reported shortly thereafter. Additionally, train runs 214 and 215 reported traction faults and greasy rails. At 8:56 am, train run 216 reported overshooting Pape Station.

Figure 1 - Ruptured hose on RT56 on Jan. 14

2.1.2 Work Car Recovery

TCC was not aware of the hydraulic fluid spill until reports from train crews[2] of slippery rail conditions started at 8:29 am. The available records suggest, work crews only discovered the hydraulic fluid leak from RT56 at 9:45 am after the work car was already relocated to the Greenwood Yard. Sufficient information was not provided to determine why the hydraulic fluid

[2] Incident Log 202401140855897, TTC, 2024.01.14.

leak was not discovered and reported prior to revenue service operations. An in-depth evaluation of TTC's operational practices is outside the scope of this report; however, Hatch recognizes that coordination between departments to address spill incidents may need improvement, including processes to identify, contain, and remediate fluid spills.

2.1.3 Spill Site Cleanup

After train operators reported slippery rail conditions, spin/slide events, and a station platform overshoot, TCC contacted Track and Structures personnel at 9:00 am to investigate the track between Sherbourne and Donlands stations. At 10:00 am, a track crew was dispatched to assess and clean the fluid spill. TTC's records note the crew completed cleanup efforts between Chester and Pape stations at 10:33 am but pools of fluid and slick rail conditions were observed between Broadview and Chester Stations. At 10:47 am, the track crew cleared the area between Broadview and Chester Stations, after reporting slick rail conditions but observing no runoff fluid on the running rails. Track personnel were advised to ride in the cab to further evaluate the condition of the rail and potential need for additional cleaning.

2.1.4 Service Disruption

Slow operation (reduced speed) was implemented from Sherbourne to Donlands stations with minimal impacts to revenue service.[3]

2.1.5 Findings

The RT56 hydraulic fluid leak was caused by a hydrostatic hose failure. Figure 1 above demonstrates the hose was breached and required replacement.

2.1.6 Conclusion

Generally, limited information was available for the analysis of the Jan. 14, RT56 incident.

TTC has advised Hatch that 47 of the 75 work cars fleet use hydraulic fluid for their functionality, and 17 of the work cars are equipped with an audible and visual low hydraulic fluid level alarm. While the activation point of the low hydraulic fluid level alarm varies among the 17 work cars, the level at which the alarm for RT-56 is activated is just below the hydraulic fluid reservoir sight glass, which is approximately 10L from full capacity. As an additional safety measure, TTC could consider shutting down the hydrostatic propulsion system automatically to prevent any further hydraulic fluid spill anytime the fluid drops below a predetermined level. The TTC could also consider coupling the above new functionality with the implementation of a data logger to record activation of the low hydraulic fluid level alarm. However, the implementation of these features would likely require substantial engineering design effort as well as potentially significant material/equipment costs. Equally important to note is that these new features can only reduce the impact of a hydraulic fluid spill and are not preventative measures. A cost and time vs. benefit analysis would need to be conducted by the TTC to determine if the implementation of these features will be beneficial to the organization.

[3] Operation Group Serious Incident Report, TTC TCC, 2024.01.14.

2.2 Jan. 17, RT17 Filter O-ring Failure

The details about the Jan. 17, RT17 incident were derived from onsite interviews with TTC staff and a TTC presentation on service impacts due to hydraulic fluid spills. The limited information available for the RT17 incident is included in this report to demonstrate the scale of work car failures TTC has experienced within a short time span and to provide additional context for Hatch's recommendations. The limited information available for this incident is provided below.

2.2.1 Spill Event

On Jan. 17, RT17 spilled 120L of hydraulic fluid on the southbound tracks between Eglinton West and Dupont stations.

2.2.2 Work Car Recovery

After the hydraulic fluid leak was discovered at 2:26 am, a Chief Supervisor was assigned to oversee the coupling of RT17 to a rescue vehicle, RT20. At 3:52 am, RT20 was coupled to RT17 and the two work cars travelled to the Greenwood Yard.

2.2.3 Spill Site Cleanup

At 3:56 am, a Track and Structures work crew arrived at the spill site to clean the hydraulic fluid leak from the rail infrastructure. After the initial cleaning effort, operators for train runs 180, 144, 145, 153, 102, 101, 181, and112 reported slippery rail conditions and an overshoot, prompting a second cleaning effort.[4] At 9:32 am, Track and Structures established a large workzone from Eglinton West to St. Claire West to further clean the rails, which remained in effect until 1:27 pm.

2.2.4 Service Disruption

The Jan. 17, RT17 incident minimally affected passenger operations, despite the reported overshoot, slippery rail conditions and subsequent clean-up efforts. TCC implemented a speed restriction, and announcements were issued to train operators to facilitate safe train handling. Further, TTC's serious incident report for the spill does not note any service disruptions.

2.2.5 Findings

A faulty hydraulic filter O-ring was cited as the root cause of the hydraulic fluid leak for RT17 (see Figure 3). Initially, faulty filter inventory and/or improper installation during replacement were identified as potential causes for the O-ring failure in conjunction with TTC maintenance staff.

[4] SIR Eglinton West – Hydraulic Spill, Operation Group Serious Incident Report, 2024.01.17.

Five years of SMS maintenance records do not provide any evidence of hydraulic filter replacements for RT17. Hatch believes the filter and O-ring components may have been due for replacement, lacking any evidence to the contrary.

Figure 2 - RT17 View of hydraulic filter mounted with failed O-ring

Figure 3 - RT17 Close-up view of failed hydraulic filter O-ring

2.2.6 Conclusion

The review of TTC's maintenance records for RT17 suggest the filter and failed O-ring components may have been past their service life. TTC maintenance personnel typically mark the installation date on the filter, but this practice alone, without updating the service history in a record keeping system, can lead to missing required component maintenance. TTC maintenance reporting practices also require improvement, as the level of information in the SMS maintenance work order system did not always provide sufficient detail to determine when filters are due for replacement (i.e., part numbers for old filters and replacement filters).

2.3 Feb. 10, RT7 Filter O-ring Failure

The details about the Feb. 10, RT7 incident were derived from onsite interviews with TTC staff and a TTC presentation on service impacts due to hydraulic fluid spills. The limited information available for the RT7 incident is included in this report to demonstrate the scale of work car failures TTC has experienced within a short time span and to provide additional context for Hatch's recommendations. The limited information available for this incident is provided below.

2.3.1 Spill Event

On Feb. 10, RT7 spilled 5L of hydraulic fluid in the Greenwood Yard during a pre-departure inspection. No further details were provided about the spill incident.

2.3.2 Work Car Recovery

Work car recovery efforts were not required, as the incident occurred in the Greenwood Yard.

2.3.3 Spill Site Cleanup

Details regarding the cleanup of the hydraulic fluid leak were not provided.

2.3.4 Service Disruption

There were no impacts to revenue service, as the hydraulic fluid leak was discovered during a pre-departure inspection.

2.3.5 Findings

A faulty hydraulic filter O-ring was cited as the root cause of the hydraulic fluid leak. Evidence of the described faulty filter with defective O-ring was not available at the time of Hatch's onsite visit. However, a picture of the filter mounting housing that was taken at the time of the repair was provided. Faulty filter inventory and/or improper installation during replacement were identified as the potential causes for the O-ring failure. TTC personnel explained that the entire filter assembly (filter and filter mounting housing) was replaced by a new filter assembly after the failure due to the obsolescence of the original filter type.

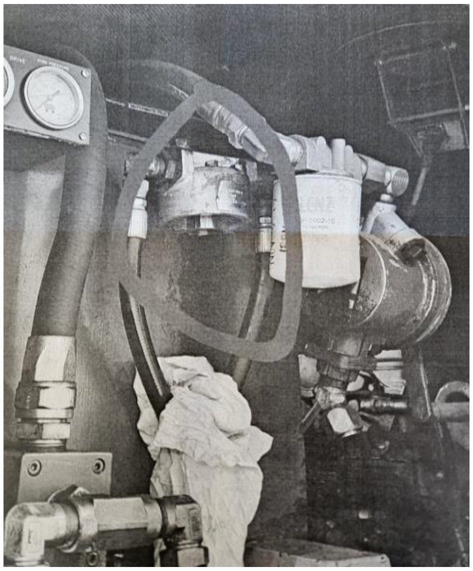

Figure 4 - RT7 Hydraulic Filter Mounting Housing, Original Configuration. Failed Filter Removed

Figure 5 - RT7 Hydraulic Filter and Filter Mounting Housing, New Configuration (Current)

Five years of SMS maintenance records (see Figure 6 below) do not provide any evidence of hydraulic filter replacements for RT7. The O-rings used in the filter assembly likely hardened and fractured due to use beyond their service life, given the O-rings are composed of rubber. The interval and procedure for the inspection and maintenance of the filters is unclear or not specified by TTC or the Original Equipment Manufacturer (OEM) of the work cars.

Serial	A/Fdate	Descrip	Notes
RT7	17/May/24	Work Car	REPAIRS REQ.: PRECAUTIONARY REPAIRS TO COMPRESSOR, HYDRAULICS,TRANSMISSION,PUMPS,MOTORS
RT7	15/May/24	Work Car	INSPECTION OF ALL HYDRAULIC LINES & LOAD TEST OF ALL FUNCTIONS REQUIRED. WorkDone INSPECTED ALL HYDRAULIC LINES & LOAD TEST OF ALL FUNCTIONS COMPLETED. ITEMS: ENGINE, BRAKES, HYDRAULICS, TRANSMISSION RESULTS: HOLD AS A PRECAUTION; FOUND SWEATING AT COMPRESSOR, HYDRAULICS, TRANSMISSION LABOUR: [redacted]
RT7	14/Feb/24	Work Car	HYDRAULIC OIL LEAK AT RETURN FILTER HOUSING WorkDone REPLACED FILTER AND FILTER HEAD WITH DONALDSON ASS Y. TESTED. OK.
RT7	06/Apr/22	Work Car	MINOR HYDRAULIC LEAK UNDER CAR WorkDone REPLACED 1/4 HYDRAULIC LINE
RT7	24/Mar/22	Work Car	MAJOR OIL LEAK UNDER CAR WorkDone REPLACED 3 MAIN HOSES REFILLED TRAY FLUID, TESTED OK
RT7	19/Mar/20	Work Car	OIL LEAK AT VANAIR COMPRESSOR WorkDone REPAIRED, REPLACED O RING TESTED OK

Figure 6 - RT7 Recent SMS maintenance records.

2.3.6 Conclusion

A review of TTC's maintenance records suggests the O-rings used in the filter assembly may have failed due to suspected use beyond their service life. TTC should develop maintenance requirements for the filters based on the lifecycle of the components, including inspection and service intervals as well as maintenance procedures.

2.4 April 22, RT41 O-ring Failure

The details about the Apr. 22, RT41 incident were derived from a TTC presentation on service impacts due to hydraulic fluid spills and are included in this report to demonstrate the scale of work car failures TTC has experienced within a short time span and to provide additional context for Hatch's recommendations. The limited information available for this incident is provided below.

2.4.1 Spill Event

On April 22, RT41 spilled 50L of hydraulic fluid while shunting north to WYE in the Greenwood Yard.

2.4.2 Work Car Recovery

Work car recovery efforts were not required, as the incident occurred in the Greenwood Yard.

2.4.3 Service Disruption

There were no impacts to revenue service.

2.4.4 Findings

Hatch was informed an O-ring failed but details to further analyze the failure were not available, as no pictures or other evidence was provided for the incident.

The SMS records (See Figure 7 below) indicate that RT41 may have still been leaking on April 25 after vehicle maintenance replaced an O-ring on April 22. However, vehicle maintenance confirmed no new leak was found. Multiple entries were recorded in the SMS maintenance record keeping system for the O-ring failure. The O-ring repair was performed on April 22nd which was noted in one work order entry. However, days later a staff member noticed a duplicate ticket for the O-ring failure was still open and closed it, citing the repair performed on April 22nd. As a result, the maintenance history for the failed O-ring is not documented clearly.

Serial	A/Fdate	Descrip	Notes
RT41	16/May/24	Work Car	HYDRAULIC LEAK, DRIPS COMING FROM A HOSE CONNECTIO N TAMPING EQUIPMENT
RT41	16/May/24	Work Car	INSPECTION OF ALL HYDRAULIC LINES & LOAD TEST OF ALL FUNCTIONS REQUIRED. WorkDone INSPECTED ALL HYDRAULIC LINES & LOAD TEST OF ALL FUNCTIONS COMPLETED ITEMS: PROPULSION RESULTS: HOLD AS A PRECAUTION, SEEPAGE AT PRESSURE SENSOR FOR PROPULSION PRESSURE LABOUR: [redacted] WORKCAR IS AT KEELE
RT41	16/May/24	Work Car	operator reports minor hydraulic leak coming from hose for unknown reason. [redacted] reports 1/4 of a litre lost. valve isolated to prevent further le akage. rt41 operated to keele yard under its own p ower. WorkDone shop inspection required.
RT41	16/May/24	Work Car	OPERATOR REPORTS MINOR HYDRAULIC LEAK COMING FROM HOSE FOR UNKNOWN REASON. [redacted] REPORTS 1/4 OF A LITRE LOST. VALVE ISOLATED TO PREVENT FURTHER LE AKAGE. RT41 OPERATED TO KEELE YARD UNDER ITS OWN P OWER. SHOP INSPECTION REQUIRED.
RT41	15/May/24	Work Car	INSPECTION OF ALL HYDRAULIC LINES & LOAD TEST OF ALL FUNCTIONS REQUIRED. WorkDone INSPECTED ALL HYDRAULIC LINES & LOAD TEST OF ALL FUNCTIONS COMPLETED. ITEMS: PROPULSION, BRAKES, ENGINE, HYDRAULICS, TAMPING EQUIPMENT RESULTS: NO LEAKS FOUND. LABOUR: [redacted]
RT41	09/May/24	Work Car	HYDRAULIC LEAK AT DOUBLE VANE PUMP HY830X17.17L WorkDone REPLACED PUMP. TESTED OKAY
RT41	27/Apr/24	Work Car	REPORT OF HYDRAULIC LEAK - WHEN CREW PARKED WORK C AR ON 26 TRACK IN YARD THEY NOTICED THE LEAK WorkDone REPLACED BLOWN O-RING. SEE [redacted]
RT41	25/Apr/24	Work Car	CAR LEAKING HYDRAULIC OIL IN WORK MODE WorkDone INSPECTED NTF
RT41	22/Apr/24	Work Car	UNSPECIFIED HYDRAULIC LEAK WorkDone REPLACED O-RING ON PROPULSION LINE; DISTRIBUTION B LOCK TOPPED UP OK - TESTED OKAY
RT41	22/Apr/24	Work Car	REPORT OF HYDRAULIC LEAK - WHEN CREW PARKED WORK C AR ON 26 TRACK IN YARD THEY NOTICED THE LEAK
RT41	13/Jun/23	Work Car	MAJOR HYDRAULIC LEAK UNDER #1 CAB WorkDone TIGHTENED FITTING-TESTED OKAY.
RT41	28/Dec/22	Work Car	MODIFY BOTH COUPLERS TO ADD HOSES AND VALVES FOR P ARKING BRAKE RELEASE (SIMILAR RT21) WorkDone COMPLETED BY A [redacted]
RT41	13/Sep/22	Work Car	PARKING BRAKE HYDRAULIC RELEASE HAND PUMP SEIZED WorkDone REPAIRED HYDRAULIC HANDPUMP, TESTED OK
RT41	12/Nov/20	Work Car	CRA DISABLE BY LOW HYDRAULIC ALARM, POSSIBLE LEAK AT VIBRATORS WorkDone INSPECTED, REFILLED TANK, FOUND OIL VALVE SLIGHTLY OPEN, CLOSED TESTED OK
RT41	22/Sep/20	Work Car	HYDRAULIC LEAK AT SPLITTER GEAR BOX WorkDone PLEASE SEE TICKET [redacted]
RT41	30/Aug/20	Work Car	REMOVE AND OVERHAUL ALL HYDRAULIC PUMPS WorkDone ALL 6 SENT TO SUNSOURCE. REHOSED, NEW FILTERS, OIL, 6 BARRELS OF OIL, TESTED OK
RT41	10/Mar/20	Work Car	STANDARD 90 DAY INSP. (SOP PENDING) WorkDone INSPECTION COMPLETED PASSED, REPLACED 10 HOSES TESTED OK

Figure 7 - RT41 SMS Maintenance records

2.4.5 *Conclusion*

No definitive conclusions can be drawn regarding the failed O-ring that caused RT41 to spill 50L of hydraulic fluid while shunting north to WYE in the Greenwood Yard, given the limited information available for the analysis of the incident. However, the lack of detail provided for the RT41 O-ring failure in the maintenance work order system, reinforces the need for more detailed service descriptions in TTC's maintenance reporting.

2.5 May 13, RT56 Hydraulic Hose Failure

The details about the May 13, RT56 incident were derived from onsite interviews with TTC staff and internal TTC reports and available information. TTC asked Hatch to perform a more in-depth investigation of the May 13, RT56 hydraulic fluid spill, given the incident caused a 730-minute shutdown of Line 2 and a reduced speed zone on Line 1.

2.5.1 Spill Event

On May 13, a TTC RT56 subway work car experienced a major hydraulic fluid leak while stationed on the northbound track at the north end of Spadina station. As noted in internal agency reports, TTC personnel were cleaning a vent shaft using the RT56's on-board power washer when they noticed the hose reel pulsating, strange noises emanating from the work car, and other concerning observations. TTC personnel used the emergency stop button to deactivate the power washer pump and examine the RT56, revealing a hydraulic hose had failed, spraying fluid on the work car and surrounding area including the third rail and running rails (see Figure 8 below).

After the discovery of the hydraulic hose failure, the equipment was shutdown at 4:09 am and stationed at the work site for 70 minutes as hydraulic fluid leaked from the failed hose. At 5:17 am, RT56 was then coupled to another work car, RT46, and towed to Spadina Station to vacate the work site for cleaning. The work cars departed Spadina Station at 5:43 am. Appendix B breaks down the timeline of the events that occurred after the spill was discovered, using video footage and transcripts of the correspondence between on-site employees and TCC personnel.

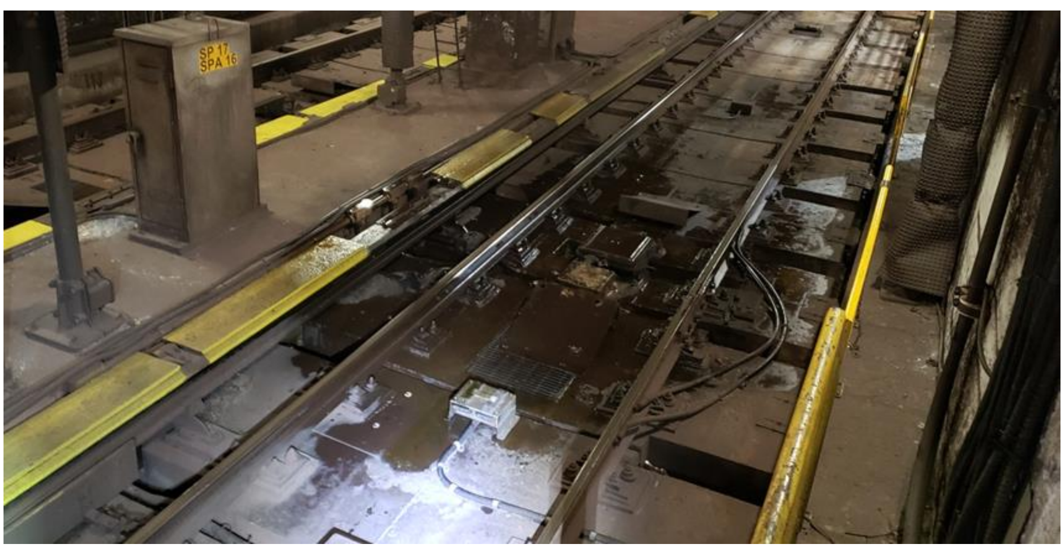

Figure 8 - Hydraulic fluid spill at Spadina station work site

2.5.1.1 Hydraulic Fluid Spill Distribution

TTC personnel estimated about 5 liters of fluid leaked from RT56 to track level based on visual observation. However, the failed hose, operating under a working pressure of 2500 psi, generated a large spray pattern and released approximately 100L to 140L of fluid into a catch basin below the work car and covered the third rail, running rails, track bed and sections of the carbody.

The 100L to 140L approximation includes the hydraulic fluid that saturated the pump room (see Figure 9 below) and coated the RT56 carbody underframe (see Figure 10 below). Cut-outs in the center and left side of the pump room floor area enabled hydraulic fluid to seep through the side sills.

Figure 9 - Overhead view of engine room

Figure 10 - View of engine room from undercar

Once back at Greenwood Yard, RT56 was briefly started (engine turned on) and a large spray pattern of hydraulic fluid was generated even under a standby pressure of 350 psi. This exercise confirmed the hydraulic fluid spraying from the hose coated the underside of the RT56 significantly during the initial spill at the work site north of Spadina station.

An engine off test was also performed on the hydraulic system, using a new hose with a ball valve opened on the end, to simulate a 1/8-inch diameter hole. The results of the test show that the hose was leaking at a drip rate of at least 150mL/min even after the engine was shut off during the incident.

2.5.2 *Work Car Recovery*

Misunderstandings about the amount of leaked fluid, the functionality of the work cars, and the relocation plan for RT56 increased the area impacted by the spill.

1. Despite a plan to temporarily move RT56 to Bay Lower Station to characterize and contain the hydraulic fluid leak, the foreperson that was first on the scene was surprised to discover the RT56/RT46 work car consist traveled through Bay Lower and continued to the Greenwood Yard on Line 2, which increased the range of the hydraulic fluid leak

on Line 1 and Line 2. TTC has since updated their vehicle recovery protocol for track level spills that occur during revenue service, which designates which staff members (Assistant Manager – Transit Control, Person in Charge, Wayside Supervisor, etc.) are responsible for each vehicle recovery task in the event of a fluid spill[5].

2. Employees assumed that shutting off the engine would significantly reduce the flow of hydraulic fluid from RT56 and limit the spill to the work area, but the hydraulic fluid coating the underside of RT56 shook loose from the carbody while in motion. Additionally, cut-outs in the pump room floor area enabled hydraulic fluid to seep through the side sills onto the tracks.
3. A Hatch analysis approximated 100L to 140L of fluid spilled during the incident rather than the 5L estimation provided by TTC employees. Note: The hydraulic fluid coating the underside of RT56 and filling the pump room as well as the catch basin located below the work car within the track bed was not readily visible to TTC employees.

The initial plan to temporarily park the work car consist at Bay Lower to evaluate RT56 and assess the hose for further leakage could have prevented the 12-hour service disruption by limiting the spill to Line 1. Sufficient information was not provided to determine what efforts were taken to contain the fluid spill, and further investigation of TTC’s spill response efforts is outside the scope of this report.

2.5.3 Spill Site Cleanup

After RT46 moved RT56 from the work area, TTC personnel used absorbent, degreaser, and cloth material to clean up the spill. Despite the initial cleanup effort, operators on Line 2 reported spin-slide events and platform overshoots after the start of revenue service, indicating manual cleaning efforts did not sufficiently address the fluid spill. A subsequent cleanup crew composed of 12 people was dispatched to further clean the affected areas.

Sufficient information was not provided to determine why the initial cleaning efforts were not successful (e.g. lack of procedure, communication, etc.). However, Hatch recognizes the efficiency of the cleaning protocol for hydraulic fluid spills may need improvement but specific recommendations to this effect are outside the scope of this report. It took one supervisor an hour to transport supplies from the Greenwood Yard to Bloor-Yonge Station, travelling by surface. TTC to consider the use of work cars to deliver cleaning supplies, the storage of fluid spill kits on the work cars (particularly cars with large volume fluid tanks), and additional improvement measures.

2.5.4 Service Disruption

During the initial clean up effort, the work cars were temporarily parked at the Spadina station platform for 25 minutes. Additional hydraulic fluid leakage was not apparent to TTC personnel at the time. However, once RT56 was in motion from Spadina Station, hydraulic fluid adhering to the underframe, pooled in sections of the carbody, and dripping through the failed hose was

[5] WI STT P7-S5-W520 rev. r13-05-24a, SUBWAY – VEHICLE SLOW ORDER, TTC TRANSIT CONTROL

transferred to the tracks. RT56 continued to leak hydraulic fluid while pushed south on the northbound tracks from Spadina to Museum station and then when pulled from Museum to Bay Lower and then East to Greenwood Yard, creating slippery rail conditions.

Figure 11 - Hydraulic fluid leaked on rails and track bed at Sherbourne station

On eastbound Line 2, revenue trains experienced spin-slide events and emergency braking applications (see Table 1) shortly after the start of service. Additionally, train run 223 (travelling eastbound on Line 2) reported a platform overshoot at Yonge at 6:05 am, noting rail issues. Subsequent train runs 226, 228, 233, 234 and 235 all experienced spin-slide events and positioning losses. This resulted in red signal violations due to positional uncertainty (E28s) and Emergency Brake application reporting due to lost positioning (E13s).

Table 1 – YMSS Data for Line 2 on May 13, 2024

Serial	Boxes2	A/Fdate/Time	Notes	Actual KPH	Commanded KPH	Location2	Bound	Combined
5108	r-223	13/May/24 06:04 AM	SCS, Doube Spin Slide Mismatch	34	50	Bay(Upper) to Yonge	EB	Bay(Upper) to Yonge EB
5209	r-223	13/May/24 06:05 AM	EMERG BRK OTHER > 10KPH 11KPH 210			#N/A	#N/A	#N/A
5268	r-223	13/May/24 06:05 AM	EMERG BRK OTHER > 10KPH 21KPH 207			#N/A	#N/A	#N/A
5269	r-223	13/May/24 06:05 AM	EMERG BRK OTHER > 10KPH 32KPH 53			#N/A	#N/A	#N/A
5188	r-226	13/May/24 06:15 AM	SCS, Doube Spin Slide Mismatch	10	27	Sherbourne Station	EB	Sherbourne Station EB
5018	r-226	13/May/24 06:20 AM	EMERG BRK OTHER > 10KPH 17KPH 169			#N/A	#N/A	#N/A
5019	r-226	13/May/24 06:20 AM	EMERG BRK OTHER > 10KPH 19KPH 113			#N/A	#N/A	#N/A
5188	r-226	13/May/24 06:20 AM	SCS, Doube Spin Slide Mismatch	06	27	Sherbourne to Castle Frank	EB	Sherbourne to Castle Frank EB
5188	r-226	13/May/24 06:20 AM	SCS, E28 Position Certainty Violation, E.B. Applie	11	25	Sherbourne to Castle Frank	EB	Sherbourne to Castle Frank EB
5223	r-226	13/May/24 06:20 AM	EMERG BRK OTHER > 10KPH 18KPH 103			#N/A	#N/A	#N/A
5188	r-226	13/May/24 06:21 AM	EMERG BRK OTHER > 10KPH 18KPH 4			#N/A	#N/A	#N/A
5188	r-226	13/May/24 06:22 AM	SCS, Doube Spin Slide Mismatch	08	60	Castle Frank Station	EB	Castle Frank Station EB
5188	r-226	13/May/24 06:22 AM	SCS, E28 Position Certainty Violation, E.B. Applie	00	60	Castle Frank Station	EB	Castle Frank Station EB
5132	r-228	13/May/24 06:22 AM	EMERG BRK OTHER > 10KPH 35KPH 3			#N/A	#N/A	#N/A
5133	r-228	13/May/24 06:22 AM	EMERG BRK OTHER > 10KPH 36KPH 3			#N/A	#N/A	#N/A
5344	r-228	13/May/24 06:22 AM	SCS, Doube Spin Slide Mismatch	42	61	Yonge to Sherbourne	EB	Yonge to Sherbourne EB
5344	r-228	13/May/24 06:22 AM	SCS, E28 Position Certainty Violation, E.B. Applie	35	61	Yonge to Sherbourne	EB	Yonge to Sherbourne EB
5344	r-228	13/May/24 06:25 AM	SCS, E13/E22 EB applied due to loss of positioning	34	15	Yonge to Sherbourne	EB	Yonge to Sherbourne EB
5344	r-228	13/May/24 06:28 AM	SCS, Doube Spin Slide Mismatch	11	25	Sherbourne to Castle Frank	EB	Sherbourne to Castle Frank EB
5344	r-228	13/May/24 06:29 AM	SCS, Doube Spin Slide Mismatch	13	75	Castle Frank to Broadview	EB	Castle Frank to Broadview EB
5344	r-228	13/May/24 06:29 AM	SCS, E28 Position Certainty Violation, E.B. Applie	12	75	Castle Frank to Broadview	EB	Castle Frank to Broadview EB
5344	r-228	13/May/24 06:30 AM	SCS, Doube Spin Slide Mismatch	02	75	Castle Frank to Broadview	EB	Castle Frank to Broadview EB
5344	r-228	13/May/24 06:31 AM	SCS, E28 Position Certainty Violation, E.B. Applie	00	75	Castle Frank to Broadview	EB	Castle Frank to Broadview EB

For Line 1, the number of spin-slide events detected on the route per truck is detailed in the YMSS data table below (Table 2) obtained from TTC, starting with the first set of revenue vehicles, which experienced spin-slide events starting at 6:11 am. The initial spin-slide events on Line 1 prompted an advisory to operators to travel at restricted speed.

Table 2 – YMSS Data for Line 1 on May 13, 2024

Date(MM/DD/YY)	Time Range	Train	Run Number	Location (between)	# Spin-Slide Events per truck
5/13/2024	6:11:14 to 6:18:36 AM	TR565	R120FH053121A	Museum & Spadina	99
5/13/2024	6:17:40 to 6:22:32 AM	TR557	R121FH053608A	Museum & Spadina	81
5/13/2024	6:23:56 to 6:28:39 AM	TR586	R123FH054055A	Museum & Spadina	57
5/13/2024	6:29:45 to 6:35:07 AM	TR590	R124FH054537A	Museum & Spadina	55
5/13/2024	6:37:54 to 6:41:12 AM	TR542	127	Museum & Spadina	31
5/13/2024	6:41:37 to 6:47:32 AM	TR587	R130FH055943A	Museum & Dupont	59
5/13/2024	6:48:27 to 6:53:49 AM	TR549	R131FH060425A	Museum & Dupont	136
5/13/2024	6:54:15 to 7:01:02 AM	TR579	R042MH060112A	Museum & Dupont	220
5/13/2024	7:00:10 to 7:02:54 AM	TR570	R153GH065400A	St. George & Dupont	59
5/13/2024	7:01:26 to 7:06:28 AM	TR598	R033UH065200A	Museum & Dupont	131
5/13/2024	7:06:02 to 7:21:58 AM	TR584	R142MH060612A	St. George & Dupont	67
5/13/2024	7:09:07 to 7:26:30 AM	TR576	R134FH061349A	Museum & Dupont	141
5/13/2024	7:26:34 to 7:34:21 AM	TR541	R020LH070347A	Museum & Dupont	55
5/13/2024	7:27:49 to 7:30:09 AM	TR606	R137FH061831A	Spadina & Dupont	23
5/13/2024	7:30:22 to 7:32:02 AM	TR595	140	Spadina & Dupont	10
5/13/2024	7:36:46 to 7:36:52 AM	TR540	141	Dupont	2
5/13/2024	7:37:02 to 7:37:38 AM	TR564	152	Spadina	6
5/13/2024	7:43:16 to 7:43:24 AM	TR568	R136FH063517A	Spadina	20
5/13/2024	7:44:41 to 7:48:49 AM	TR573	145	St. George & Dupont	18
5/13/2024	7:48:21 to 7:52:14 AM	TR556	R044FH064137A	Spadina & Dupont	25
5/13/2024	7:50:56 to 7:55:25 AM	TR589	R146FH064447A	Spadina & Dupont	18
5/13/2024	7:58:32 to 7:58:47 AM	TR547	147	Dupont	5
5/13/2024	7:59:28 AM	TR559	149	Spadina	1
5/13/2024	8:16:17 AM	TR599	122	St. George	1
5/13/2024	12:13:30 to 12:13:32 PM	TR545	123	Museum	2
				Total	1322

Transit Control records do not indicate a restricted speed zone advisory for Line 2 even though the first spin-slide event was reported at 6:05 am. The YUS line PA call issued at 6:12 am to advise operators of the restricted speed zone northbound Line 1 from Museum to Spadina station should have been extended to Line 2 between St. George and Greenwood.

The T1 cars that operate on Line 2 do not have the same level of reporting, monitoring and recording of wheel spin-slide activity through the Automatic Train Control (ATC) system as the Toronto Rocket Cars that operate on Line 1. This limits the ability to issue speed restriction notifications to T1 operators in real-time to prevent platform overshoots. Transit Control decisions are based on operator reports for the T1 cars on Line 2. Additionally, the T1s were travelling at higher speeds which also contributed to platform overshoots, leading to E28s, E13s, and the eventual 6:50 am call to suspend service on Line 2 between St. George and Broadview Stations.

As stated previously, a cleanup crew composed of 12 people was dispatched to the affected areas on Line 2 to further clean the spill. As such, the hydraulic hose failure and subsequent leak of hydraulic fluid from RT56 caused a service disruption of 730 minutes (from 6:50 am to 7:00 pm), including impacts to peak service revenue operations. An investigation was initiated to determine the cause of the spill incident.

2.5.5 Findings

2.5.5.1 Failure Mechanism

An investigation of TTC's May 13, 2024 spill incident determined an abraded hose routed tightly against the chamfered edge of a steel ring in the floor grate was the failure mechanism that caused the hydraulic fluid leak. Over years of service, the motion of the hose against the ring caused wear and visible abrasions on the hose. The continued abrasion of the hose exposed the wire mesh which created a sharp edge on the ring and eventually caused the hose to fail, enabling hydraulic fluid to leak from the hose.

Figure 12 - Abrasion on the hose

Figure 13 - Wear on the ring

After examining the failed hose pictured in Figure 12, Geoffrey Philipsen, a Senior Product Application Engineer for a hydraulic hose supplier, confirmed the observed abrasions were the failure mechanism that caused the spill incident. The hose and ring were then sent to Acuren Testing Laboratories (formally Cambridge) in Oakville for visual, microscopic, and scanning electron microscope examination.

The Acuren report concludes that "Abrasive wear during the service was likely the cause for damages on the hydraulic hose. Wear marks were evident on the worn surface of wire strands. Wear marks were also observed on the flat tip of the broken wire strands.[6] The Acuren report is available in Appendix A.

2.5.5.2 Contributing Factors Hose

2.5.5.2.1 Routing and Bundling

The hydraulic hose routing and bundling contributed to the failure that caused the spill incident. The failed hose was not routed per the work car OEM's routing scheme. In the work car OEM's routing scheme pictured in Figure 14, the work car OEM claims the hoses are routed vertically and over the engine starter to create a larger bend radius that avoids sharp angles. TTC maintenance staff believe this routing approach subjects the hosing to heat from the engine and leaves the hose bundle exposed to chafing due to unconstrained movement.

[6] 128-24-HAT003-J152359, Failure Analysis Examination of a Hydraulic Hose, Acuren Group Inc, 8 July 2024

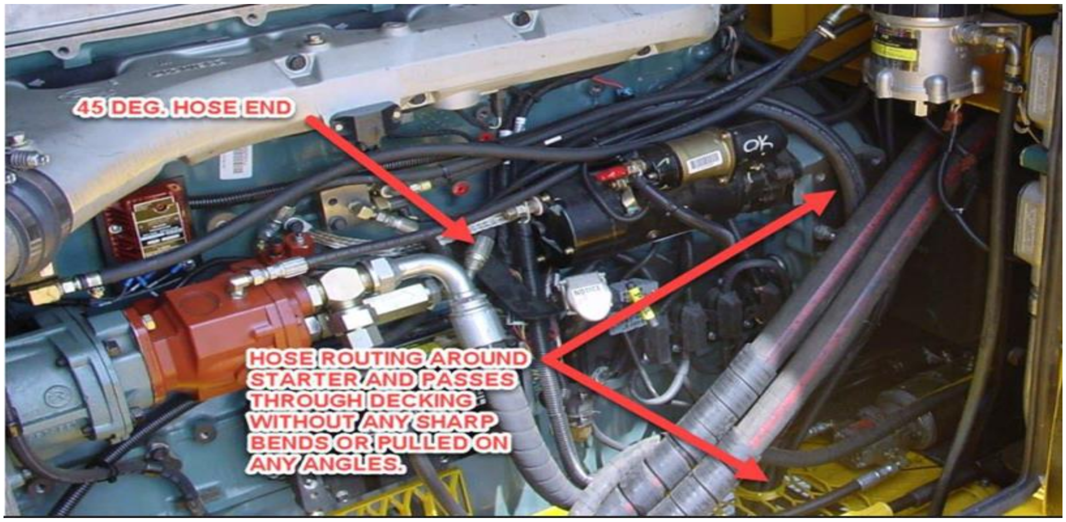

Figure 14 - RT56 original work car OEM routing

Over the years, TTC millwrights adapted the routing to address issues with the workcar OEM's hose arrangement. The TTC routing scheme pictured in Figure 15 below used a 90-degree fitting instead of the work car OEM's 45-degree fitting, is shorter in length, and avoids the engine. However, TTC's routing scheme created a sharp hose angle at the exit point of the circular steel floor ring, which led to the abrasion discussed in Section 2.5.5.1 that eventually wore through the hose.

TTC maintenance personnel are still working to develop an optimal routing scheme and floor grate opening. As an interim repair measure, the original circular ring was cut out and replaced with a larger rectangular shape (see Figure 16) after the May 13 incident. Now, the hoses are bound together (orange arrow) to reduce the angle (indicated by the blue arrow) at the exit point to reduce the risk of similar failures. However, it is noted that the hoses are still in contact against the steel ring and are still subject to abrasion through movement.

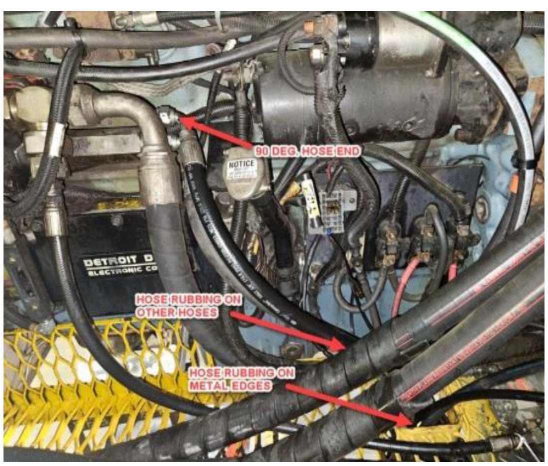

Figure 15 - RT56 TTC hose routing in May

Figure 16 - RT56 hoses as of June 6

In accordance with Hatch's recommendation to improve configuration control, identified equipment issues should be reviewed for disposition, and if necessary appropriate TTC staff should review and approve any design changes for incorporation. Further, the implementation of changes should be confirmed by quality assurance resources.

2.5.5.2.2 Maintenance Personnel and History

The investigation of TTC's recent hydraulic fluid spills identified several contributing factors to the hydraulic hose failures, including organizational issues such as limited resources and differing staff competencies.

The employee rosters provided to Hatch indicate there are four licensed millwright employees TTC relies on to maintain the work car hydraulic systems. Hatch's review of the TTC provided SMS data (Table 3), indicated most of the recent hydraulic work on RT56 has been performed by employees holding the Coach Technician designation. Further, the review of sample data from TTC SMS maintenance records, suggests the most senior millwright has not performed work on the RT56 hydraulic hoses and many of the other work cars in the fleet since 2021 (prior to the incident).

TTC noted that Coach Technicians have the skills and competency to work on work car hydraulic systems and the tasks performed by Coach Technicians are generally confined to the replacement of components (pumps and motors) which is supplementary to the millwrights' activities.

TTC noted difficulties in hiring and retaining experienced millwrights following the COVID 19 pandemic and an internal union seniority shuffle. Currently, the licensed millwright employee with the longest tenure has eight years of general experience working in TTC's shop. Hatch was informed this millwright trained the more junior millwrights, each of whom has 1.5 years of TTC experience (plus any additional outside experience including licensure). The Coach Technicians were later mentored by both the senior and more junior millwrights. Peer-to-peer training is a recognized industry approach to familiarizing employees with equipment. However, it is noted that the influx of employees with less than 2 years of work car experience may have impacted the mentorship process.

Improved hydraulic inspection procedures should be developed and supplemented with peer-to-peer training. As previously noted, TTC's SMS system does not provide sufficient information regarding the maintenance history of the work cars and improvement to information capture will aid the technicians by providing additional history for the repair of hoses and other work car system components.

Table 3 – RT56 Summary of Hydraulic System Repairs/Replacements (2023 and 2024)

Item #	Equip	Descrip	Notes	# Labour	SymDate
1	RT56	Work Car	WATER PRESSURE HOSE LEAKING / BROKEN WorkDone REPLACED HOSES + TIGHTENED FITTINGS.	2 CT	18/May/23
3	RT56	Work Car	HOSE FROM TANK TO WATER PUMP IS LOOSE AT THE VALVE WorkDone REBUILT RETURM LINE PIPING.	1 CT	26/Jun/23
2	RT56	Work Car	DAMAGED ALL 3 WATER HOSES FROM PUMP TO HOSE REEL WorkDone DAMAGED HOSES REPLACED - TESTED OK.	1 MW, 2 CT	31/Jul/23
4	RT56	Work Car	BROKEN HYDRAULIC LINE FOR WASTE BIN CONTROLS WorkDone REPLACED HYD. HOSE. [**REDACTED**]	1 CT	26/Sep/23
5	RT56	Work Car	HYDRAULIC FLUID LEAK - AREA BETWEEN SHERBOURNE AND PAPE FOUND TO HAVE FLUID ON RUNNING RAILS CAUSING NUMEROUS SCS ISSUES AND ONE OVERSHOOT WorkDone REPLACED HYDRAULIC HOSE FOR REMOTE PUSHER LIMITER, TOPPED UP OIL, YARD TESTED; WASHED ENGINE/PROPULS ION ENCLOSURE	4 CT	14/Jan/24
6	RT56	Work Car	ONE SHUT-OFF VALVE FOR HYDRAULIC TANK LEAKING WorkDone REPLACED SHUT OFF VALVE. TOPPED UP OIL;	3 CT	24/Jan/24
7	RT56	Work Car	COMPRESSOR NNOT WORKING WorkDone REPALCED COMPRESSOR MOTOR CLUTCH - TESTED OK	1 CT	20/Feb/24
8	RT56	Work Car	TRANSMISSION LIGHT/BUZZER IS ON WorkDone REPLACED TRANSMISSION LUBE FILTER. REPAIRED DAMAGE D SIGNAL WIRE	1 CT	30/Apr/24

MW = Millwright

CT = Coach Technician

The RT56 vehicle and other work cars in the fleet are custom built vehicles. Over time TTC has updated some of the work cars to address functionality and obsolescence issues. As a result, a gap has developed between the available documentation and the current configuration of some vehicles, hampering the millwrights', and other tradespersons' capability to effectively perform work car repairs.

Additionally, an incomplete 90-day inspection report conducted in April for RT56 work car #PC09634I suggests a lack of quality assurance and control in TTC's maintenance process. The evaluation of the hydraulic system components was not clearly documented as part of April's Engine inspection. It is unclear if TTC maintenance staff followed up on the omission of the hydraulic system inspection. In addition to staff, experience, and documentation limitations, initial observations indicate the parts and materials required to perform equipment repairs and replacements may not be properly marked and stored, perpetuating observed maintenance issues.

2.5.6 Conclusion

The initial spill incident was caused by a hydraulic hose failure. The hose failed due to abrasion over a period of time against the chamfered edge of a steel ring in the flooring of the engine compartment. Inadequate maintenance practices and procedures for the routing, repair, and upkeep of hydraulic hoses resulted in the failure of the hose over time. Additionally, the failure to temporarily park the work car consist at Bay Lower increased the physical area of the spill, causing a reduced speed zone on Line 1 and a 730-minute service disruption on Line 2 (from 6:50 am to 7:00 pm), due to reports of spin-slide events on both lines and station platform overshoots on Line 2.

The availability of reference documentation for the hydraulic system components would help TTC develop improved maintenance procedures and training materials for the performance of effective component repairs and replacements, including the hose routing. Hatch also recommends TTC implement improvements to their vehicle recovery procedures such as better staff coordination and guidance to address hydraulic fluid leaks (e.g. providing a on-call work car technical expert to support operators, TCC, and Track and Structure in the event of a hydraulic fluid leak). Since the May 13, RT56 spill incident, TTC has implemented the following measures to reduce the risk of future hydraulic fluid spills and subsequent service disruptions:

1. Technicians are inspecting each work car prior to service. Work cars that fail the inspection pass/fail criteria are not permitted to go into service, which has reduced work car incidents.
2. TTC has updated the vehicle recovery protocol for track level spill incidents that occur during or after revenue service. The updated protocol instructs employees not to move a work car until a track level spill issue is characterized and communicated to management.

2.6 May 15, RT84 Vacuum Clutch Failure leading to Hose Failure

The details about the May 15, RT84 incident were derived from onsite interviews with TTC staff and internal TTC reports and available information. The information available for the RT84 incident is included in this report to demonstrate the scale of work car failures TTC has experienced within a short time span and to provide additional context for Hatch's recommendations.

2.6.1 Spill Event

On May 15, 2024, at 1:52 am, a TTC RT84 work car spilled approximately 200L of hydraulic fluid onto the rail bed on the northbound track near Eglinton Station on Line 1, while excavating track ballast to make room for cable conduits using the work car vacuum[7]. After 5 minutes of use, the vacuum malfunctioned, and the ballast sucked into the hose did not go into the hopper. The operator also observed a burning fluid odour. According to internal TTC reports, the operator and Person in Charge (PIC) discovered a hydraulic fluid leak, a broken driveshaft, a deformed shaft guard, and a hydraulic hose that was physically pulled out from its fitting after examining the engine compartment.

2.6.2 Work Car Recovery

The PIC called TCC to report RT84 was disabled due to a hydraulic fluid leak which spilled approximately 200L of fluid onto the rail bed on the northbound track near Eglinton Station. Initially, the PIC and other onsite personnel physically pushed RT84 away from the spill site to further examine the work car. At 4:39 am, RT21 was coupled to RT84 to tow the disabled work car to the Davisville Yard.

2.6.3 Spill Site Cleanup

Onsite personnel cleaned the area where the spill occurred after RT84 was pushed away from the site. RT84 was then towed to the Davisville Yard. At 4:55 am, a test train reported no spin-slides events were observed, confirming RT84 was relocated to the yard without further incident and the hydraulic fluid leak was successfully cleaned. TTC kept a cleanup crew on standby as an additional precaution.

2.6.4 Service Disruption

The RT84 incident did not cause a service disruption, given the hydraulic fluid spill and cleaning to address the spill occurred prior to revenue service hours.

[7] 1_Service_Impacts_Due_to_ Hydraulic_Spills_Presentation.pdf, page 25

Figure 17 - RT84 Spill NB Eglinton on May 15

2.6.5 Findings

The hydraulic fluid spill was caused by a series of events. First the excessively worn driveshaft clutch plates seized and disintegrated, enabling the driveshaft to rotate freely unconstrained. The flailing driveshaft then hit the housing cage, causing the housing cage to impinge on a hydraulic hose at the fitting area. The force of the impact severed the hose from its fitting, causing the evacuation of hydraulic fluid onto the rail bed.

The RT84 SMS maintenance records for the past 12 years include 3 vacuum clutch replacements (11 April 2019, 01 Feb. 2017 and 02 April 2012). Though, the clutch component is expected to last a lot longer. The clutch units should be regularly inspected, given TTC has replaced 3 clutches in a 12-year period for the RT84 work car.

Figure 18 - RT84 clutch housing with broken driveshaft

Figure 19 - RT84 severed hydraulic hose

Figure 20 - RT84 engine compartment with broken drive shaft and damaged shaft guard

2.6.6 Conclusion

At the time of the incident, TTC did not have inspection criteria for the clutch plate. TTC has since obtained a clutch plate maintenance procedure and appropriate service interval from the clutch OEM, providing TTC maintenance a basis to identify condemning limits for replacement. This will allow TTC maintenance to establish an inspection regimen for the clutch plate component.

The inspection requirements for the clutch plate should be implemented for RT56 and any other vehicles in the fleet using this clutch. TTC's updated pre-departure inspections for the work cars and associated pass/fail criteria, will further reduce the occurrence of work car failures on the mainline.

2.7 May 16, RT41 O-ring Failure

The details about the May 16, RT41 incident were derived from onsite interviews with TTC staff and internal TTC reports and available information. The information available for the RT41 incident is included in this report to demonstrate the scale of work car failures TTC has experienced within a short time span and to provide additional context for Hatch's recommendations. However, the volume of fluid spilled during the May 16, RT41 incident was well below the reporting threshold, which is 1L per TTC's spill policy.

2.7.1 Spill Event

On May 16, TTC personnel observed a hydraulic fluid leak on RT41 as the work crew was tamping ballast on the eastbound track near Keele Station using the work car. The leak was observed after the work car was moved to another location during tamping. The initial inspection of the work car indicated the leak was minor and a junction block with either a loose or broken gasket/seal was the source of the leak. TTC reported the work car only leaked 0.25L of hydraulic fluid before onsite employees took action to prevent further spilling.

2.7.2 Work Car Recovery

Onsite personnel advised TCC of the leak and the Chief Supervisor was dispatched to the work site. After, the PIC and Chief Supervisor inspected the track area, the work car was relocated to Keele siding under its own power for further examination. No further details were provided regarding work car relocation efforts.

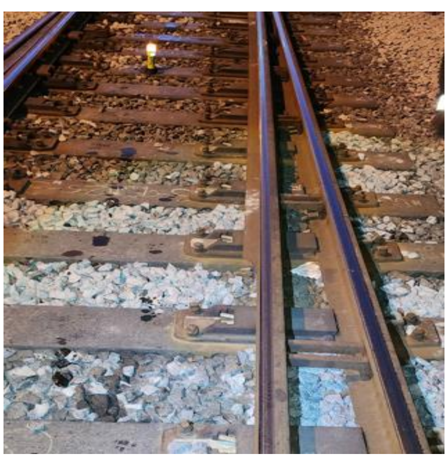

Figure 21 - RT41 Hydraulic fluid spill at work site (see track bed)

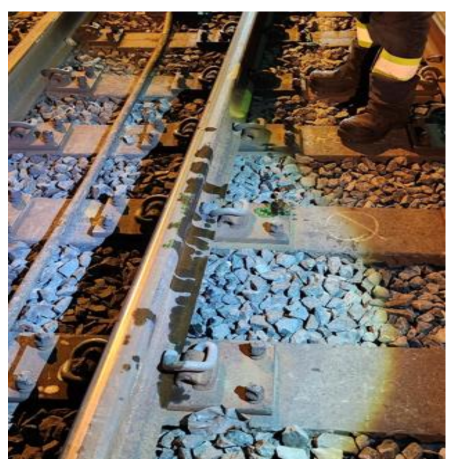

Figure 22 - RT41 Hydraulic fluid spill at work site (see running rails)

2.7.3 Spill Site Cleanup

During the inspection of the track, the PIC and Chief Supervisor observed fluid drips on and between the running rails from Keele and Dundas West Stations, noting most of the fluid was concentrated at the location of the work car. No further details were provided regarding the cleanup of the May 16, RT41 hydraulic fluid spill.

2.7.4 Service Disruption

The RT41 incident did not cause a service disruption, given the hydraulic fluid leak and cleaning to address the leak occurred prior to revenue service hours.

2.7.5 Findings

A failed O-ring underneath the pressure sensor was identified as the root cause of the hydraulic fluid leak. The removal of the O-ring from the pressure sensor revealed the O-ring was excessively compressed and fractured along one edge.

Figure 23 - RT41 Pressure Sensor with O-ring

Figure 24 - RT41 Failed O-ring

The pressure sensors and FKM rubber O-rings come as an assembly from Hydac, located in Germany. TTC advised the last recorded maintenance for this assembly was in 2015 when a major overhaul/re-build activity was undertaken. Over 9 years, the O-ring could have hardened over time, becoming more brittle, resulting in a minor leak.

The appearance of the pressure sensor and surrounding area suggest an attempt was made to fix the minor leak on a previous occasion. Scoring marks on the pressure sensor (see Figure 25) and yellow engine mounting block suggest that an incorrectly sized tool was used to manipulate the nut ring. Additionally, the initial review of the pressure sensor assembled on RT41 showed the electrical connector end strain relief was bent at an angle and the sleeve on the strain relief was pulled away from the black connector ring, exposing the wires within. Unfortunately, the SMS maintenance system does not show any record of work performed on the pressure sensor. The unknown tradesperson who attempted to proactively fix the slow leak was being diligent in addressing a problem. However, it is possible the pressure sensor was over torqued during the attempted fix of the initial leak. TTC has now received information on the Hydac sensor, which recommends a tightening torque of 20 Nm.

Figure 25 - Marks on RT41 pressure sensor

2.7.6 Conclusion

The condition of the failed O-ring and pressure sensor assembly suggest a previous attempt to repair a minor leak may have caused the failure. The undocumented work performed on RT41 should have been recorded to track the condition of the pressure sensor. Updates to TTC's maintenance protocols should consider configuration control for quality assurance as well as improved maintenance reporting and recordkeeping practices.

2.8 May 26, RT18 Hose Failure

The details about the May 26, RT18 incident were derived from onsite interviews with TTC staff and internal TTC reports and available information. The information available for the RT18 incident is included in this report to demonstrate the scale of work car failures TTC has experienced within a short time span and to provide additional context for Hatch's recommendations.

2.8.1 Spill Event

On Sunday May 26, 2024, locomotive RT18 experienced a hydraulic hose failure while a work crew was using it (coupled to RT11) to perform work for TTC's ATC project. Service was shutdown over the weekend of May 15th to perform this work under a shared Impassable Work Zone on the westbound track of Line 2 between Victoria Park and Kennedy Stations. At 6:41 am, a contractor noticed a hydraulic hose leak on RT18 and informed work staff who notified the PIC that "an engine problem" was observed. TTC maintenance personnel arrived on the scene at 4:00 pm and determined that one of RT18's twin engines had a broken high-pressure hose at one of the pumps, causing hydraulic fluid to leak. The leak resulted in approximately 30L of fluid leaking onto an open cut section of ballasted track.

2.8.2 Work Car Recovery

The work crew was advised to leave RT18 in place, before the work car was decoupled from RT11 for the installation of a temporary repair hose. RT18 was then cleared by the Work Area Coordinator (WAC) to travel to Victoria Park for further repairs.

2.8.3 Spill Site Cleanup

TTC personnel performed a track walk to confirm that the leak was contained to the immediate location of the work car. There are no details about the cleanup of the spill in the information available to Hatch.

2.8.4 Service Disruption

The spill incident did not cause a service disruption, as service was already suspended through the area for the weekend under a shared Impassable Work Zone.

Figure 26 - RT18 spill area

Figure 27 - RT18 failed hose

2.8.5 Findings

The hydraulic hose failure was caused by the use of an incorrect fitting and improper hose rating type. TTC personnel told Hatch that staff observed "weeping of a hydraulic hose" on May 22nd and May 23rd during a fleet inspection and requested a replacement hose. A 5000 PSI rated hose was used for the assembly of the replacement hose, instead of the required 3000 PSI rated hose due to the lack of material availability. The Shop used the available one-piece fittings on the 5000 PSI hose, which requires two-piece fittings. The replacement hose failed on May 26th shortly after the May 24th installation on RT18. The original hose from May 23 was not available for further analysis at the time of Hatch's visit.

Hatch also observed a general disorganization of the work area and materials, including a lack of clear identification of the hoses and fittings in the storage area of the shop floor. Note: An audit was not performed to confirm the validity of Hatch's findings regarding the condition of the work area and materials.

Figure 28 - Hose storage area

Figure 29 - Fittings area

Figure 30 - Hose assembly area

The SMS maintenance records for RT18 (see Figure 31) do not specify which hoses have been replaced, so it is unclear who worked on the failed repair hose.

Serial	A/Fdate	Descrip	Notes
RT18	26/May/24	Work Car	RE-INSPECTION OF ALL HYDRAULIC LINES & LOAD TEST OF ALL FUNCTIONS REQUIRED. WorkDone RE-INSPECTION OF HYDRAULIC LINES AND LOAD TEST OF ALL FUNCTIONS COMPLETED. REPAIRS: REPLACED #1 PUMP PRESSURE HOSE WITH A LONGER AND STRAIGHTENED FITTINGS ON BOTH ENDS. LABOUR: [redacted]
RT18	23/May/24	Work Car	RE-INSPECT ALL HYDRAULIC LINES & LOAD TEST OF ALL FUNCTIONS REQUIRED. WorkDone INSPECTED ALL HYDRAULIC LINES & LOAD TEST OF ALL FUNCTIONS COMPLETED. REPAIRS: #2 END STOUFF CLAMP FOR STEEL PIPE #1 END ENGINE OIL HOSE PUMP PRESSURE LINE PRESSURE HOSE AT COMPRESSOR CONTROL VLV LABOUR: [redacted]
RT18	20/May/24	Work Car	RE-INSPECT ALL HYDRAULIC LINES & LOAD TEST OF ALL FUNCTIONS REQUIRED. WorkDone INSPECTED ALL HYDRAULIC LINES & LOAD TEST OF ALL FUNCTIONS COMPLETED. RESULTS: FOUND PRESSURE LINES AND FUEL LINES THAT REQUIRED REPLACEMENT AS A PRECAUTION REPAIRS: REPLACED 8 PRESSURE LINES, FUEL LINES AND TESTED OK. REPLACED HOSES TO COMPRESSOR MOTOR AND PRESSURE LINE AT PUMPS AT BOTH ENDS, SECURED, TESTED OK. LABOUR: [redacted]
RT18	15/May/24	Work Car	INSPECTION OF ALL HYDRAULIC LINES & LOAD TEST OF ALL FUNCTIONS REQUIRED. WorkDone INSPECTED ALL HYDRAULIC LINES & LOAD TEST OF ALL FUNCTIONS COMPLETED. ITEMS: BRAKE CYLINERS, HYDRAULICS RESULTS: NO LEAKS FOUND. REPLACED BRAKE CYLINDER AS A PRECAUTIONARY MEASURE. LABOUR: [redacted]
RT18	07/May/24	Work Car	HYDRAULIC LEAK AT #1 END WorkDone REPLACED O-RING AT COMPRESSOR CONTROL VALVE TEST P ORT. TOPPED UP 20L OF HYDRAULIC FLUID. TESTED OK
RT18	14/Dec/23	Work Car	LOW FUEL PRESSURE CODES ACTIVE WorkDone INSTALLED FUEL FILTERS. NTF.
RT18	26/Jun/23	Work Car	LOW FUEL PRESSURE CODES ACTIVE WorkDone CLEANED FUEL FILTER.

Figure 31 - RT18 SMS Maintenance records regarding hydraulics and inspections prior to May 26

2.8.6 Conclusion

The availability of assembly drawings and configuration control may have prevented the improper assembly of the replacement hose. TTC could not provide Hatch a hose assembly procedure or other relevant documentation at the time of the site visit. Hatch recommended TTC review the assembly method for various types of replacement hoses for the development of procedures. Documentation for the hoses should include a full bill of materials listing the hose requirements, and drawings that specify the fitting requirements, length, placement of fittings relative to the curve of the hose, and a proof test. This documentation would improve configuration control and inventory management.

3. Report Conclusions

The life cycle of a work car is about 30 years, and the average age of the work car fleet is 17 years[8]. Almost all the work cars inspected during Hatch's site visit exhibited wear and tear issues. As the subway work cars age, the execution of scheduled inspections (calendar day and periodic inspections) and effective component repairs and replacements becomes essential to maintain the operability and reliability of the vehicles to support TTC's Infrastructure State of Good Repair (SOGR) Program. However, Hatch's evaluation demonstrated the level of information recorded in TTC's SMS maintenance reporting system does not always provide sufficient information to identify and track the maintenance performed on some work cars.

Onsite inspections and staff interviews showed there are work car components that are due for replacement that are not flagged in the system. Further, maintenance and inspection intervals and criteria are not available for several work car subsystem components. A defined maintenance and inspection regimen and improved record keeping would help address frequent component failures. For example, the RT84 vacuum clutch has failed 3 times in the last 12 years, although the component is expected to last a lot longer. The vacuum clutch is also used on RT56, which has undergone 3 vacuum clutch replacements in the last 5 years. TTC maintenance has since implemented inspections for the vacuum clutch to prevent future failures, having received inspection criteria from the OEM.

The configuration of some of TTC's work cars has evolved since the delivery and commissioning of the vehicles due to extensive customization and the replacement of obsolete components. As a result, OEM documentation is often not available for the work cars. Additionally, TTC does not appear to have a formal method for the storage and identification of the materials required to maintain the hydraulic system components (to be confirmed through TTC audit). The lack of documentation, configuration control and assembly methods for work car maintenance is impacting the effectiveness of repairs/replacements (i.e. the wrong hose rating and fittings were used to fabricate a hose for RT18). The limited availability of documentation is also hindering the agency's ability to develop training materials for the upkeep of hydraulics.

In addition to taking measures to prevent hydraulic fluid spills, TTC should continue to evaluate the vehicle recovery process for continued improvement. Misunderstandings between TCC and onsite personnel in the May 13, RT56 incident prevented the effective containment of the spill area and subsequent work car recovery. TTC has since updated the agency's vehicle recovery protocols for better coordination between TCC and onsite staff in the event of a hydraulic fluid spill. TTC has also implemented pre-departure inspections for the work cars. Work cars that fail the inspection pass/fail criteria are not permitted to go into service, which has reduced work car incidents. Hatch is recommending several actions to further reduce the risk of future hydraulic leak issues.

[8] 1_Service_Impacts_Due_to_ Hydraulic_Spills_Presentation.pdf, page 3

3.1 Comparison with other Transit Agencies

The lack of detailed documentation for the design and maintenance of the work car fleets is highlighted as a major issue in this report, especially for the repair of hydraulic hoses. However, Hatch's experience with other major transit agencies in North America like TTC, suggest that design and maintenance documentation supplied by work car OEMs does not usually contain detailed information on the installation of the hydraulic hoses except when mandated by a procurement specification or used for very specific applications (e.g. rigid hoses, specialty hoses and fittings, and components that are hard to procure and/or have long lead times).

Well-designed hydraulic systems have clamps and bulkhead fittings that help assure the routing of replacement hoses conforms to the OEMs original design, whereas systems that rely on tie straps do not typically incorporate similar guidance. Upon vehicle delivery, some agencies develop their own drawings and materials lists to facilitate preventive and corrective maintenance down the line, adapting the drawings over time due to increased familiarity with the work cars, obsolescence, and updates or modifications to components; however, this is not standard practice. As observed at TTC, Technicians at many agencies maintain the work cars based on experience and the components and materials currently installed on the work cars. If documentation is provided, the hydraulic hose routing information is typically minimal (e.g. a hydraulic system schematic with hose and fitting OEM part numbers), especially if the equipment is older.

Relatively newer work car procurements for large transit agencies usually include comprehensive documentation in the purchase price and scope of deliverables (e.g., Illustrated Parts Catalogue (IPC), Running Maintenance Manuals, and Heavy Repair Manuals, etc.) to guide the transit agency in their repair and replacement of hydraulic fluid hoses and fittings.

Transit agencies typically replace hoses only after they fail or sustain noticeable damage. However, some agencies perform periodic inspections of the hydraulic system, including the examination of hoses for signs of rubbing, degradation or leakage before component failures occur. A transit agency similar to the TTC performs periodic inspections of the hydraulic hoses on a 120-day cycle (TTC's 90-day periodic inspection includes the evaluation of the hydraulic system components)[9].

The performance of mid-life overhauls on work cars is not common practice for transit agencies. In one known exception, a transit agency completed a factory overhaul of a work car and determined that purchasing a new replacement vehicle is a better option given the overhaul cost and schedule. Hatch recommends that TTC assess the overall SOGR of a vehicle and perform an overhaul of just the hoses, if an otherwise sound vehicle has aged hoses. Transit agencies typically order replacement hoses from the OEM (if OEM part numbers are provided) or takes the damaged hoses to a hydraulic hose supplier for replication.

[9] TTC Standard Inspection Report

Standards and recommended practices such as SAE J517 and J1273 for hose type and routing do exist and RCS RVE may wish to review and incorporate the practices provided by these standards into their hoses/fittings repair and replacement process. However, when maintaining SOGR for hydraulic hoses these must also be accompanied with good experience and lessons learned. At one agency, a replacement hydraulic hose that was routed past a turbo charger was stiff enough to not droop at the time of installation. However, after a short period of time with exposure to the heat in the engine room, the hose sagged and contacted the turbo charger. In this case no oil was spilled onto the trackbed, but a fire occurred. Knowing that the hose needed to have better support would have prevented the situation.

4. Report Recommendations

TTC should consider implementing the following actions to reduce the risk of future hydraulic leak issues.

Item No.	Priority	Category	Responsible TTC Department	Recommendation
1.i	High	Work Car Recovery Procedure	Rail Cars and Shops Transit Control	TTC to update their work car recovery procedure to incorporate guidance to address hydraulic fluid leaks, including instructions that specify how to isolate a suspected hydraulic fluid leak.
1.ii	High	Work Car Recovery Procedure	Operational Safety and Planning Rail Cars and Shops Subway Infrastructure Transit Control	TTC to develop comprehensive guidelines for coordination between work crews, managers, and TCC in response to spill incidents, including the designation of roles and responsibilities.
2.i	High	Spill Incident Clean-up Protocol	Track and Structure	TTC to consider the use of work cars to deliver cleaning supplies, the storage of fluid spill kits on the work cars (particularly cars with large volume fluid tanks), and additional improvement measures to improve the efficiency of cleaning protocol for hydraulic fluid spills.

Item No.	Priority	Category	Responsible TTC Department	Recommendation
3.i	High	Maintenance Practices and Procedures	Rail Cars and Shops	TTC to improve standard maintenance practices and procedures for work car maintenance tasks such as hydraulic hose assembly and repairs.
3.ii	High	Maintenance Practices and Procedures	Rail Cars and Shops	Identified equipment issues should be reviewed for disposition, and if necessary appropriate TTC staff should review and approve any design changes for incorporation. Further, the implementation of changes should be confirmed by quality assurance resources.
4.i	High	Inspections	Rail Cars and Shops	TTC to establish a more detailed inspection regimen for work car system components such as the hydraulic hoses that provides specific instructions to check for signs of damage (i.e., chaffing on the hose jacket, drips of fluid in the pump room, etc.). The inspection procedure should include clear pass/fail criteria for the identification of component failures.
4.ii	High	Inspections	Rail Cars and Shops	TTC to determine an appropriate inspection interval for the hydraulic hoses and other work car system components to reduce the risk of unexpected failures and unscheduled maintenance.
5.i	High	Quality Assurance	Rail Cars and Shops	TTC to implement stronger quality assurance and control processes that flag non-compliant practices/outcomes, to confirm maintenance requirements are properly satisfied, and to identify issues before they cause equipment failures. TTC to consider the performance of regular audits to confirm recommendation is implemented.

Item No.	Priority	Category	Responsible TTC Department	Recommendation
6.i	High	Configuration Control, Documentation and Inventory Management	Rail Cars and Shops	TTC to consider supplementing OEM reference material by documenting hydraulic hose details (i.e. specification of length, construction and routing) in order to maintain consistent implementation of repairs/changes.
6.ii	High	Configuration Control, Documentation and Inventory Management	Rail Cars and Shops	TTC maintenance needs to improve their inventory management protocols and configuration control guidelines.
7.i	Medium	On-Call Work Car Technical Expert	Rail Cars and Shops	TTC to consider making a technical expert available to be on-call during non-revenue service shifts when work cars are out on the line to provide guidance to Transit Control on actions to be taken for urgencies with work cars.
8.i	Medium	Training	Operations and Training Centre	TTC to develop training materials and provide formal training to qualify employees to perform work car maintenance tasks.
9.i	Medium	Maintenance Reporting	Rail Cars and Shops	TTC to update the SMS system in timely manner and improve the level of information in the reporting system to gather data to inform preventative maintenance practices and minimize impacts to revenue service and system maintenance.
10.i	Medium	Low Hydraulic Fluid Level Alarm	Rail Cars and Shops	TTC to consider shutting down the hydrostatic propulsion system automatically to prevent any further hydraulic fluid spill anytime the fluid drops below a predetermined level. Note: A cost and time vs. benefit analysis is needed to determine if the implementation of these features will be beneficial to TTC.

Item No.	Priority	Category	Responsible TTC Department	Recommendation
10.ii	Medium	Low Hydraulic Fluid Level Alarm	Rail Cars and Shops	TTC to also consider coupling the above new functionality with the implementation of a data logger to record activation of the low hydraulic fluid level alarm. Note: A cost and time vs. benefit analysis is needed to determine if the implementation of these features will be beneficial to TTC.
11.i	Low	Tooling and Equipment	Rail Cars and Shops	TTC to perform audit to evaluate the condition and labeling of the tooling.

5. Appendix A – Acuren Report

Acuren report on failed hydraulic hose, work car RT56, incident of May 13, 2024.

Acuren Group Inc.
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A Higher Level of Reliability

July 22, 2024 **Our Project No.: 128-24-HAT003-J152359**

Hatch
2800 Speakman Drive
Mississauga, ON
L5K 2R7

Attention: Mr. Chris Petersen

Dear Chris Petersen:

SUBJECT: FAILURE ANALYSIS EXAMINATION OF A HYDRAULIC HOSE

Please find enclosed the above-named report. We trust you will find it satisfactory, and we appreciate the opportunity to be of service to Hatch. At Acuren, we remain committed to providing you with world-class integrity management solutions.

Should you require any additional information, please do not hesitate to contact the undersigned at 905-208-4970 or by e-mail at pooyan.changizian@acuren.com

Please note that unless we are notified in writing, samples from this investigation will be disposed of after 60 days.

Sincerely,

Pooyan Changizian, Ph.D.
Materials Engineering and Failure Analysis

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FAILURE ANALYSIS EXAMINATION OF A HYDRAULIC HOSE

Prepared for

Mr. Chris Petersen
Hatch

Prepared by

Pooyan Changizian, Ph.D.
Materials Engineering and Failure Analysis

Reviewed by

Erhan Ulvan Ph.D., P.Eng
Manager Engineering and Lab

June 18, 2024
Acuren Project No.: 128-24-HAT003-J152359

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1.0 INTRODUCTION

Acuren received a black hydraulic hose showed damages on the body and leaking after being in service. The hose was used in a work car that was in a tunnel at the time of incident. The outside temperature was likely to be 9 – 10 °C. Acuren was asked to conduct a failure analysis examination to determine the cause of the incident. Figure 1 shows the hose during the service.

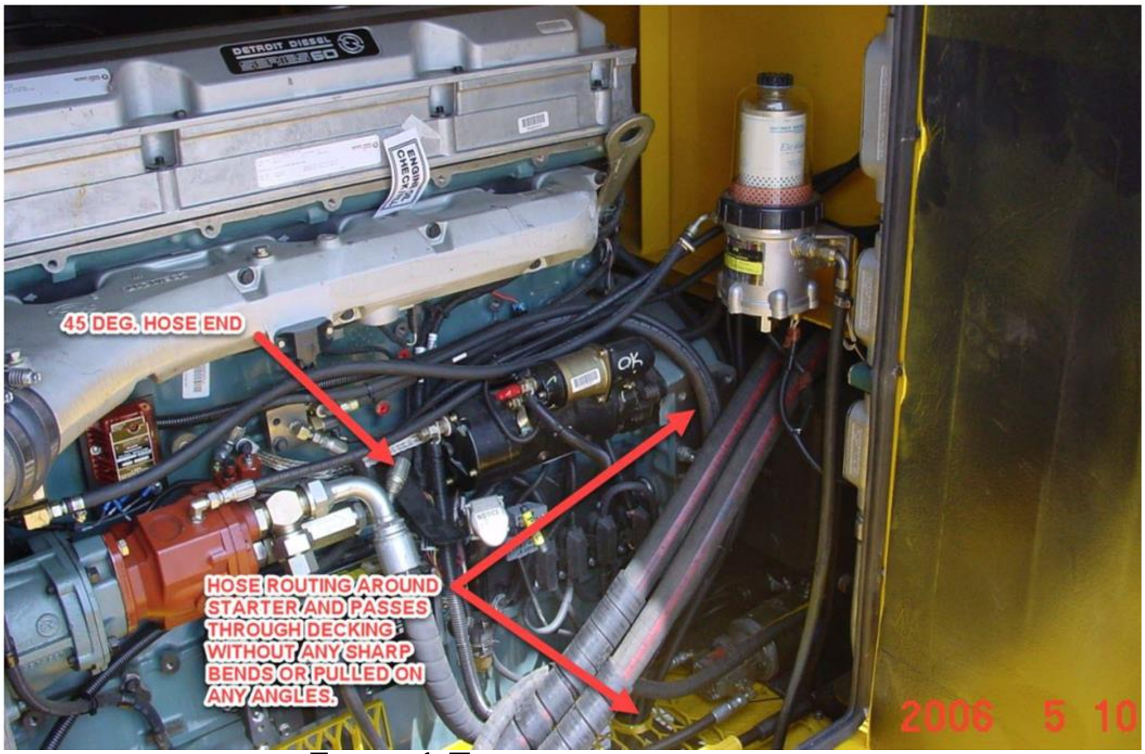


FIGURE 1. THE HOSE IMAGE IN SERVICE

ACUREN

2.0 VISUAL EXAMINATION

Acuren received the car hose along with a round ring. The hose was coming through the round ring when it was in service (see Figure 1). The two ends of the hose were called 45 Deg. End and 90 Deg. End as per client provided information/images, Figure 2. The white text "**Gates-connected 10G2 5/8" (15.9 mm) R2/2SN EN853 3625 PSI (25.0 MPa) MAX WP FLAME RESISTANT USMSHA 2G-11C > NBR/NBR PVC**" was printed on one side of the hose, Figure 3 and Figure 4. Also, the text "**AM102610 498**" was printed on the same side, Figure 5.

The hose was visually examined, and the location of areas showing damage/rubbing/leaking were measured with respect to the 45 Deg. Hose end. The results are summarized in Table …

Note that, for the ease of communication the side of the hose with printed texts is called "marked side" and the other side was called "not marked sire".

Area #	Distance from 45 Deg. End	Size of the area	Side	Description	Reference
1	about 25 inches	1.5 in. × 0.25 in.	Marked	This area showed three distinct areas with damage on the black cover that likely rubbed.	Figure 6
2	about 27 inches	2 in. × 0.25 in.	Marked	This area exhibited damage/rubbing on the cover. The wire braid reinforcement consisted of wire strands that were evident underneath the cover in the damaged area.	Figure 7
3	about 28 inches	0.5 in. × 1 in.	Not marked	The cover was totally removed in this area. The cover showed tearing/cracks in areas surrounding the damaged zone. The wire strands in the reinforcement layer were evident. Some of the wires were broken and a hole was observed at about the center of the area.	Figure 8

4	about 25 inches	6 in. × 0.25 in.	Not marked	This area showed relatively a long and shallow indication of rubbing/damage on the cover.	Figure 9
5	about 36 inches	1.5 in. × 0.5 in.	Marked	This area exhibited damaged cover in a way that the underneath reinforcement layer was evident.	Figure 10

The metal ring sent along with the hydraulic hose was also visually examined. The following observations were made:

i) To facilitate communication, the clock position was used to describe the ring as shown in Figure 11.

ii) Deformation was observed at the edge of the ring at about 8 o'clock. In addition, evidence of rubbing was evident on the inner surface of the ring at the same position, Figure 12.

iii) Similar shiny rubbed areas were observed on the edge and inner surface of the ring at 10 and 11 o'clock positions, Figure 13.

iv) The metal ring exhibited rubbing at the edge and inner surface at about 4 and 5 o'clock,

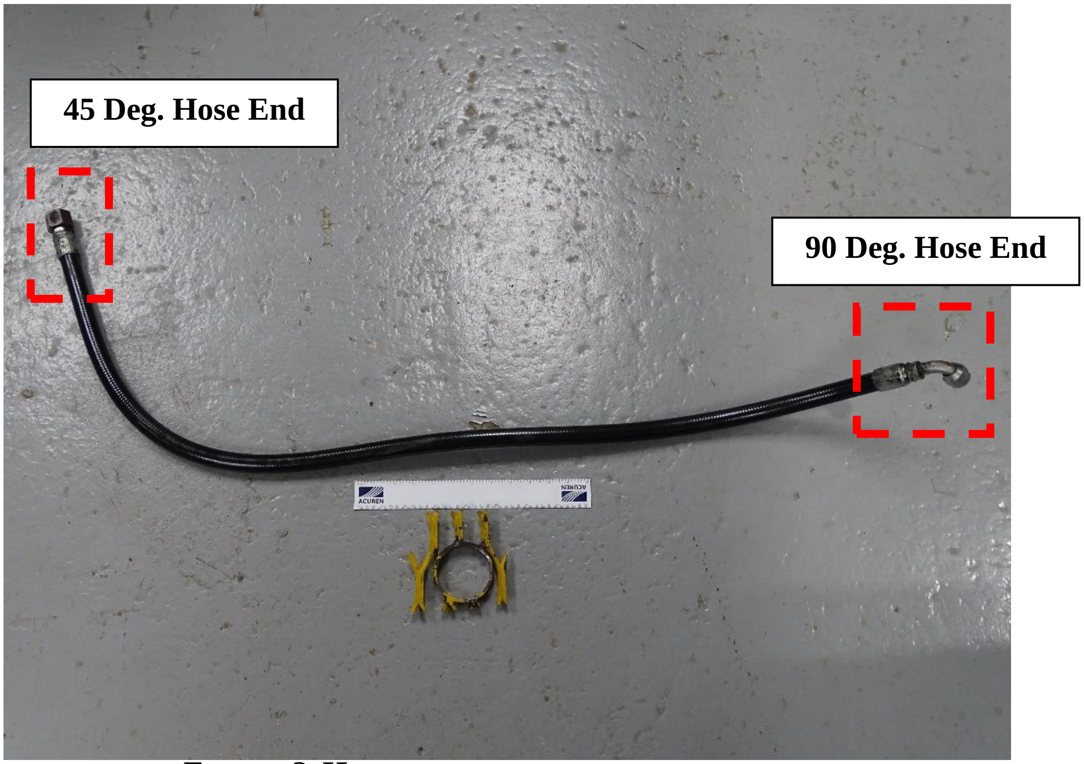


FIGURE 2. HOSE AND THE ROUND RING RECEIVED

FIGURE 3. WHITE TEXT PRINTED ON THE HOSE

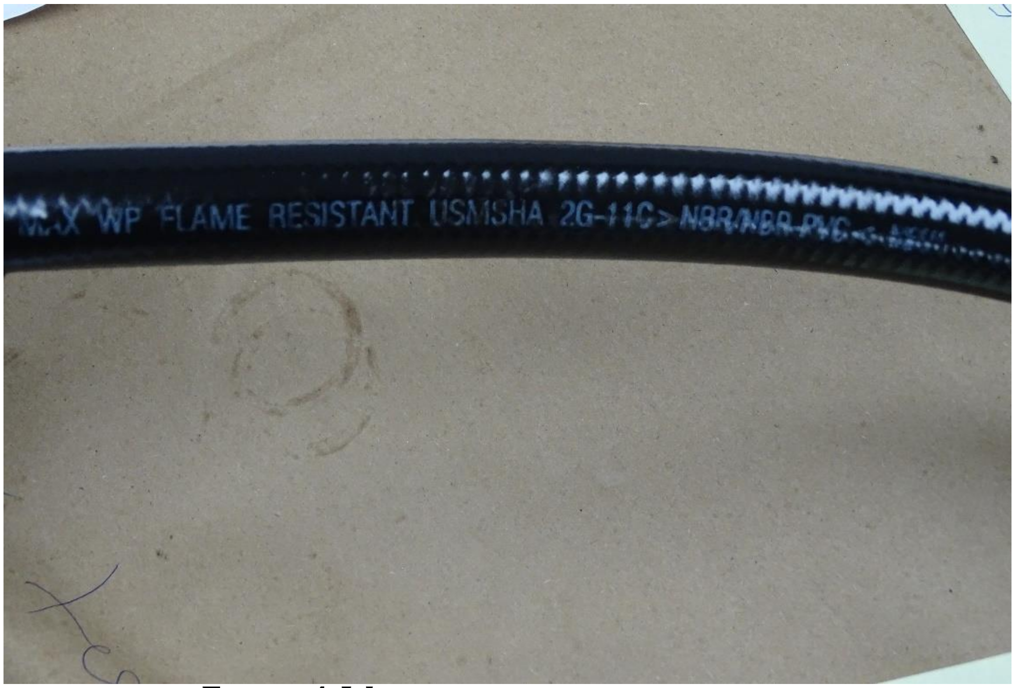


FIGURE 4. WHITE TEXT PRINTED ON THE HOSE

FIGURE 5. WHITE TEXT PRINTED ON THE HOSE

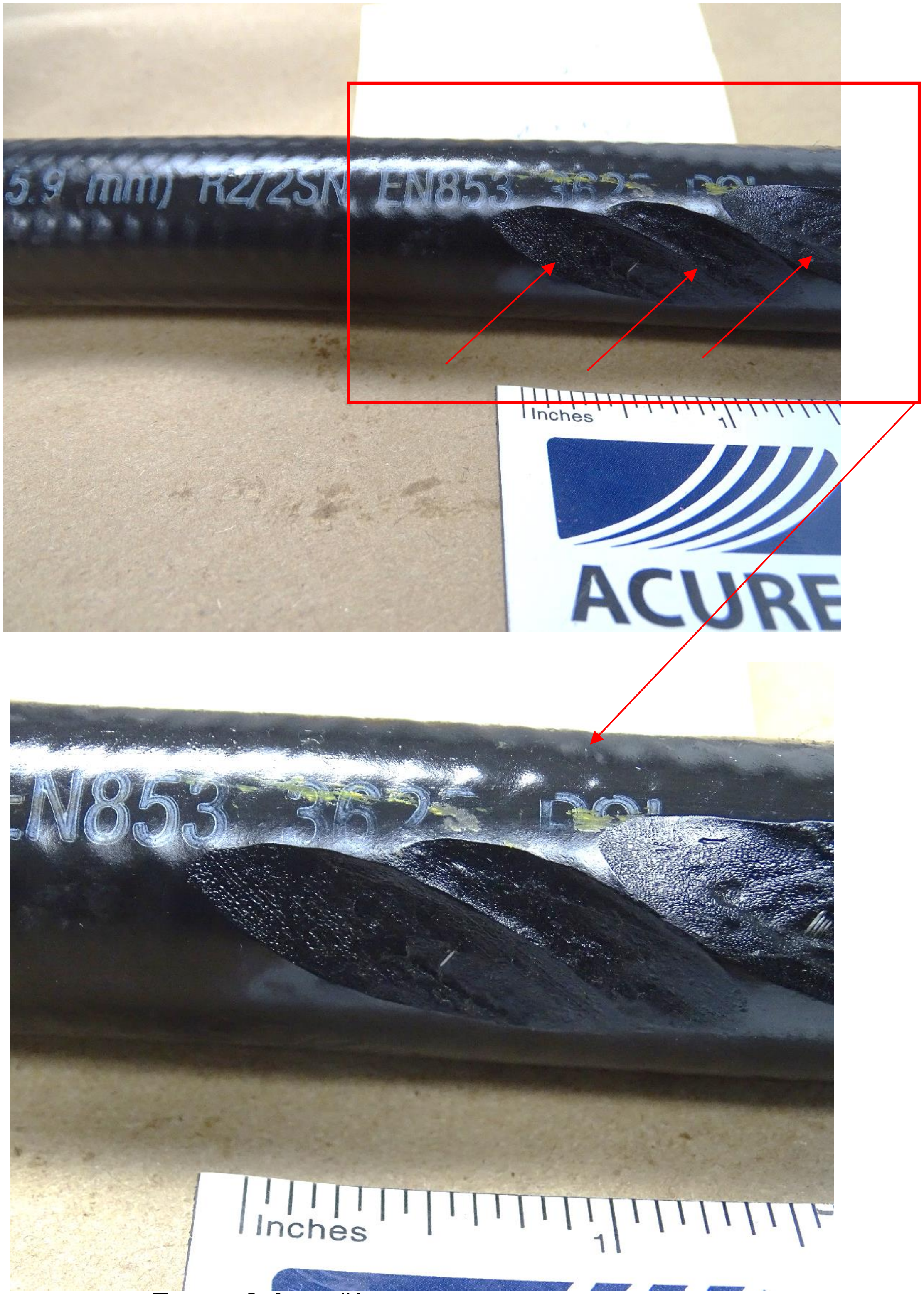


FIGURE 6. AREA #1 – SHOWING DAMAGED COVER

FIGURE 7. AREA #2 – SHOWING DAMAGE ON THE COVER, THE REINFORCEMENT WAS EXPOSED

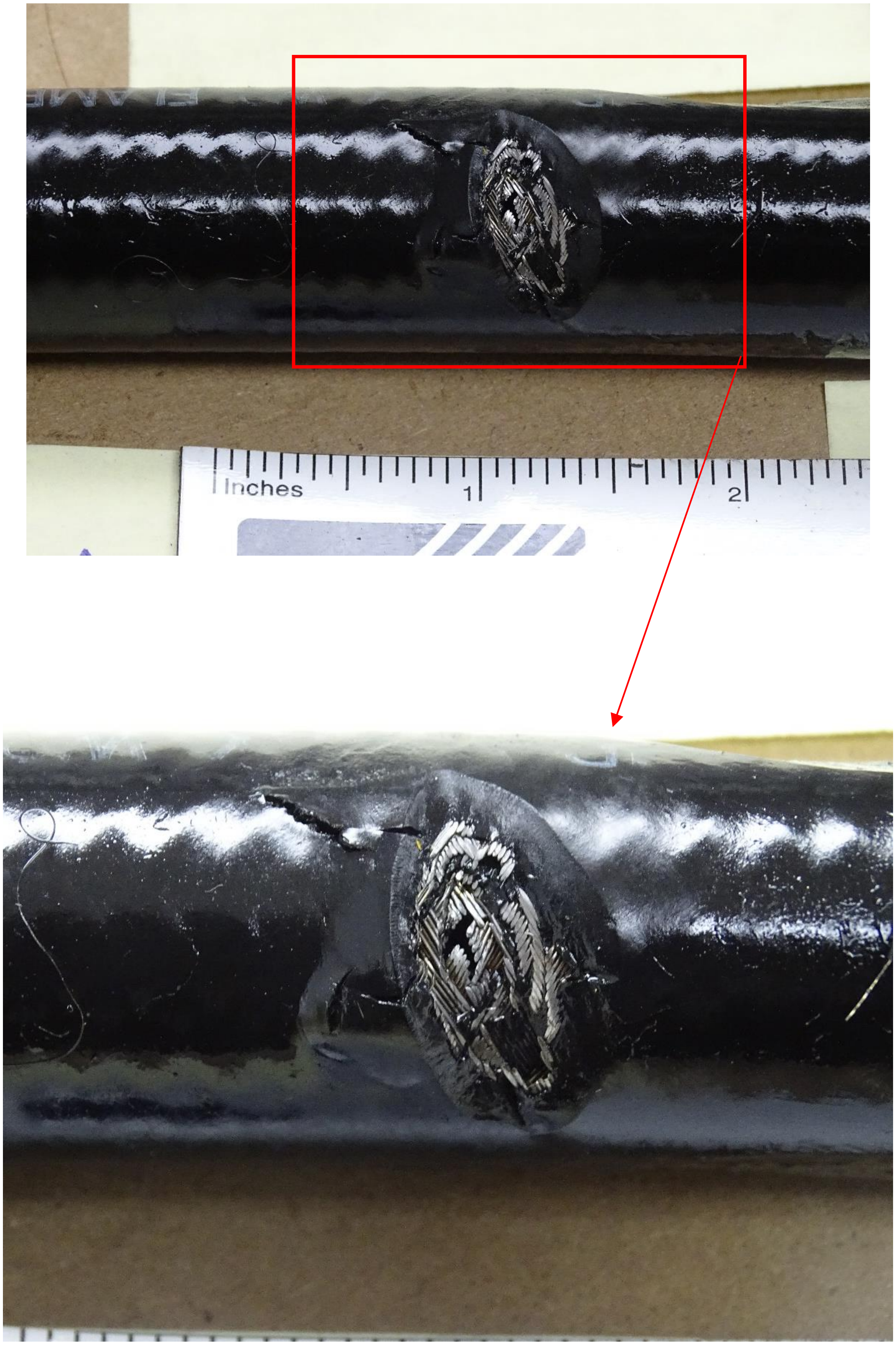


FIGURE 8. AREA 3 – SHOWING TEARING/CRACKS IN THE COVER, WIRES ARE EVIDENT AND A HOLE IS OBSERVED

FIGURE 9. AREA #4 – SHOWING RUBBING/DAMAGE ON COVER

FIGURE 10. AREA #5 – SHOWING RUBBING/DAMAGE ON THE COVER AND THE REINFORCEMENT LAYER IS EVIDENT

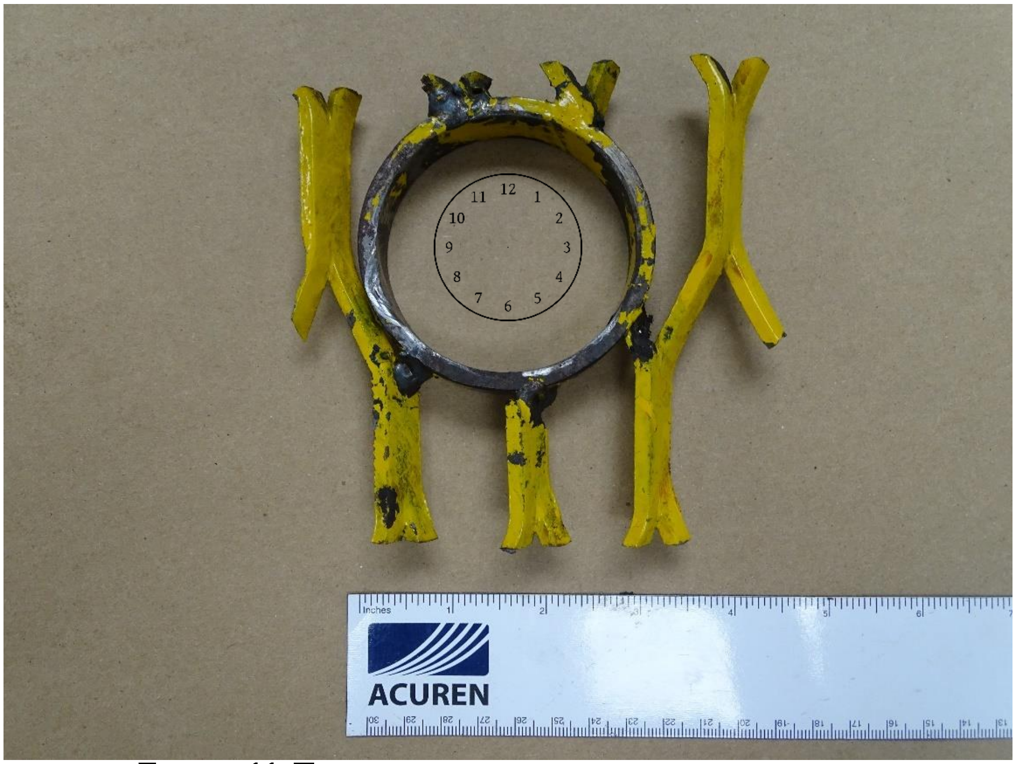


FIGURE 11. THE RING RECEIVED ALONG WITH THE HOSE

FIGURE 12. DEFORMATION OBSERVED ON THE RING AT AROUND 8 O'CLOCK LOCATION

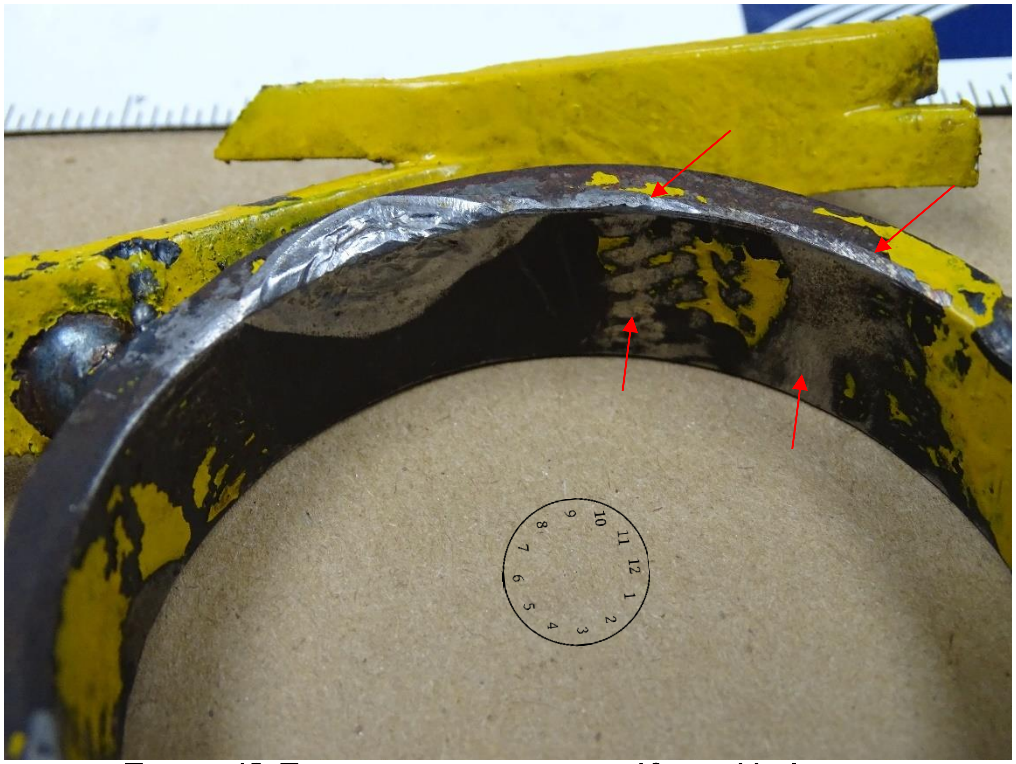


FIGURE 13. EVIDENCE OF RUBBING AT 10 AND 11 O'CLOCK

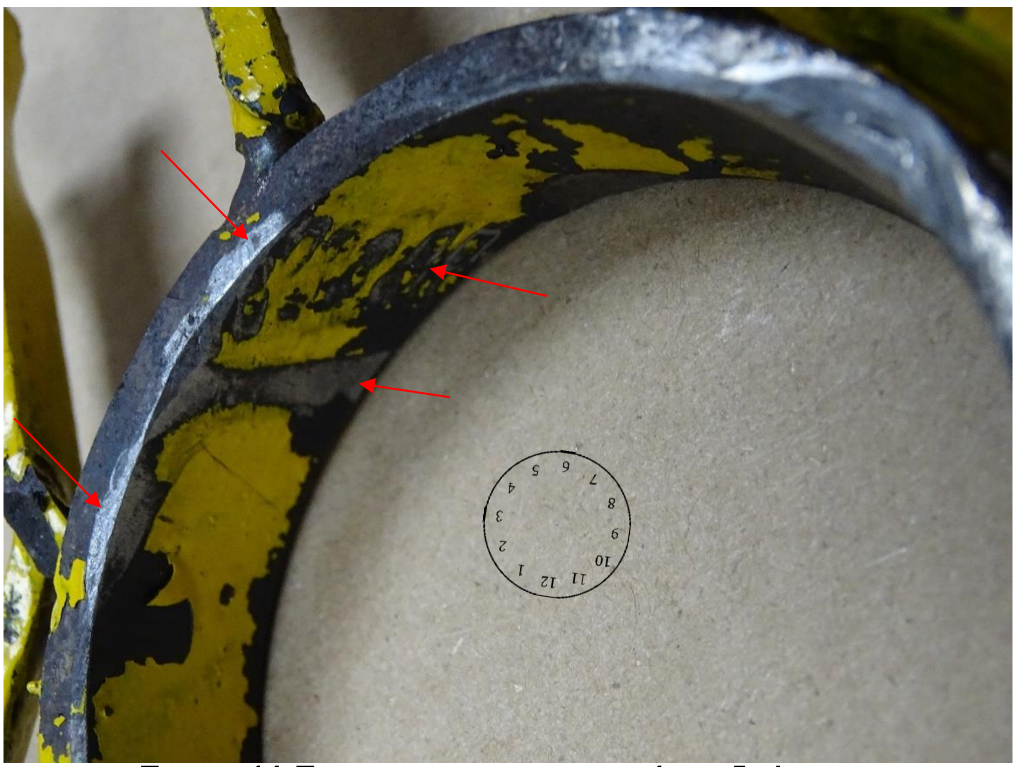


FIGURE 14. EVIDENCE OF RUBBING AT 4 AND 5 O'CLOCK

3.0 LOW MAGNIFICATION

The damaged areas along the length of the hose were examined under low magnifications using a Keyence stereo microscope. The following observations were made.

i) A general stereomicroscopic image of area 1 and 2 is presented in Figure 15. The wear marks were on the cover within the damaged areas suggesting the cover was worn out in the areas, Figure 16.

ii) The braided wires were exposed within the specific area suggesting the cover was worn away in this area. The wire strands showed relatively flat and shinny surfaces exhibiting a distinct contrast against the darker background (the cover).

iii) Figure 19 shows a general image of the area 3. The black cover was also worn away in this area, exposing the reinforcement layer. Tearing and cracks were observed in the cover in areas surrounding the damaged region.

iv) Multi layers of the reinforcement wires were worn away in this area and some of the remaining wire strands were broken/separated at the center of the damaged area, resulting a hole/leak in the hose. The appearance of the wires suggested that some of the broken strands had been in contact with a sharp object, leading to cut the wires, Figure 20. Also, some strands showed a shiny flat surface. The size of the hole at the center of the area 3 measured about 3 mm, Figure 21.

v) Figure 22 shows a general image of the damaged area 5. The wear marks were observed on the black cover within the damaged area. The first layer of the braided wires was exposed and showed a shiny flat surface, Figure 23.

FIGURE 15. AREA 1 AND 2 UNDER 10X MAGNIFICATION

FIGURE 16. CLOSER VIEW OF THE AREA 1

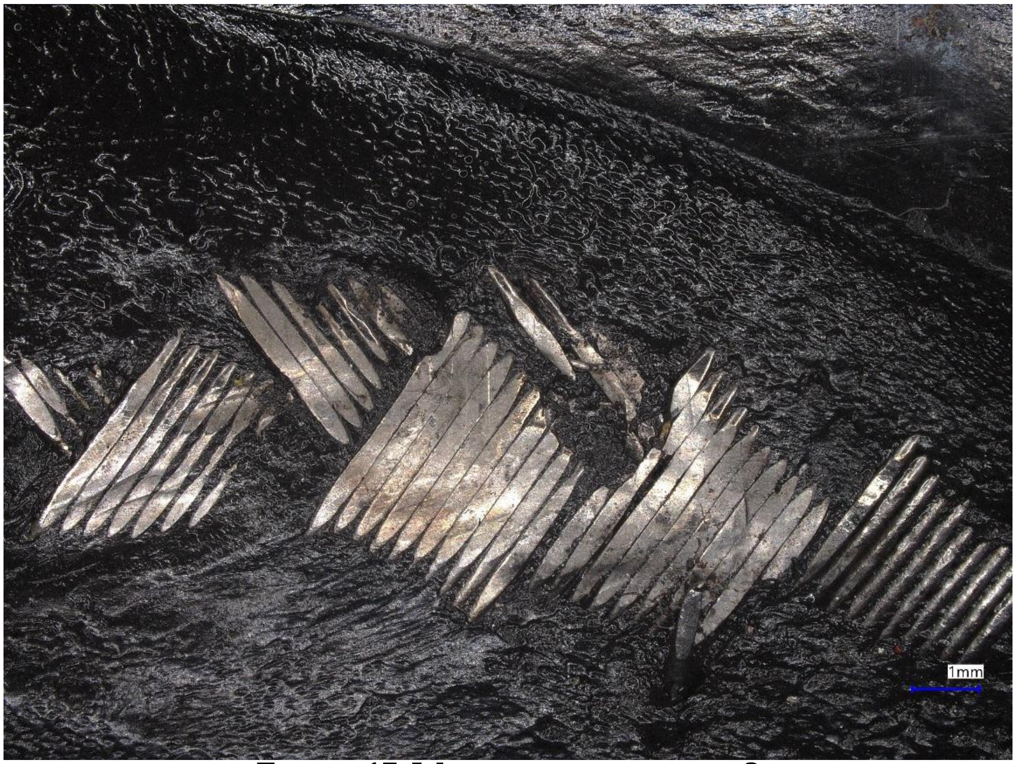


FIGURE 17. WIRES EVIDENT IN AREA 2

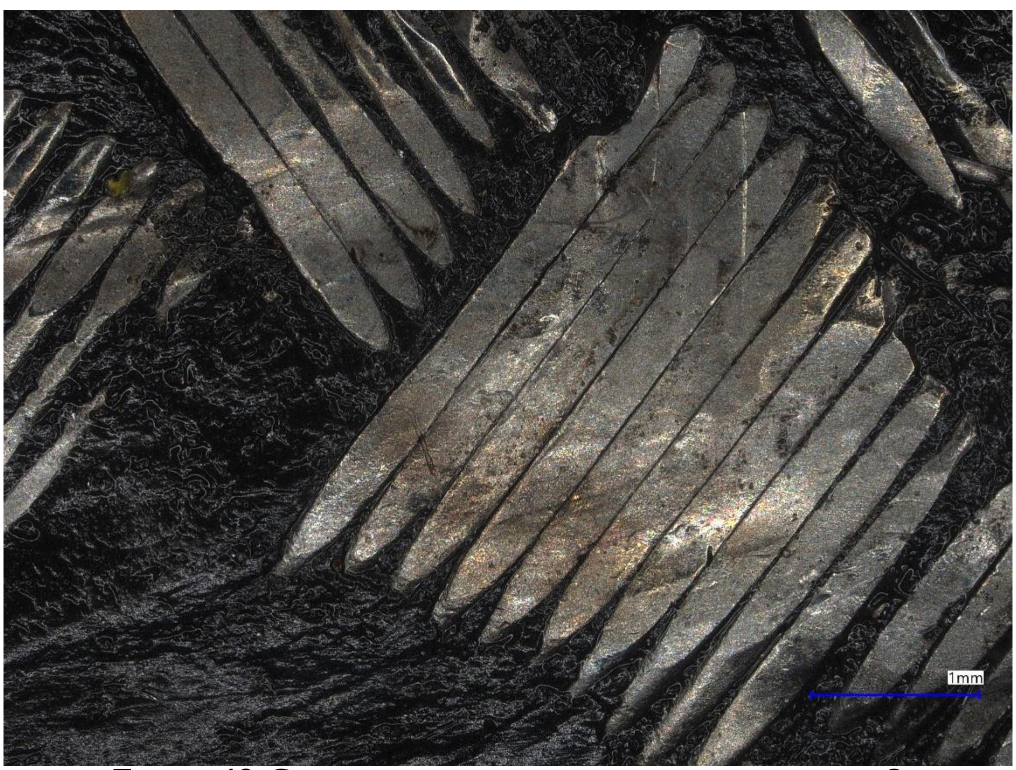


FIGURE 18. CLOSER VIEW OF THE WIRES EVIDENT IN AREA 2

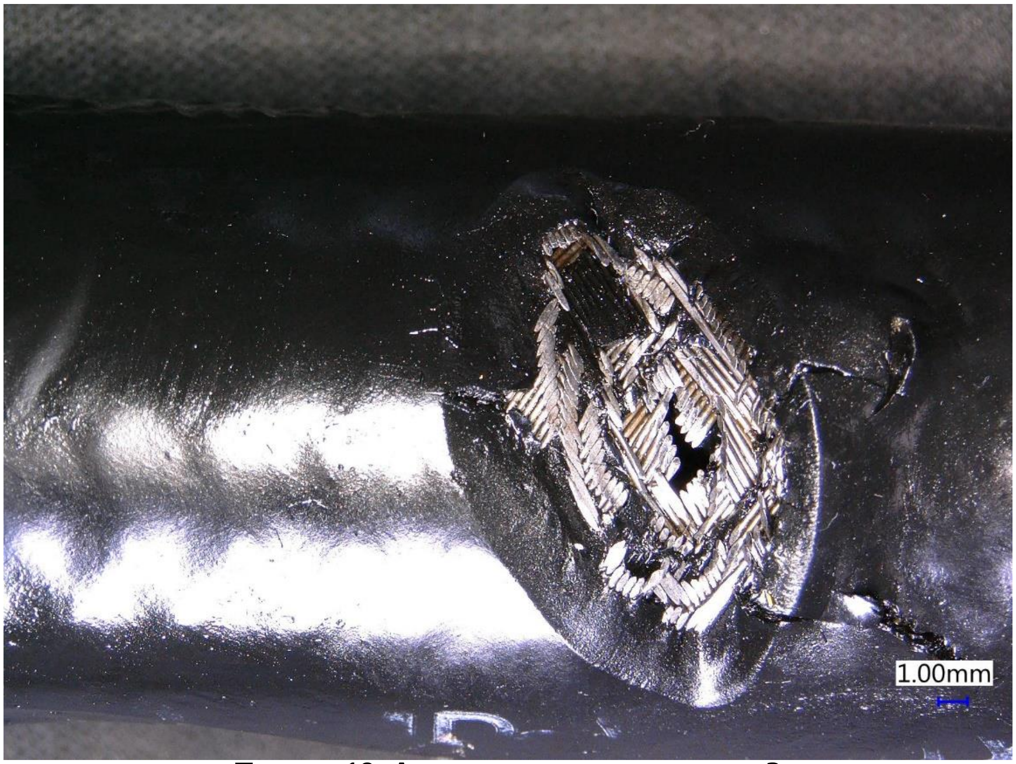


FIGURE 19. A GENERAL IMAGE OF AREA 3

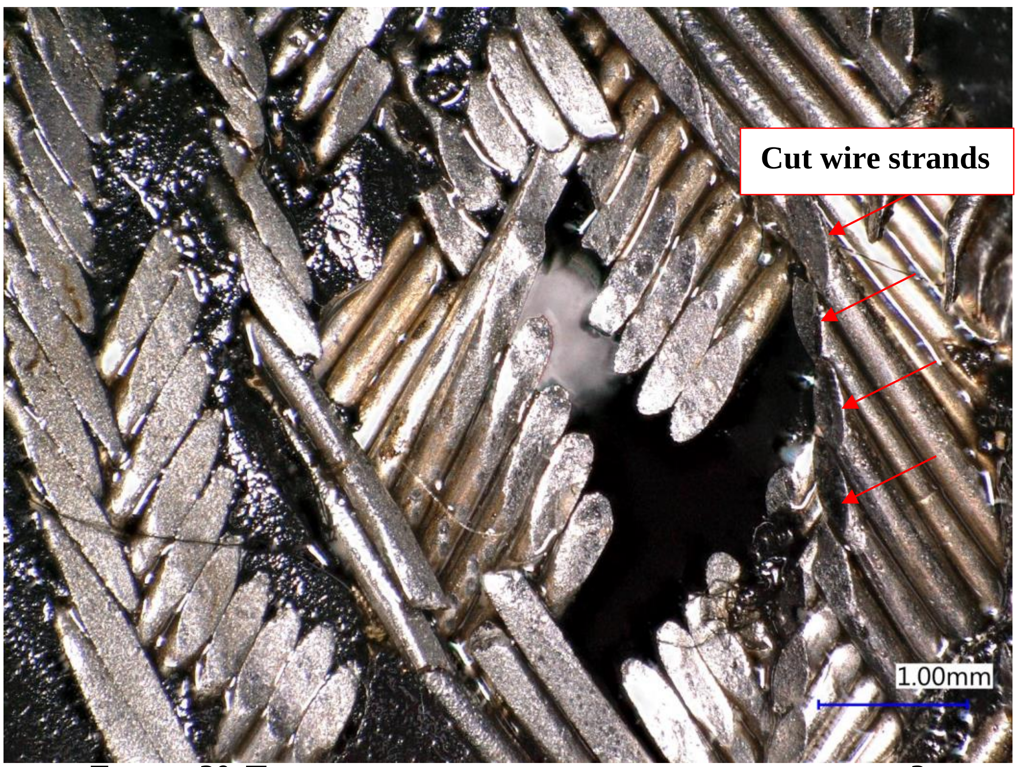


FIGURE 20. THE WIRE STRANDS IN THE DAMAGED AREA, AREA 3

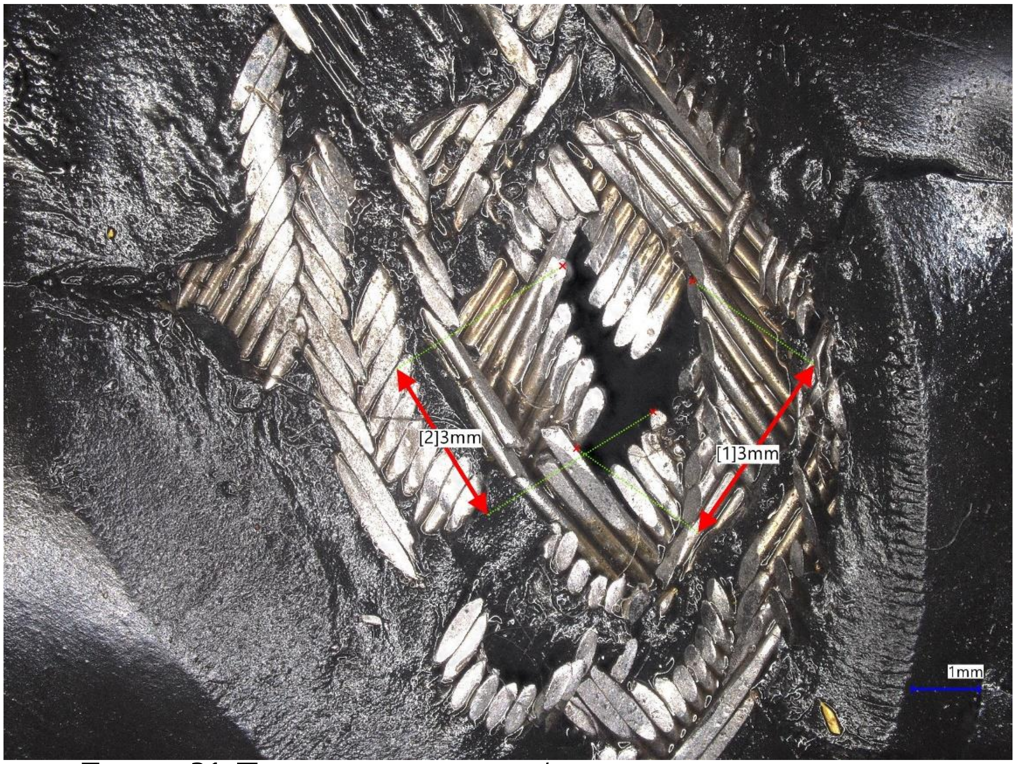


FIGURE 21. THE SIZE OF THE HOLE/LEAK AT THE CENTER OF THE DAMAGED AREA, AREA 3

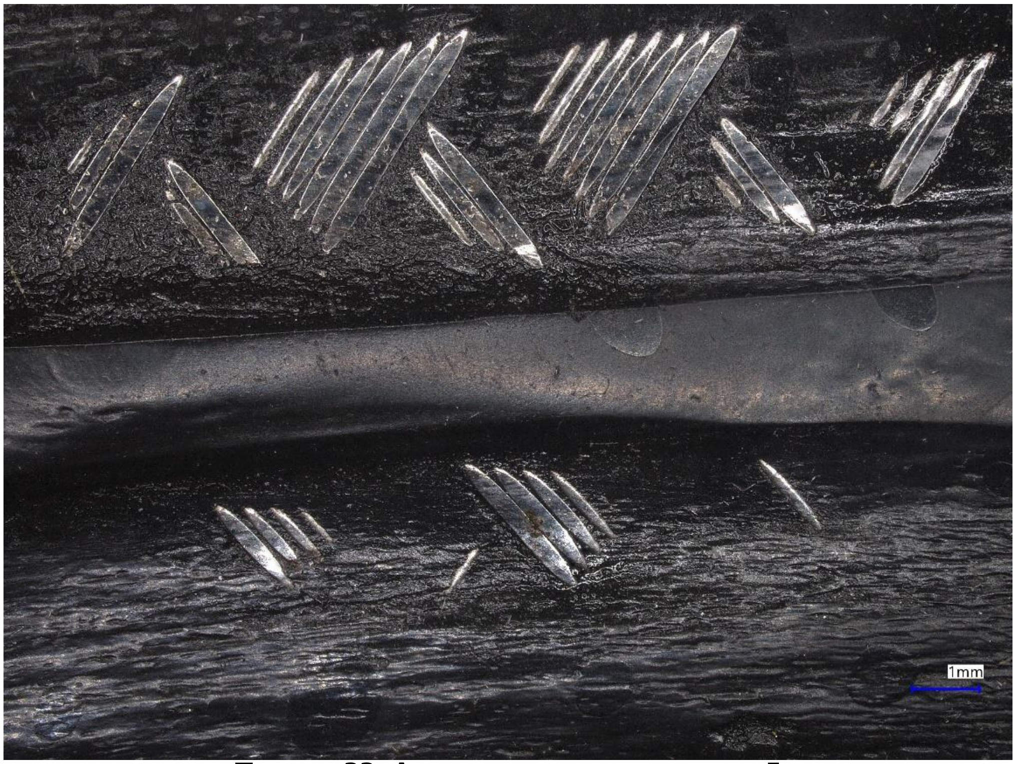


FIGURE 22. A GENERAL IMAGE OF AREA 5

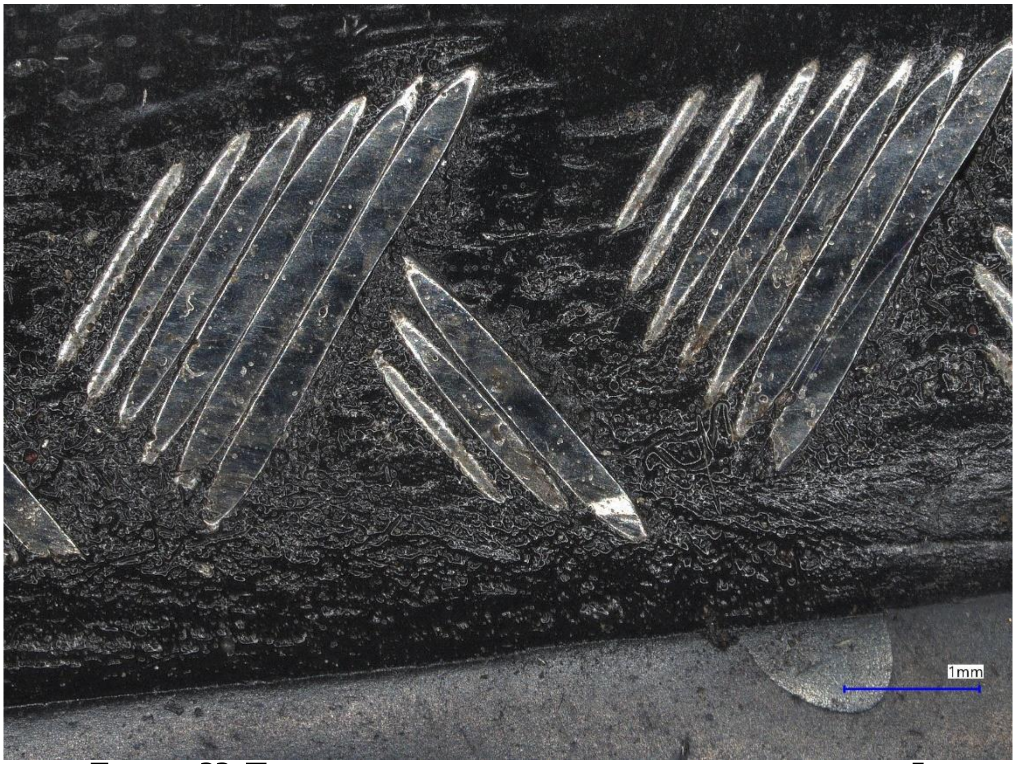


FIGURE 23. THE WIRE STRANDS IN THE DAMAGED AREA, AREA 5

4.0 SCANNING ELECTRON MICROSCOPY

The damaged areas 2 and 3 on the hydraulic hose as well as rubbed areas on the inner surface of the metallic ring were subjected to further examination using a scanning electron microscopy (SEM). The following observations were made:

i) The wire strands exhibited a flat surface at lower magnification in the damaged area 2, Figure 24. SEM examination at higher magnification revealed surface wear on the wire strands that exhibited elements of scratching, gouging and impact, Figure 25 and Figure 26. In addition, some small particles were observed on the surface of the wires, Figure 26.

ii) Figure 27 shows another example of worn flat wire strands in the reinforcement layer within the damaged area 2. Higher magnification examination showed scratches, indentations and gouging on the surface, indicating the progression of wear in this area, Figure 28, Figure 29, and Figure 30. The appearance of polymeric cover in the damaged area indicated rubbing/wear, Figure 31. Figure 32 shows the border between the worn cover and the cover outside of the area 2 (intact cover).

iii) Some of the broken wire strands in damaged area 3 showed a round portion (original shape) and a flat portion, Figure 33. Scratches and impacts/indentations were observed on the flat portion of the wires, indication of abrasive wear within the area, Figure 34, Figure 35 and Figure 36.

iv) Figure 37 presents another example of broken wire strands in the damaged area 3. The tip of the broken strands was examined at high magnification. The results show similar wear marks found on the other broken strands, Figure 38 and Figure 39.

v) There were also some exposed wire strands that were not broken but showed flat surface within the damaged area 3, Figure 40. The surface showed wear marks at higher magnification, Figure 41.

vi) Figure 42 and Figure 43 show another example of broken wire strands, exhibiting wear marks on the flat tip.

vii) The damaged area observed on the inner surface of the ring at 8 o’clock was also examined using SEM, Figure 44. The results showed scratch marks, indentation/impact marks, suggesting the presence of wear marks on the inner surface of ring, Figure 45, Figure 46, and Figure 47. The wear characteristics resembled those observed on the worn wire strands within the reinforcement layer of the hydraulic hose.

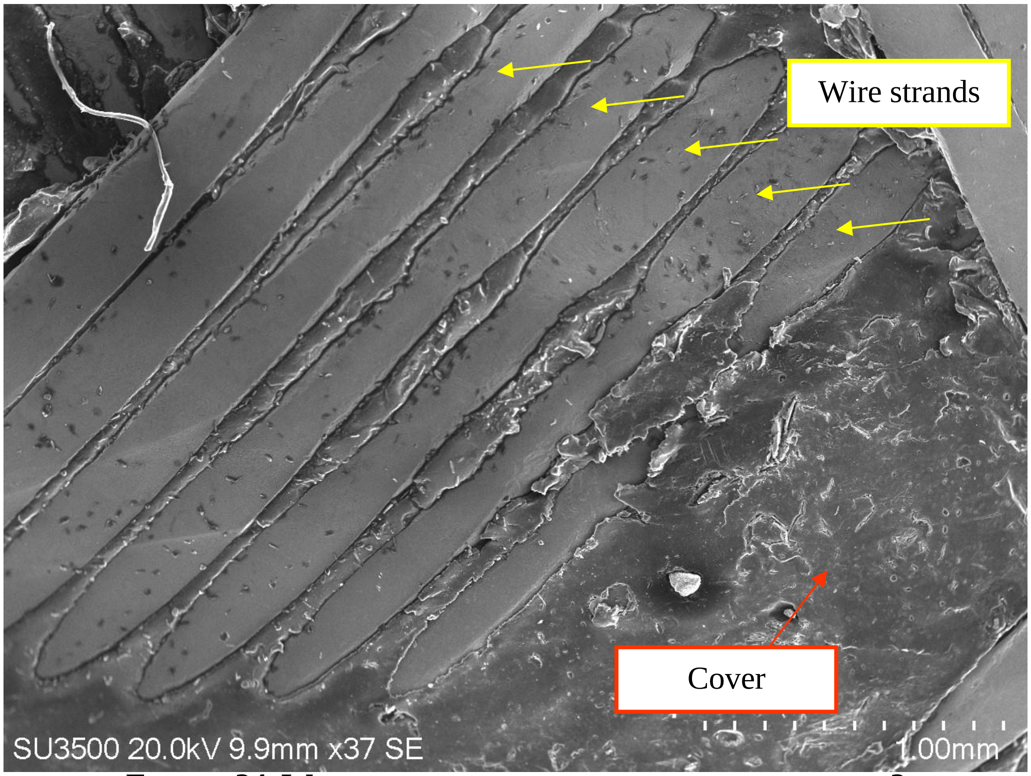


FIGURE 24. WORN WIRE STRANDS IN THE DAMAGED AREA 2

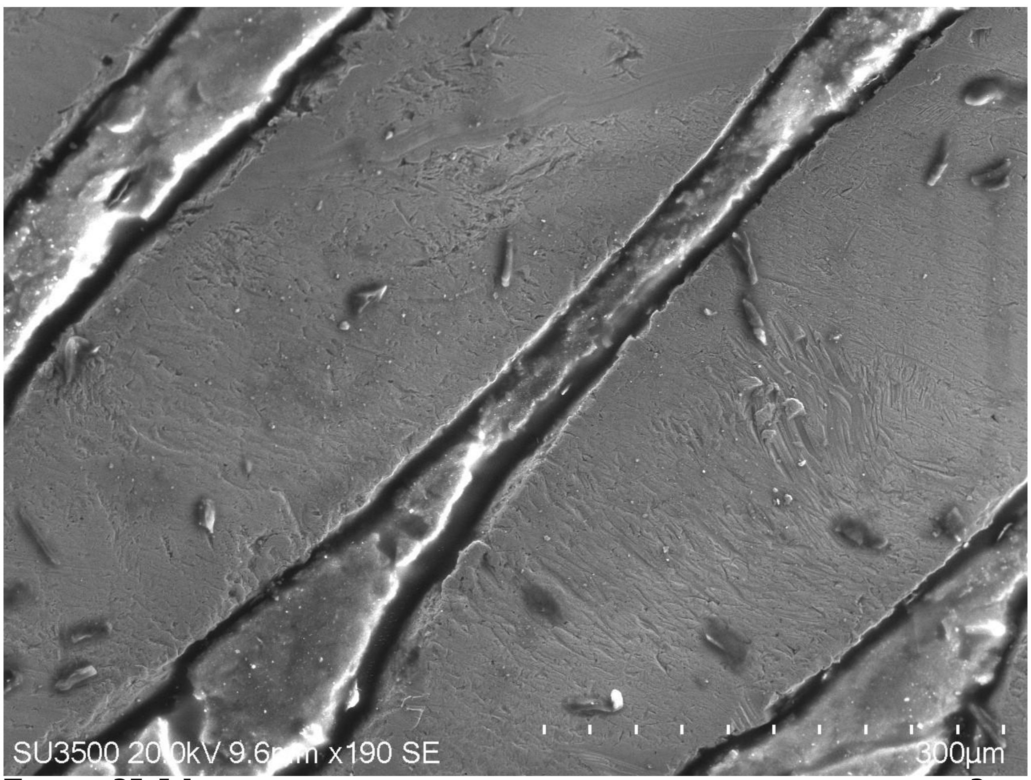


FIGURE 25. WEAR MARKS ON THE WIRE STRANDS IN THE DAMAGED AREA 2

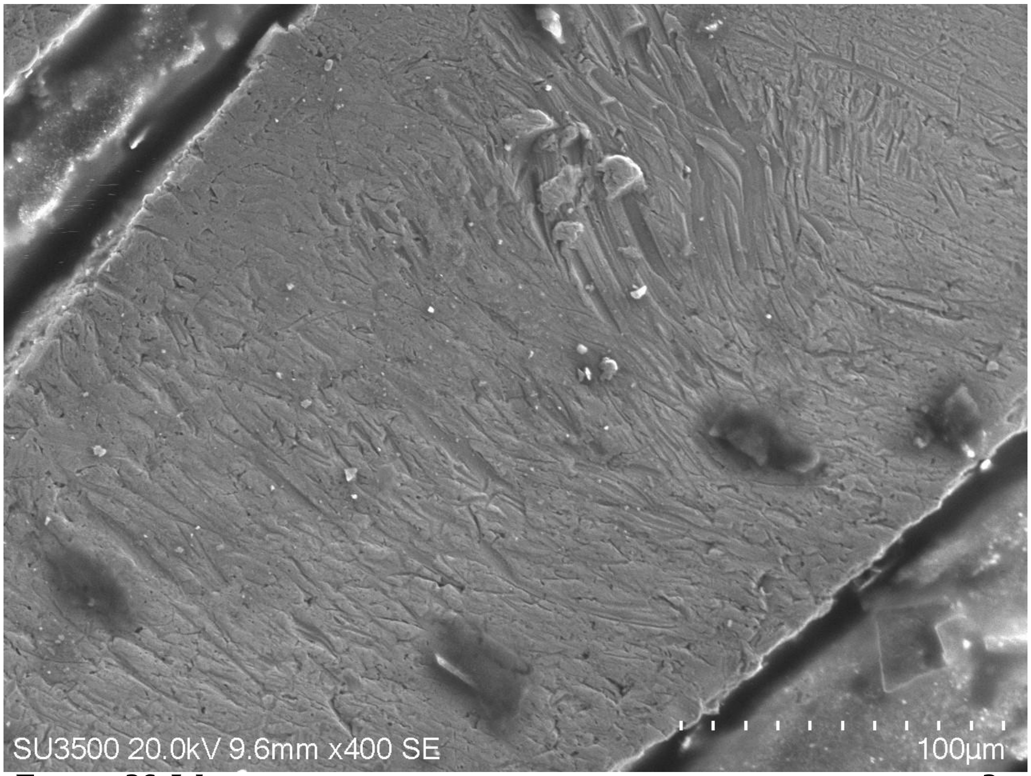


FIGURE 26. WEAR MARKS ON THE WIRE STRANDS IN THE DAMAGED AREA 2

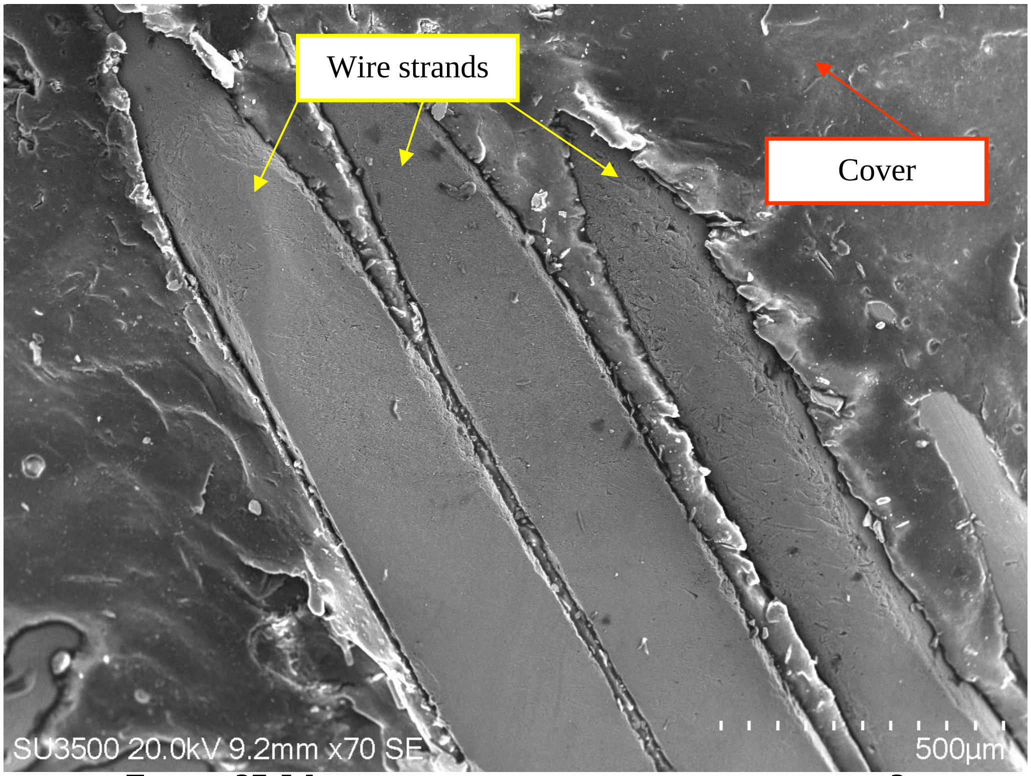


FIGURE 27. WORN WIRE STRANDS IN THE DAMAGED AREA 2

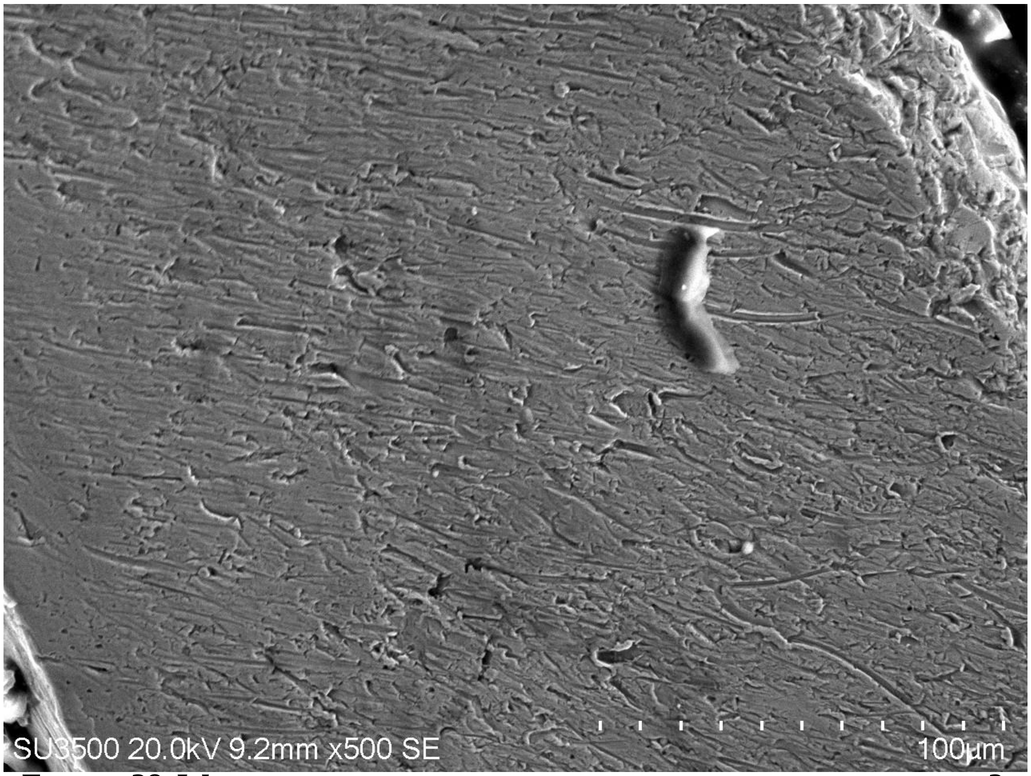


FIGURE 28. WEAR MARKS ON THE WIRE STRANDS IN THE DAMAGED AREA 2

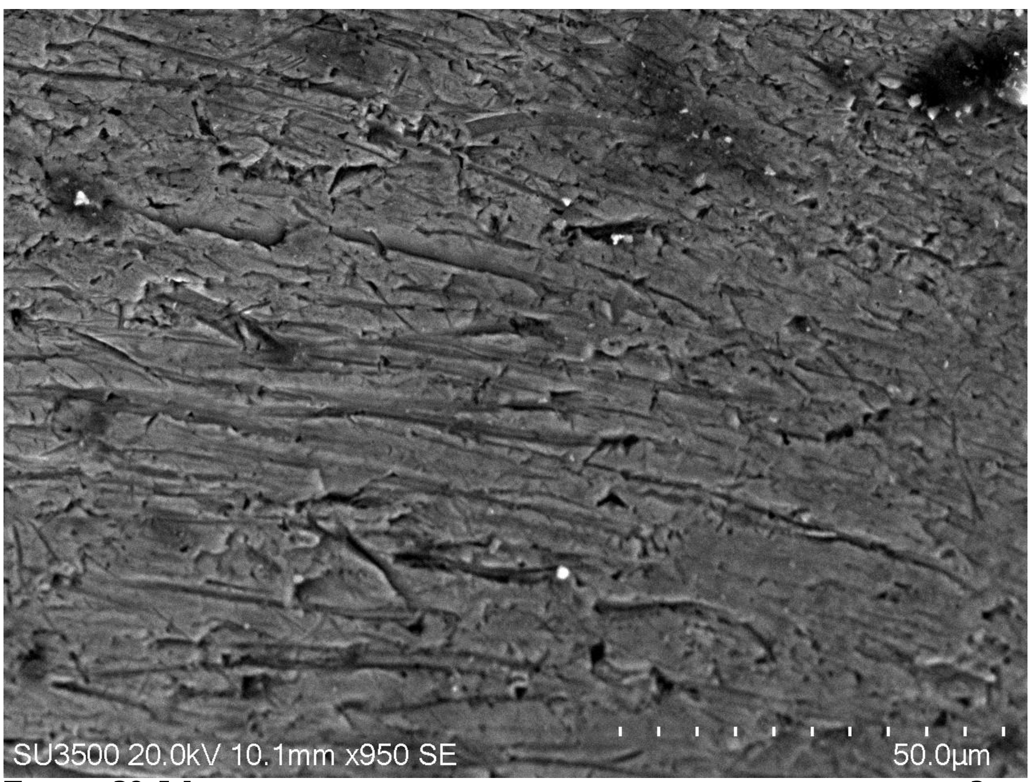


FIGURE 29. WEAR MARKS ON THE WIRE STRANDS IN THE DAMAGED AREA 2

FIGURE 30. WEAR MARKS ON THE WIRE STRANDS IN THE DAMAGED AREA 2

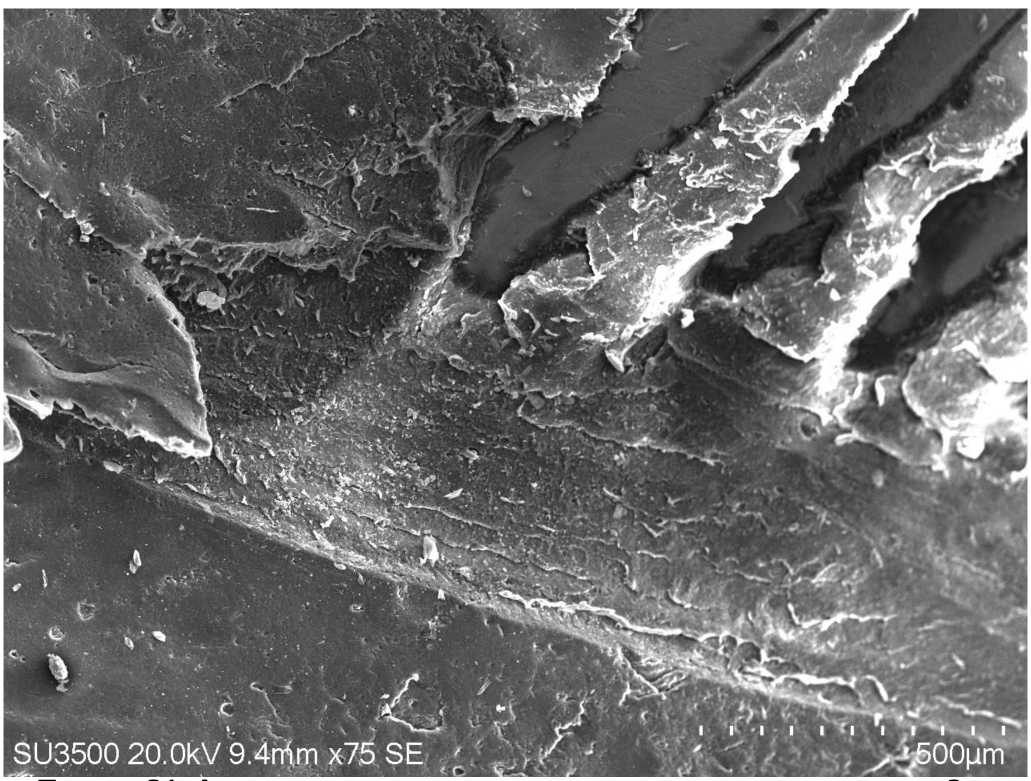


FIGURE 31. APPEARANCE OF PLASTIC COVER IN THE DAMAGED AREA 2

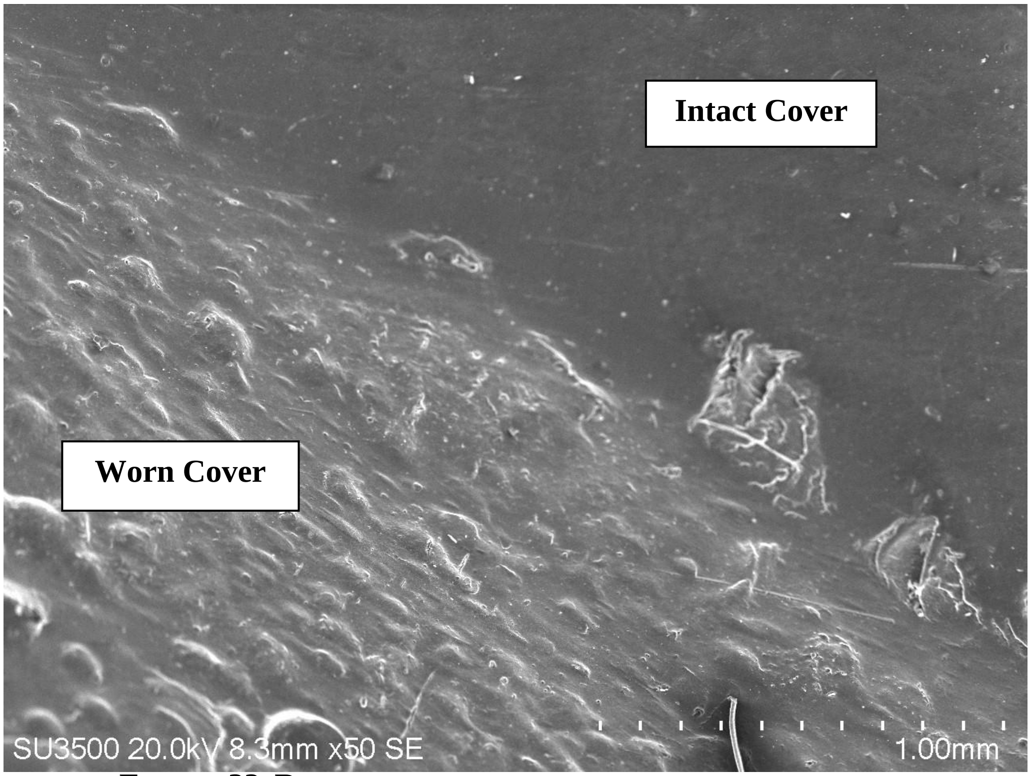


FIGURE 32. BORDER OF WORN COVER AND INTACT

FIGURE 33. BROKEN WIRE STRANDS IN DAMAGED AREA 3

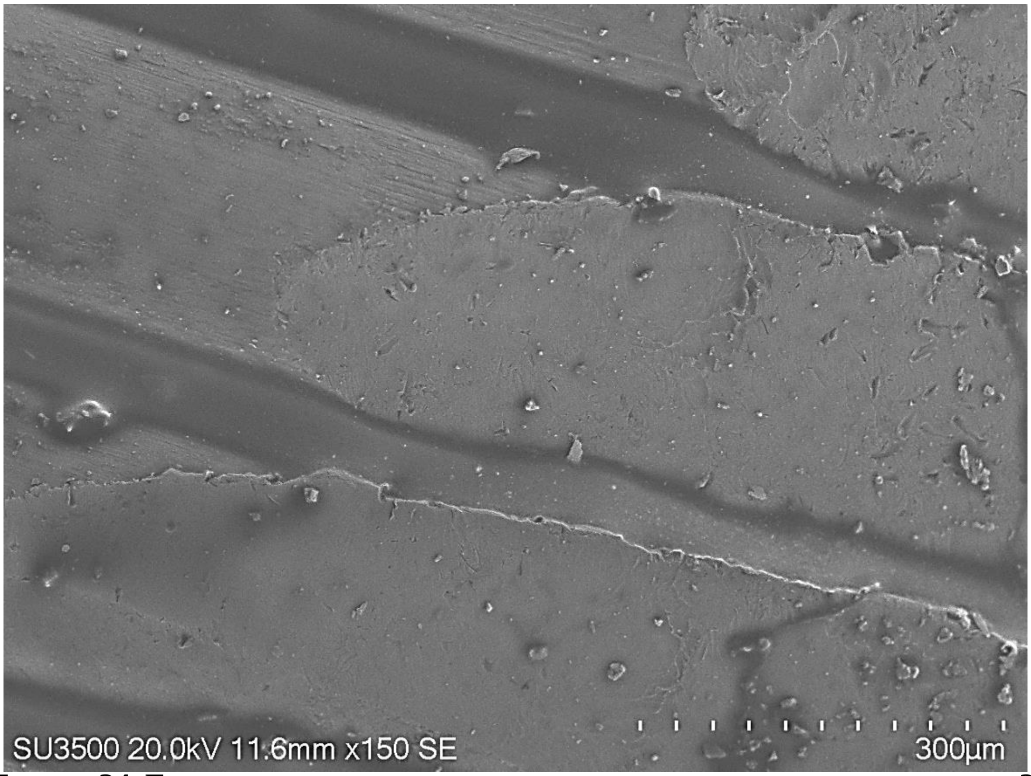


FIGURE 34. FLAT PORTION OF THE BROKEN WIRE STRANDS IN DAMAGED AREA 3

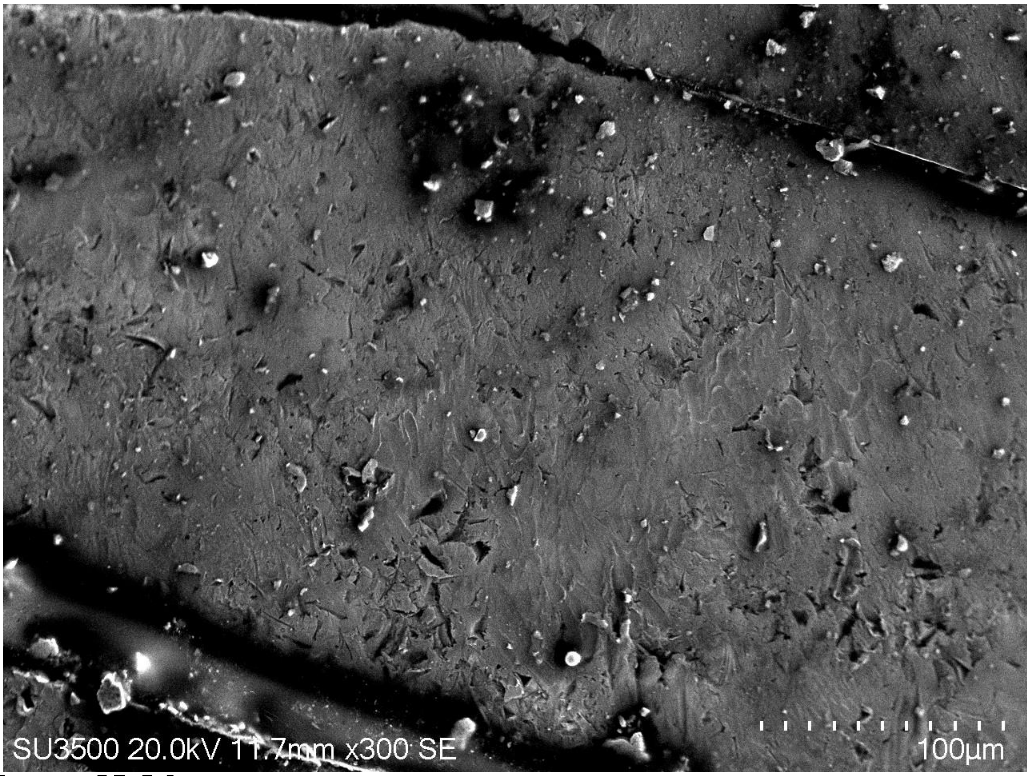


FIGURE 35. WEAR MARKS ON THE FLAT SURFACE OF BROKEN WIRE STRANDS IN DAMAGED AREA 3

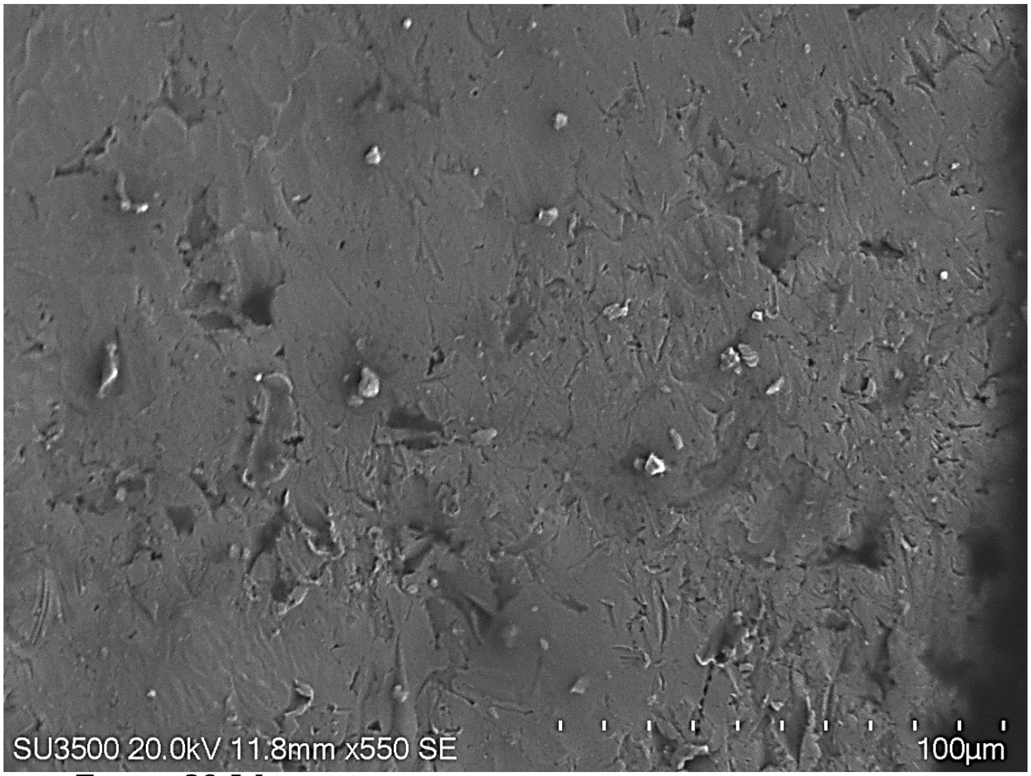


FIGURE 36. WEAR MARKS ON THE FLAT SURFACE OF BROKEN WIRE STRANDS IN DAMAGED AREA 3

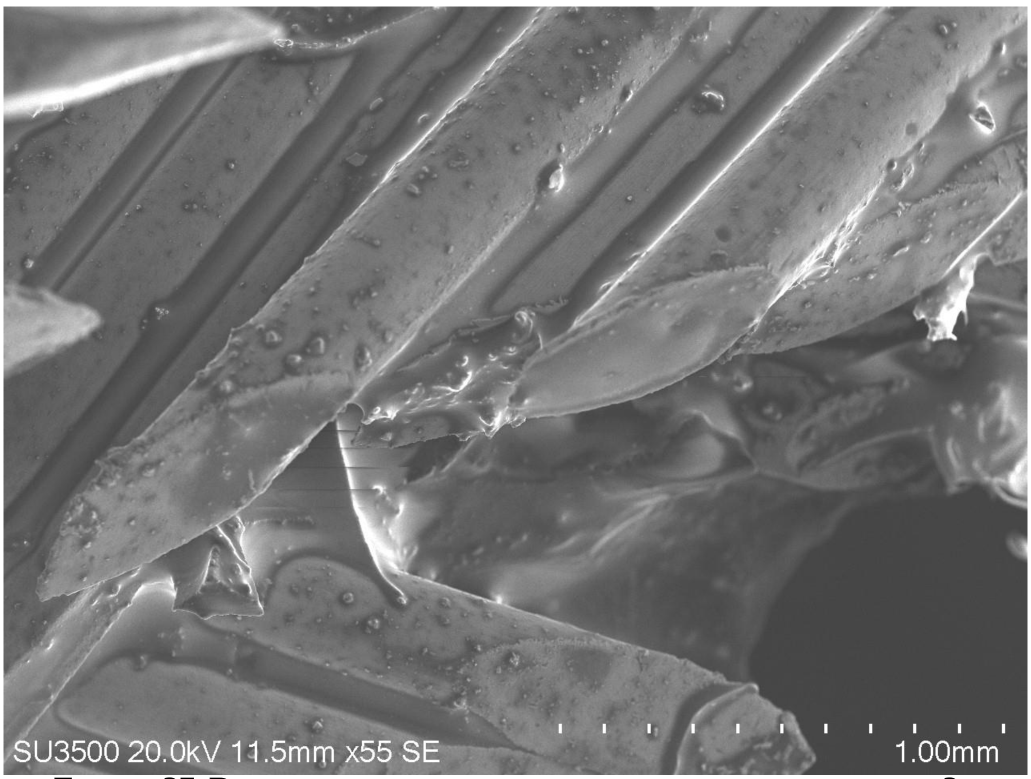


FIGURE 37. BROKEN WIRE STRANDS IN STRANDS IN DAMAGED AREA 3

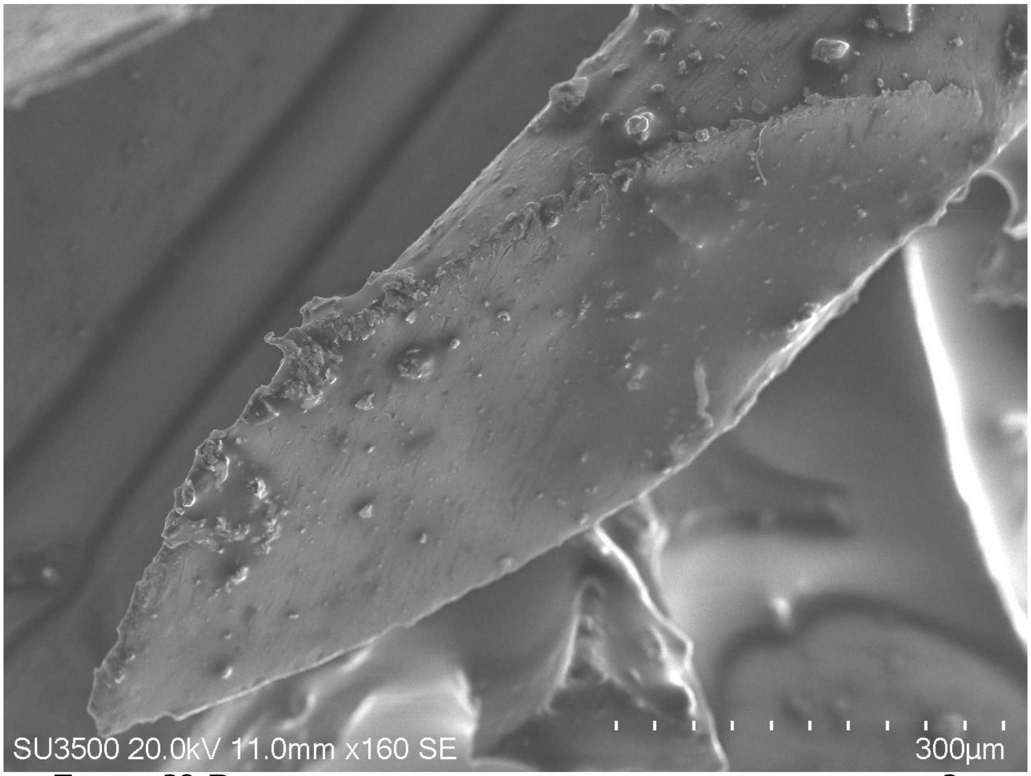


FIGURE 38. BROKEN WIRE STRANDS IN STRANDS IN DAMAGED AREA 3

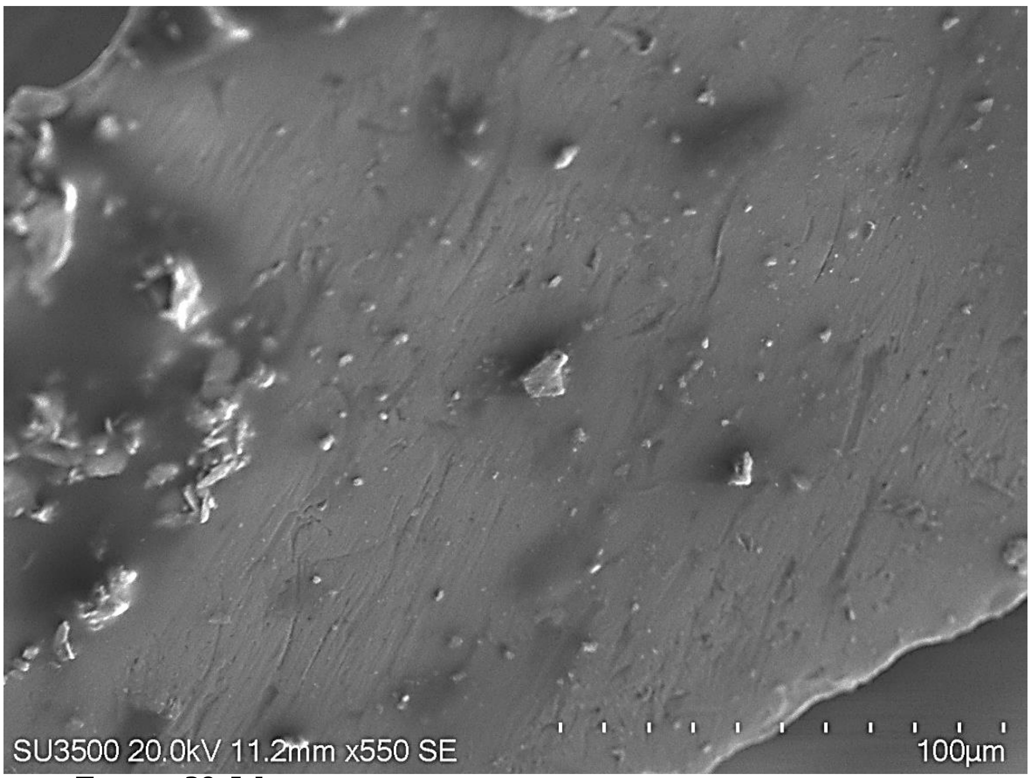


FIGURE 39. WEAR MARKS ON THE FLAT SURFACE OF BROKEN WIRE STRANDS IN DAMAGED AREA 3

FIGURE 40. EXPOSED WIRE STRANDS IN DAMAGED AREA 3

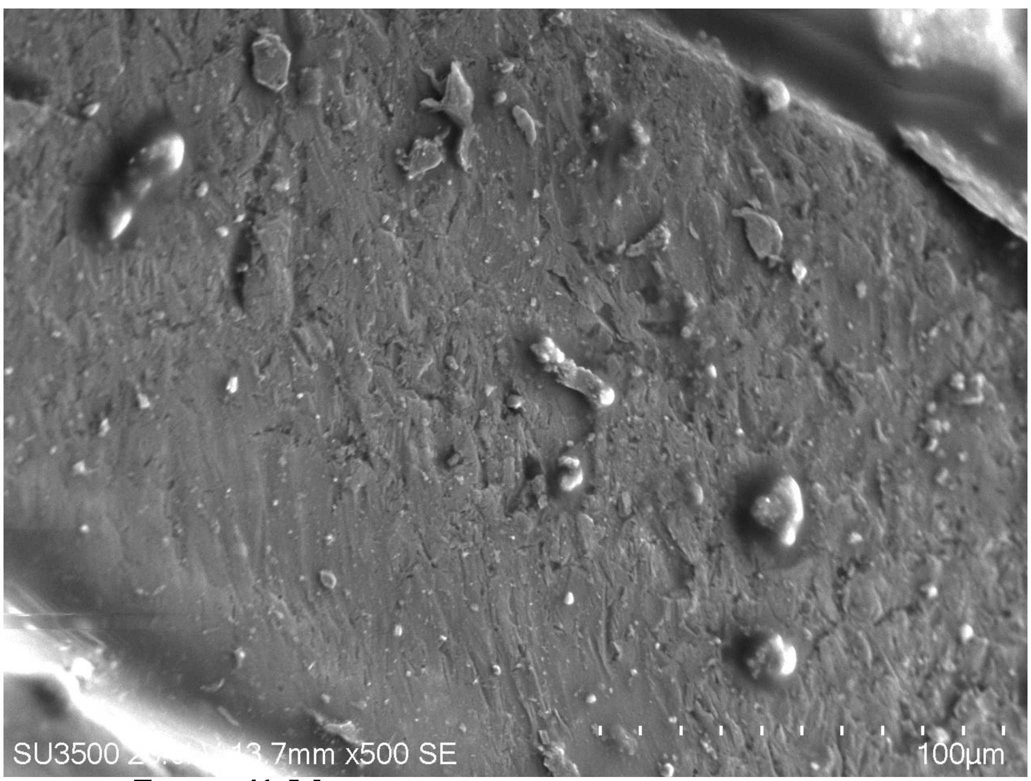


FIGURE 41. WEAR MARKS ON THE FLAT SURFACE OF WIRE STRANDS IN DAMAGED AREA 3

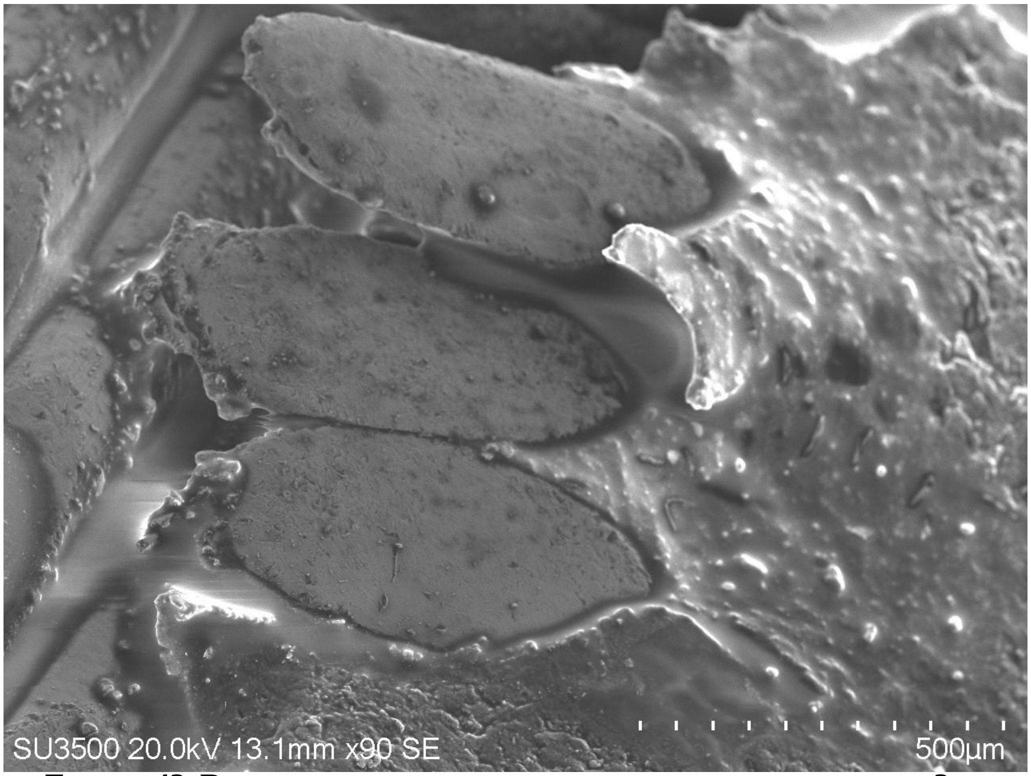


FIGURE 42. BROKEN WIRE STRANDS IN STRANDS IN DAMAGED AREA 3

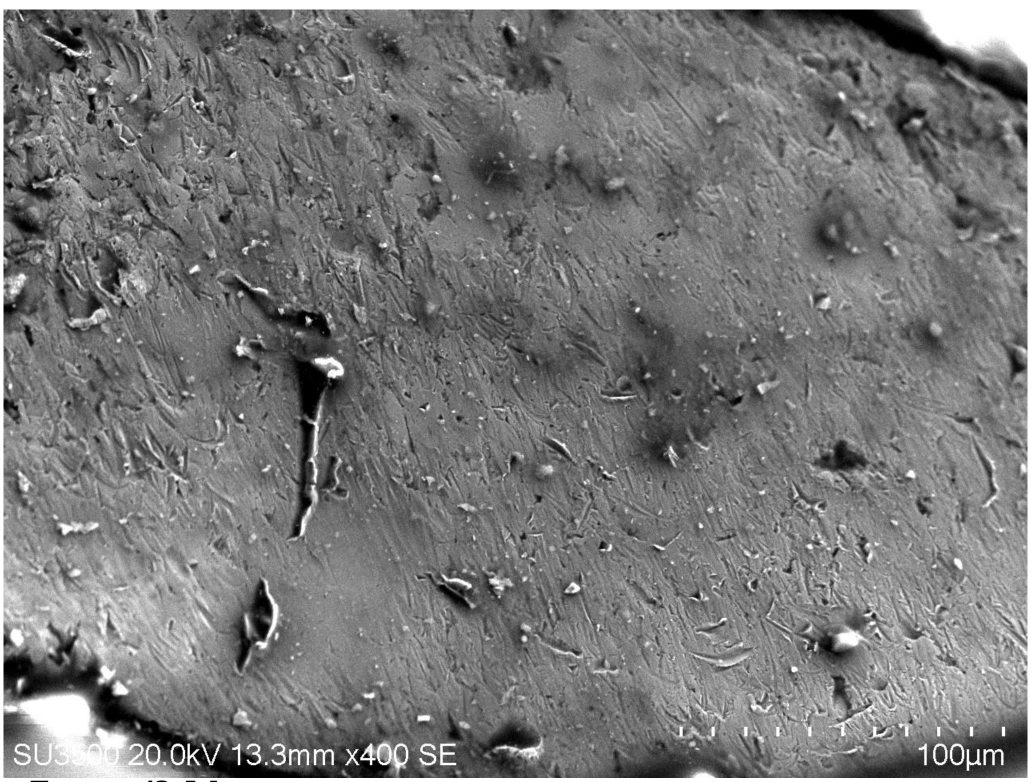


FIGURE 43. WEAR MARKS ON THE FLAT SURFACE OF WIRE STRANDS IN DAMAGED AREA 3

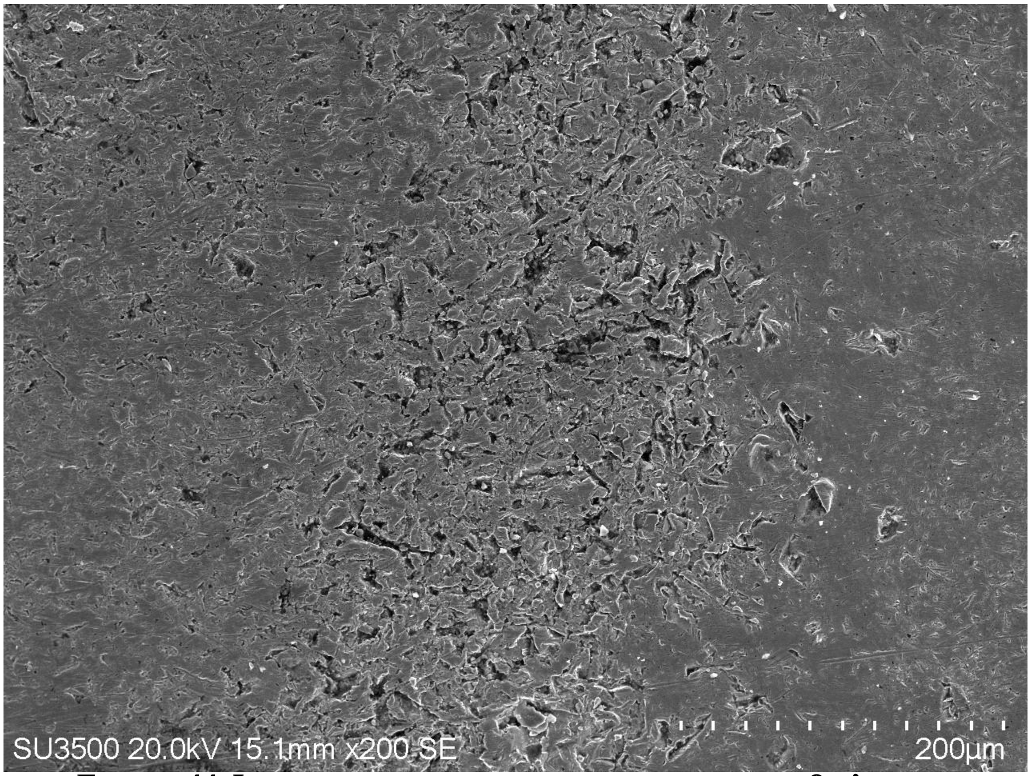


FIGURE 44. INNER SURFACE OF THE METALLIC RING AT 8 O'CLOCK

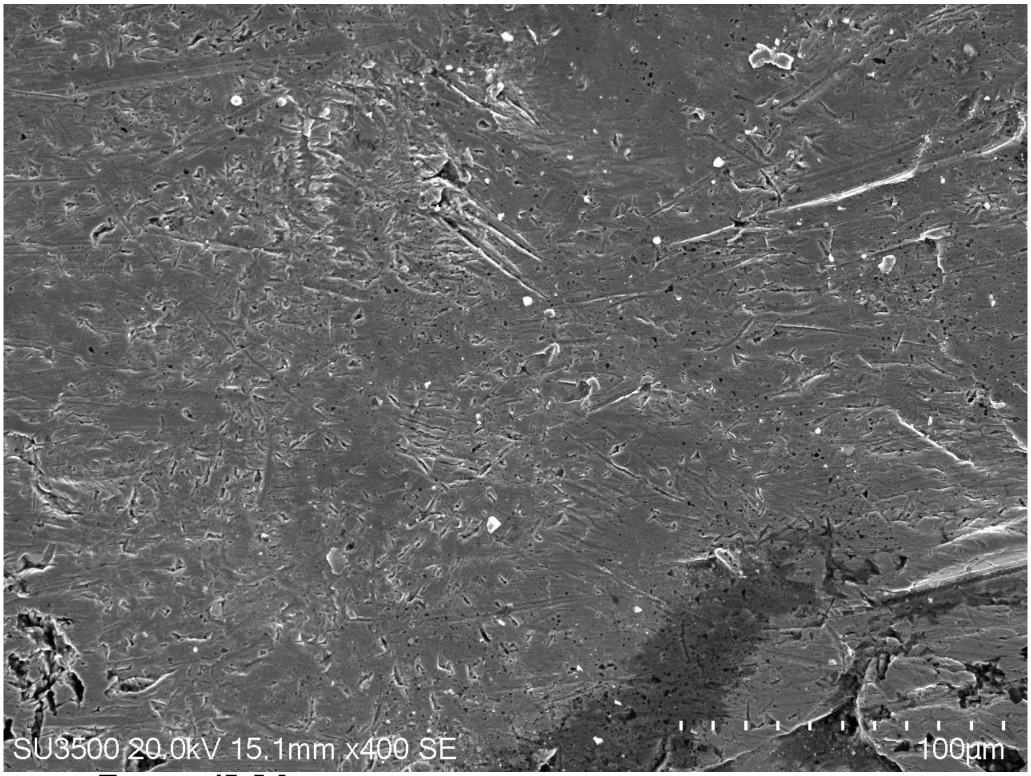


FIGURE 45. WEAR MARKS ON THE INNER SURFACE OF THE RING

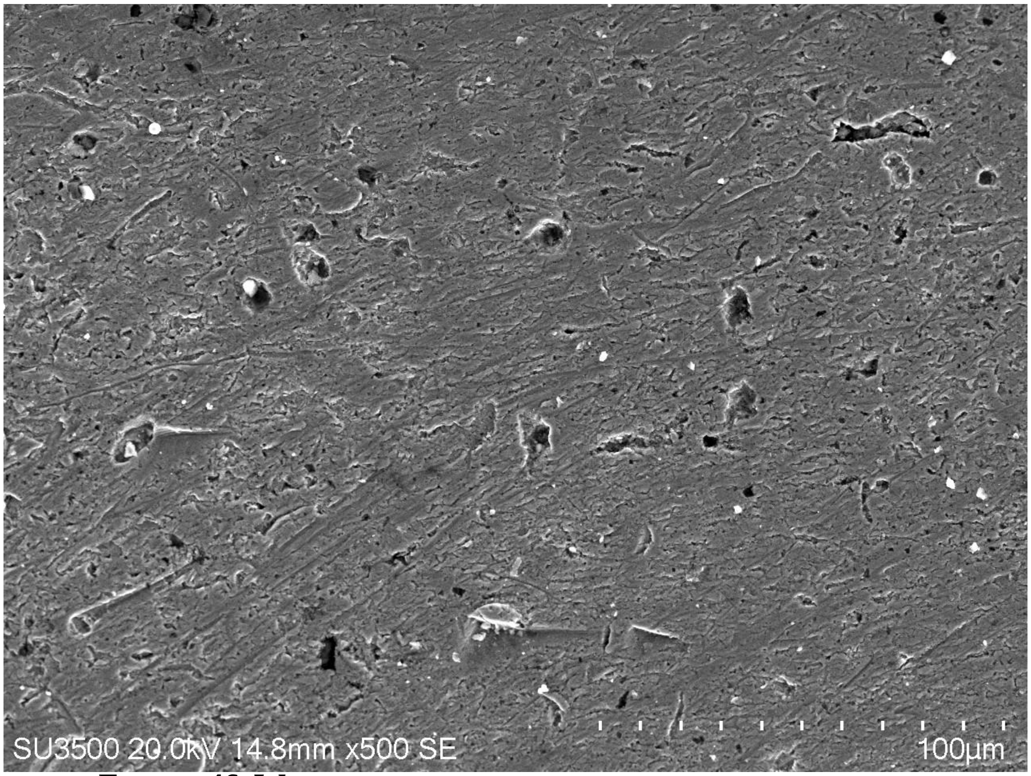


FIGURE 46. WEAR MARKS ON THE INNER SURFACE OF THE RING

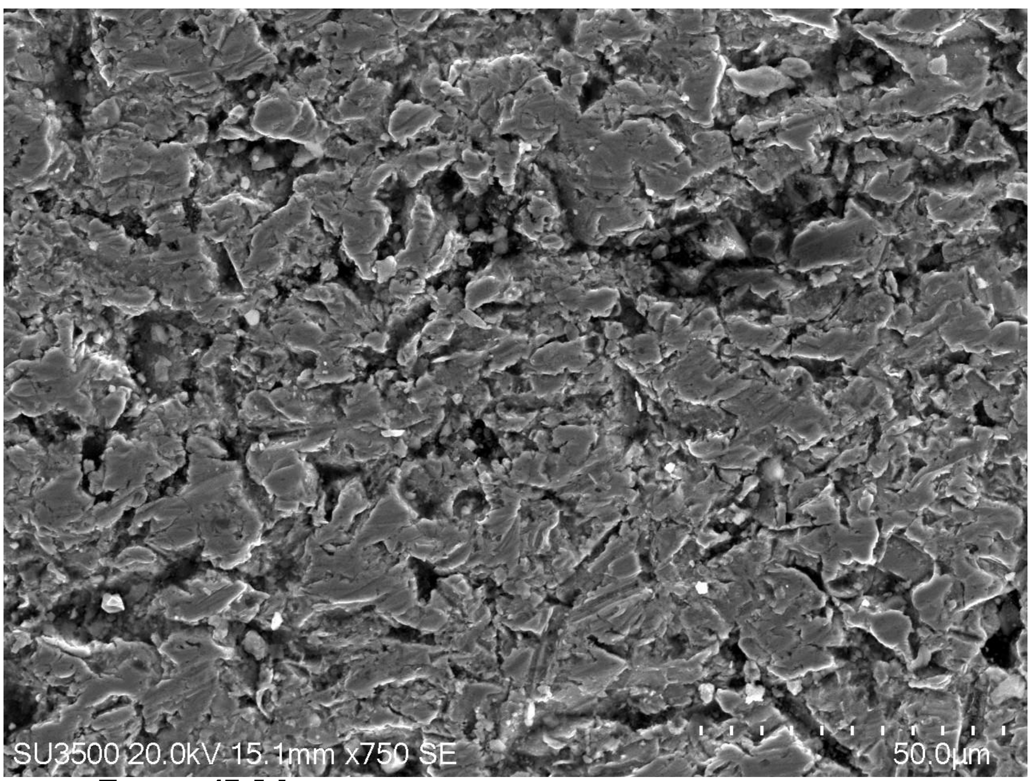


FIGURE 47. WEAR MARKS ON THE INNER SURFACE OF THE RING

5.0 METALLOGRAPHIC EXAMINATION

One section was removed from the damaged area 2 for cross-sectional metallographic examination. The section was cold mounted, ground and polished as per ASTM E3-11(2017). After examination in as-polished condition, the sample was etched using 2% nital solution in accordance with ASTM 407-23 to reveal the microstructure of the wire strands. The following observations were made.

i) Figure 48 presents a general image of the prepared cross-sectional metallographic sample in as polished condition. The cross-section shows two layers of black coating and a reinforcement layer (metallic wire strands) situated between them. The outer surface coating was thinner or totally removed in the damaged area resulted in exposure of the wire strands.

ii) Closer view of the reinforcement layer within the damaged area is presented in Figure 49 and Figure 50. The wire strands exhibited a round cross-section. However, the shape of several wire strands, particularly those situated closer to the outer surface of the hose was compromised. The wire strands that were compromised exhibited a flattened edge when viewed in cross-section.

iii) Examination after etching revealed tempered martensite structure in the wire strands, Figure 51 and Figure 52.

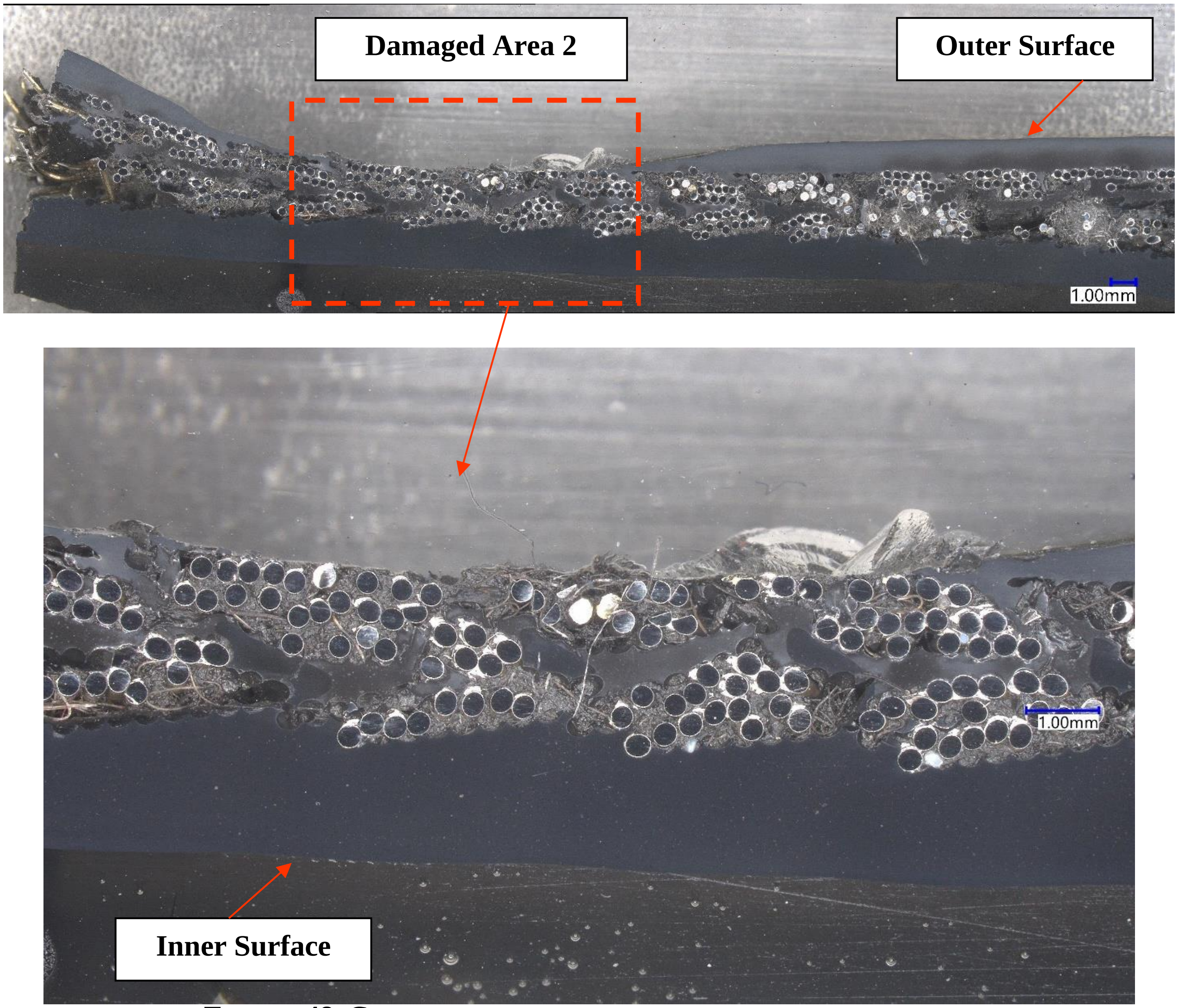


FIGURE 48. CROSS-SECTIONAL METALLOGRAPHIC SAMPLE AND CLOSER VIEW OF THE DAMAGED AREA

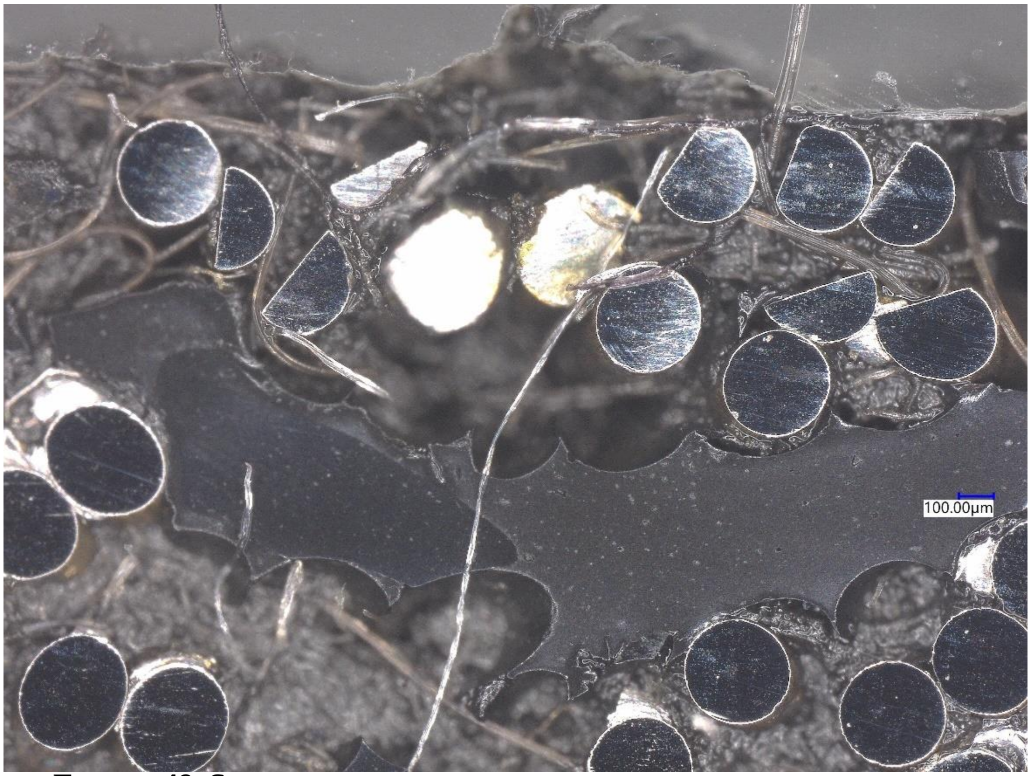


FIGURE 49. SHAPE OF THE WIRE STRANDS WITHIN THE DAMAGED AREA

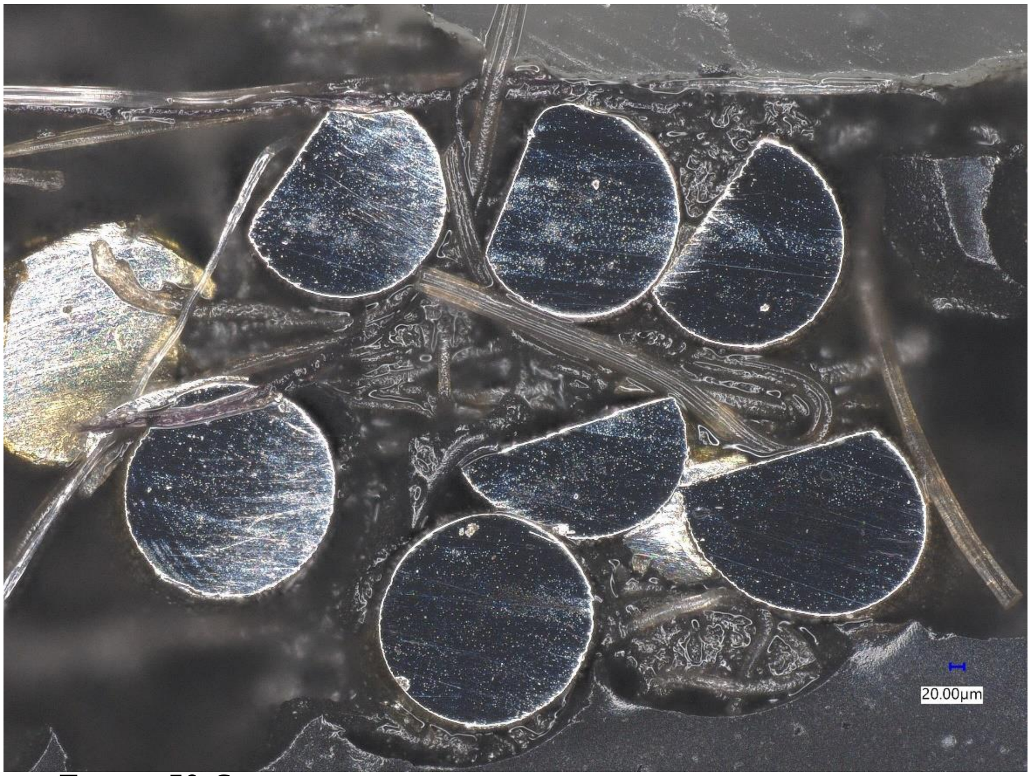


FIGURE 50. SHAPE OF THE WIRE STRANDS WITHIN THE DAMAGED AREA

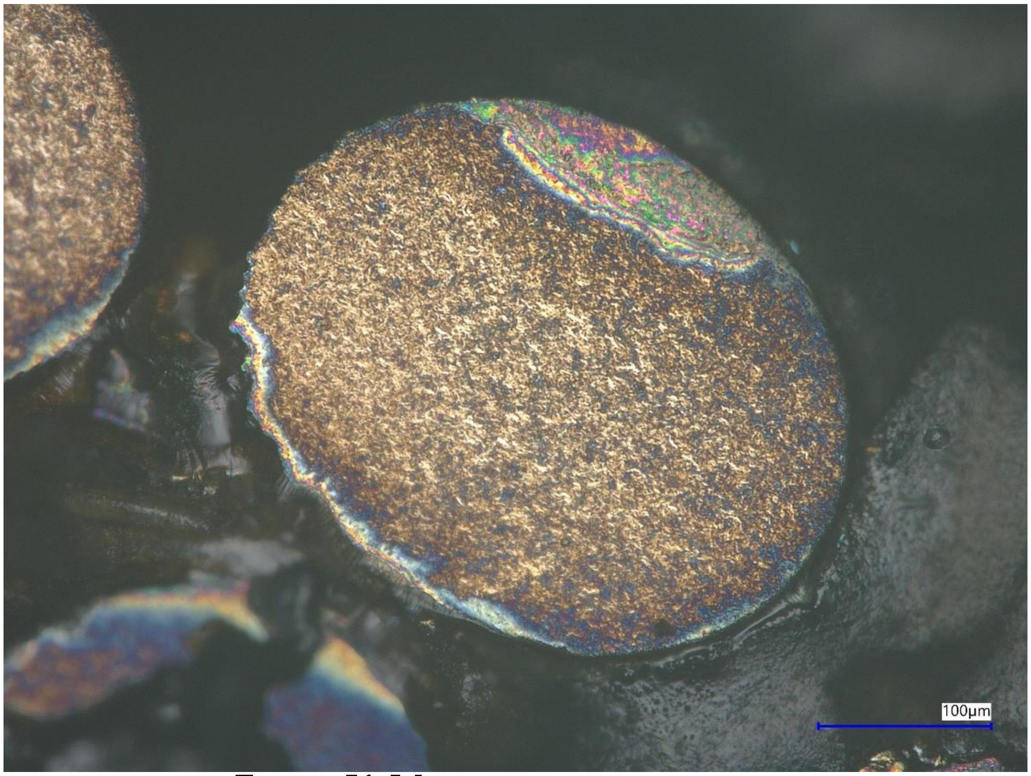


FIGURE 51. WIRE STRAND AFTER ETHCING

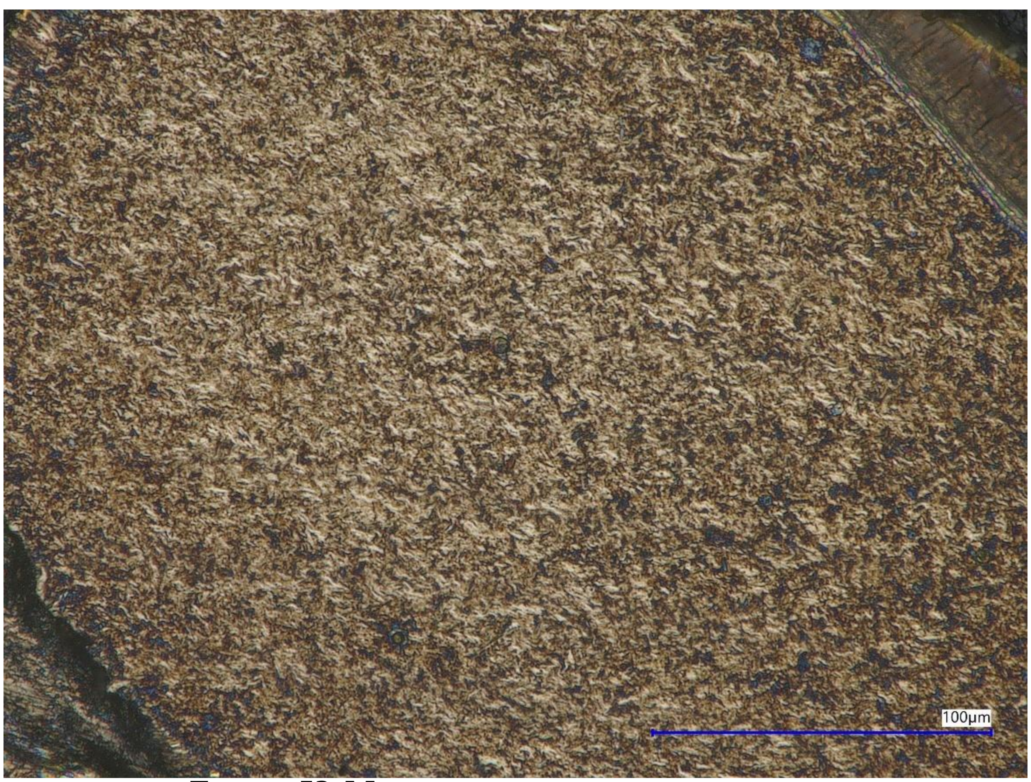


FIGURE 52. MICROSTRUCTURE OF WIRE STRANDS

6.0 CHEMICAL ANALYSIS

Some wires were extracted from the hose and subjected to the chemical analysis using Inductively Coupled Plasma Analysis (ICP) as per ASTM E1019-18, ASTM E1097-12 and ASTM E1479-16. The results are presented in Table 1.

TABLE 1. RESULTS OF CHEMICAL ANALYSIS OF WIRES

Element	Wt.%
Mn	0.58
P	< 0.010
S	0.009
Cu	0.35
Si	0.24
Ni	0.03
Cr	0.04
Fe	98.06

7.0 DISCUSSION

The hydraulic hose exhibited damages in multiple areas along the length of the hose caused by an abrasive wear process that likely occurred during the service. The braided hydraulic hose was comprised a black coating and a reinforcement layer embedded in the coating material. The reinforcement layer was made of braided steel wire strands. The coating was damaged or even totally removed in some areas. As a result, the wire strands became exposed and showed either a flat surface or complete breakage. Evidence of scratches, indentation/impact, and gouging was evident on the surface of exposed wire strands, indicating wear marks from an abrasive wear process. Similar wear marks were found on the inner surface of the ring used in the same car where the hose passed through. This suggested that at least one of the worn areas caused by rubbing the hydraulic hose against the ring's inner surface or edge. Cross-sectional metallographic examination also showed a compromised shape for the exposed wire strands within a damaged area. The compromised shape exhibited a flat edge caused by the abrasive wear process.

Upon visual examination multiple areas were observed along the length of the hose that exhibited damages. Within these areas, the black coating was partially or completely removed. In some of the damaged areas the wire strands were evident due to complete removal of the coating. The exposed wire strands exhibited a shiny flat surface. There was only one area in which the coating was completely removed, and the exposed wire strands were broken and separated. The relative locations of the damaged areas were reported with respect to the 45-degree hose end and the size of each was measured.

Scanning electron microscope was employed to examine the coating layer and the wire strands in the reinforcement layer within the damaged areas. The results revealed the presence of wear marks on the surface of the wire strands or tip of the strands that were broken. These wear marks showed scratches, impacts, and in some area gouges, indicating abrasive wear occurred.

Metallographic examination exhibited a round cross-section for most of the wire strands within the reinforcement layer. However, the shape of several wire strands was compromised within a damaged area, especially those closer to the outer surface and exposed. These wire strands exhibited a flat edge in their cross-section that caused by continued wear process during the service.

8.0 CONCLUSIONS

- Abrasive wear during the service was likely the cause for damages on the hydraulic hose
- Wear marks were evident on the worn surface of wire strands
- Wear marks were also observed on the flat tip of the broken wire strands

We trust that this report provides the information that you require. Please contact me if you require any further information, or if we can be of assistance in any other way.

Yours Sincerely,

Prepared By, **Reviewed By,**

Changizian Erhan Ulvan

Pooyan Changizian, Ph.D.
Materials Engineering and Failure Analysis

Erhan Ulvan Ph.D., P.Eng, FASM
Manager Engineering and Lab

128-24-HAT003-J152359 R0 Fialure Analysis Examination of a Car Hose - Final.docx

Please note that unless we are notified in writing, samples from this investigation will be disposed of after 60 days.

6. Appendix B – RT56 Timeline of Events for Incident of May 13, 2024

Scope of Work:

TTC contacted Hatch on May 15, 2024 to perform an independent assessment of eight work car incidents that occurred between January 14, 2024 and May 26, 2024, after a hydraulic hose failure on RT56 caused a 730-minute shutdown of Line 2. Hatch was not onsite to conduct an in-depth investigation and interview TTC stakeholders for the four incidents that occurred prior to Hatch's contract. Hatch's review of the four early work car incidents is limited to available TTC documentation.

Investigation approach method:

The evaluation of the May 13, RT56 spill event and subsequent work car incidents was conducted through the physical inspection of the work cars and failed components (where possible), interviews with TTC staff, and the review of available documentation (including maintenance history for the work cars and internal TTC reports on work car incidents).

Initial Leak

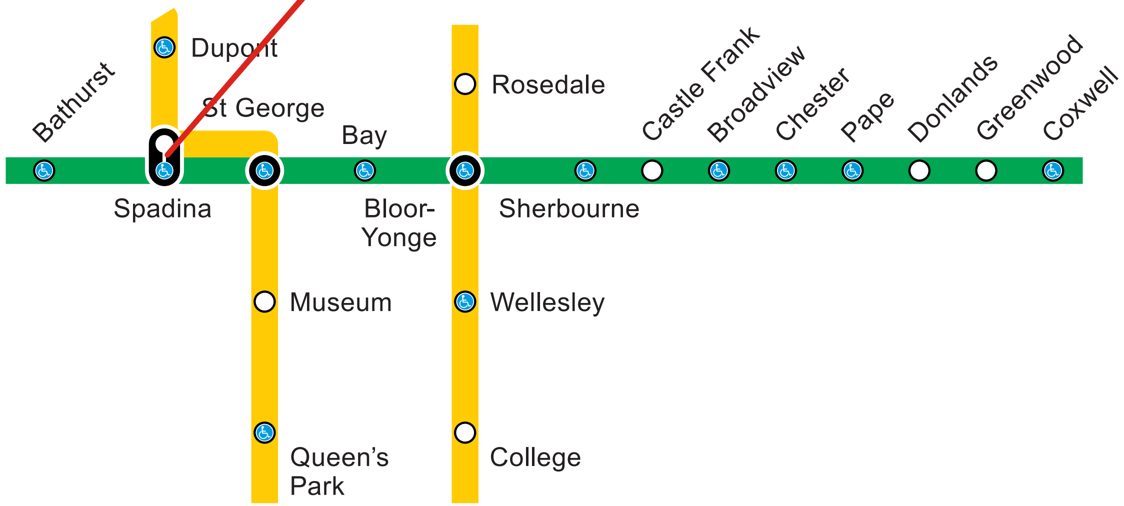
Initial Recovery

Vehicle Recovery

Greenwood Yard

Call Event Action

Call / Event / Action	Time	Description
Call	4:13 AM	Initial Call
Call	4:18 AM	Leak Described
Action	4:33 AM	Absorbent Applied
Call	4:39 AM	Leak Concern
Action	4:55 AM	RT-56 holds 5L of Fluid
Action	4:58 AM	RT-46 summoned
Action	5:17 AM	RT-46 coupled to RT-56



RT-56 Hydraulic Fluid Leak

Click Timestamp for Incident Details

Location:

Line 1 Spadina Station Northbound followed by hydraulic fluid leak Eastbound between Yonge and Broadview Station on Line 2.

Recorded By:

Head Transit Control

RT-56 Hydraulic Fluid Leak

Click **Timestamp for Incident Details**

Initial Leak

Initial Recovery

Vehicle Recovery

Greenwood Yard

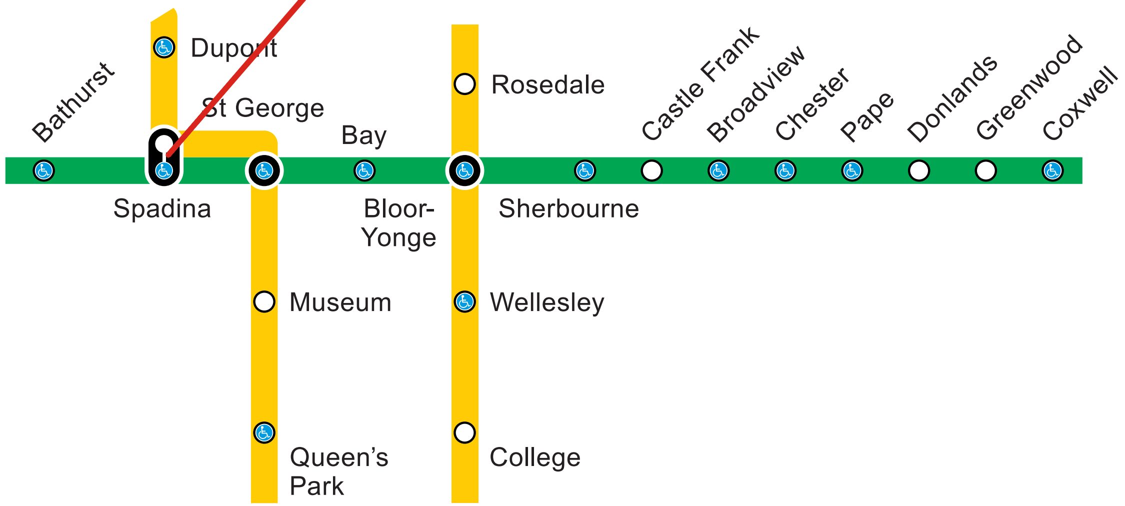
Call Event Action

5:18 AM 69484 on Scene

Suggest move to Bay Lower 5:24 AM

5:40 AM RTs Moved Off

Spadina Cleanup 5:49 AM



Location:

Line 1 Spadina Station Northbound followed by hydraulic fluid leak Eastbound between Yonge and Broadview Station on Line 2.

Recorded By:

Head Transit Control

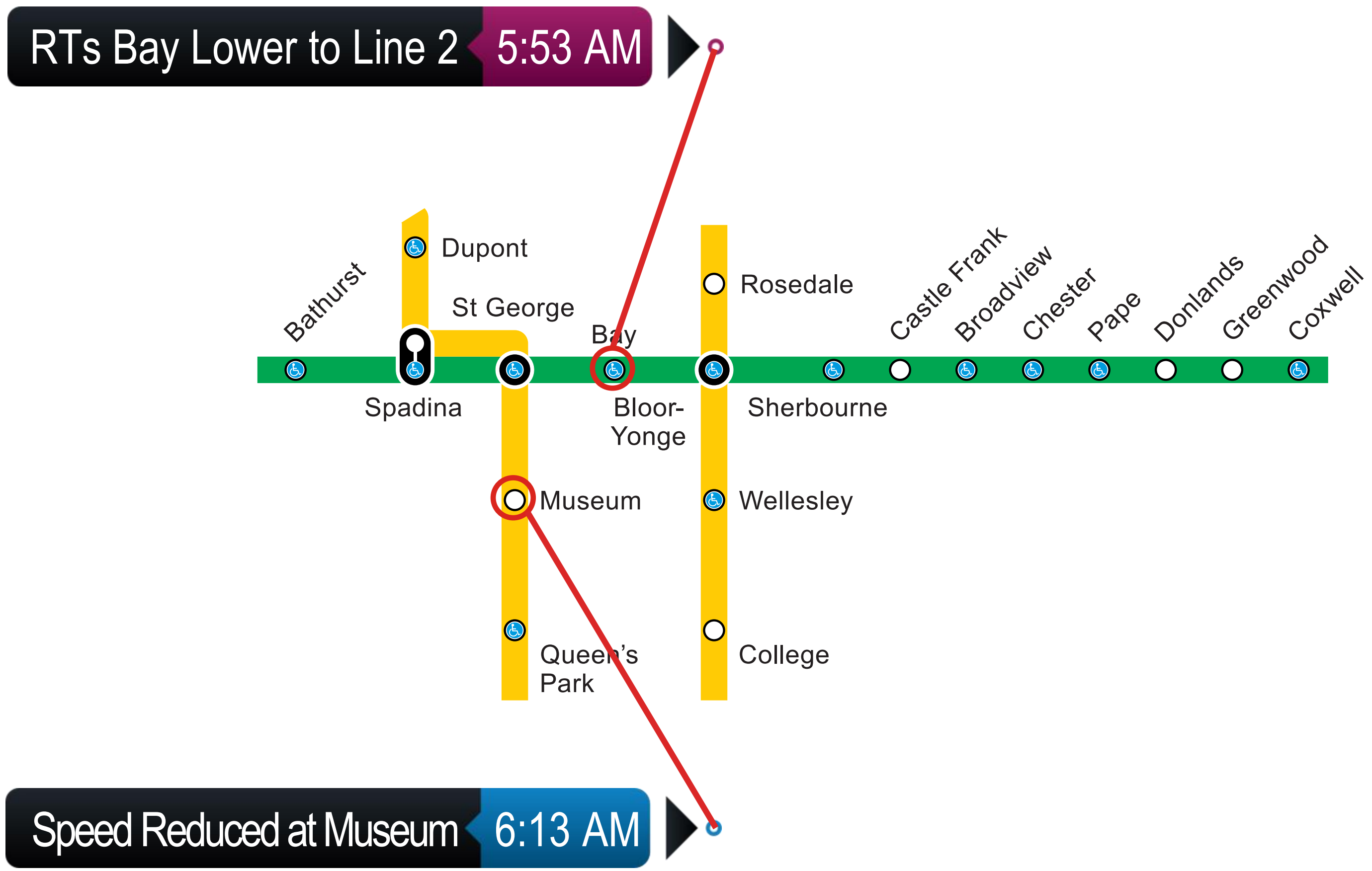
Initial Leak

Initial Recovery

Vehicle Recovery

Greenwood Yard

Call Event Action



RT-56 Hydraulic Fluid Leak

Click Timestamp for Incident Details

Location:

Line 1 Spadina Station Northbound followed by hydraulic fluid leak Eastbound between Yonge and Broadview Station on Line 2.

Recorded By:

Head Transit Control

Call Event Action

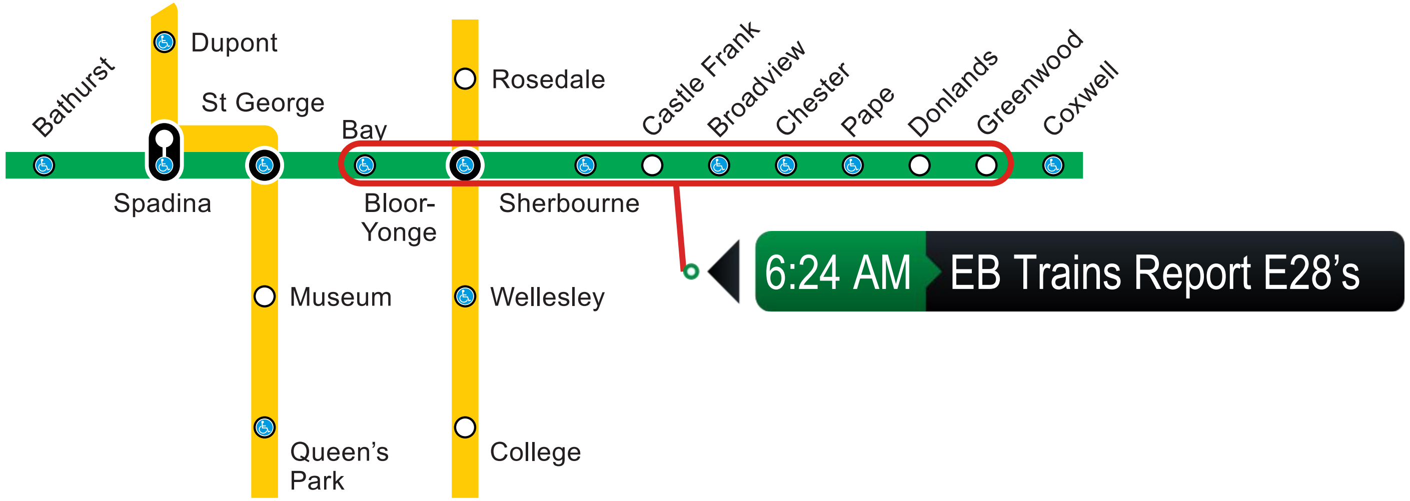
RT-56 Hydraulic Fluid Leak

Initial Leak

Initial Recovery

Vehicle Recovery

Greenwood Yard



Click Timestamp for Incident Details

Location:

Line 1 Spadina Station Northbound followed by hydraulic fluid leak Eastbound between Yonge and Broadview Station on Line 2.

Recorded By:

Head Transit Control

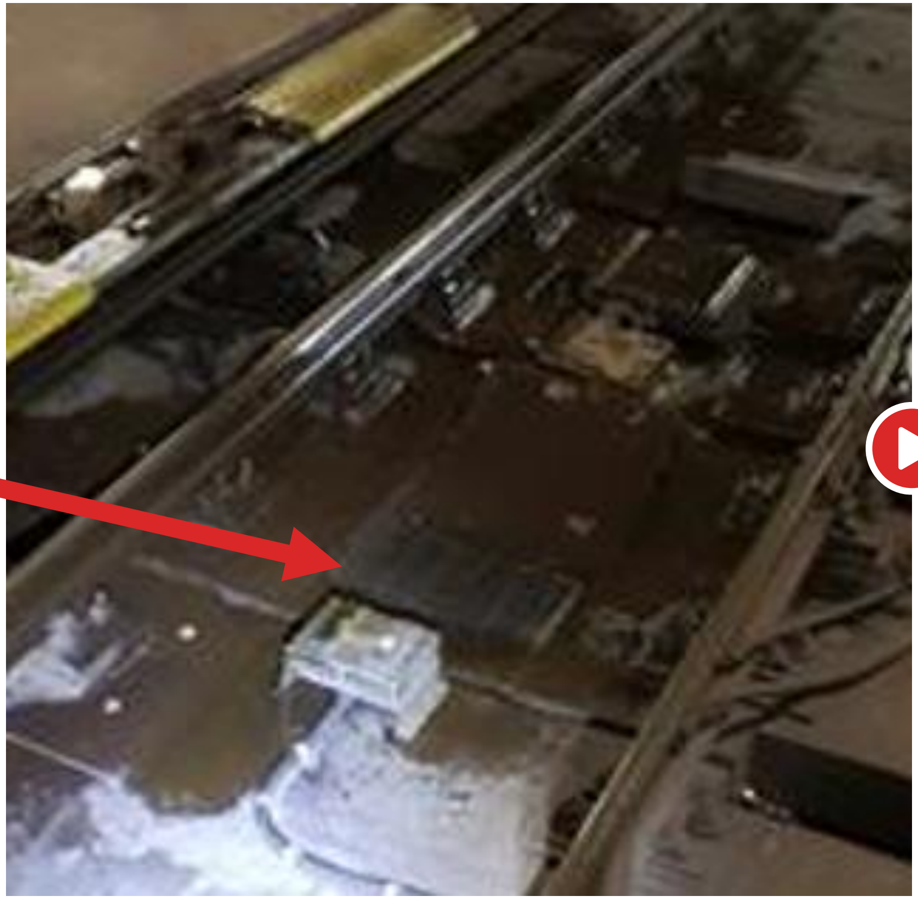
4:13 AM Initial Call

First notification of RT-56 leaking hydraulic fluid.

TIME	ORDER OF EVENTS ACTIONS	LOCATION
4:13 AM	RT-56 has leaked hydraulic fluid and needs to be towed.	North end of Spadina Station Platform

Leak thought to be only 5L at the time.

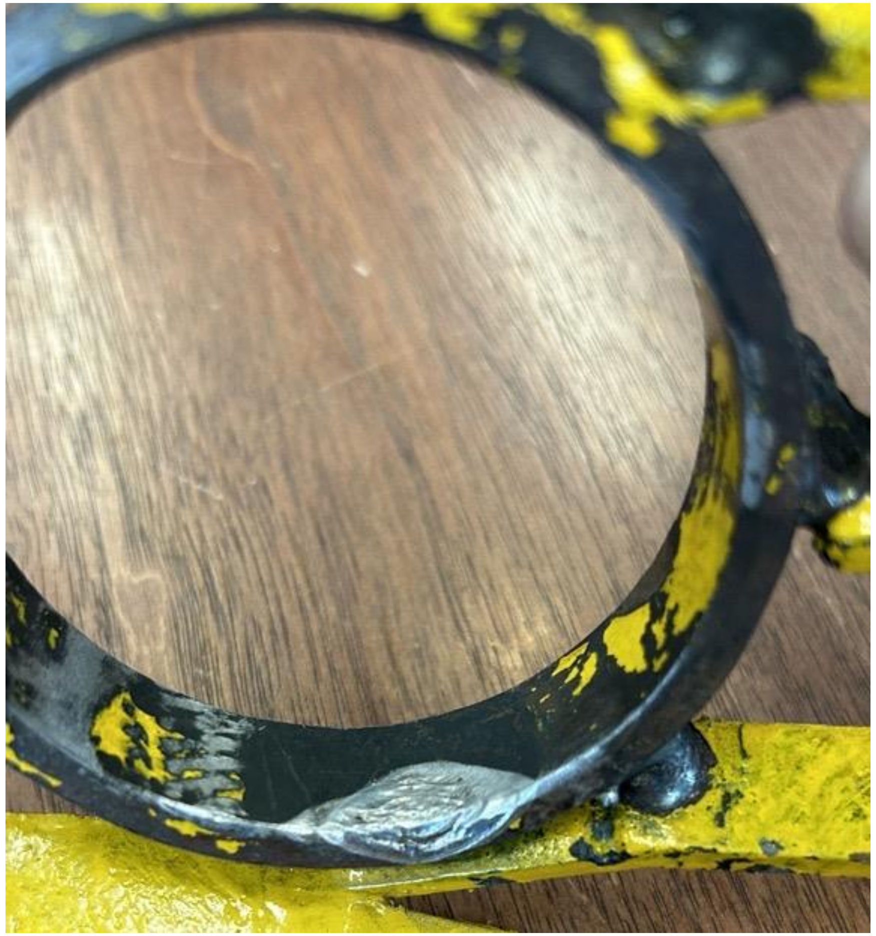
Through analysis it is estimated up to 140L was leaked at this location, with most having gone into the catch basin under this grate.



TIME	ORDER OF EVENTS ACTIONS	LOCATION
4:18 AM	Lars: “Can you estimate how many litres?” Danny: “I honestly can’t because it’s underneath the car.” Danny: “We’re trying to guess **maybe 5 litres, I don’t know**.”	North end of Spadina Station Platform

Leak thought to be only 5L at the time.

Source of the leak traced to abraded and failed hose routed tightly through and against sharp edge of ring in floor grate.



TIME	ORDER OF EVENTS ACTIONS	LOCATION
4:18 AM	Lars: “Can you estimate how many litres?” Danny: “I honestly can’t because it’s underneath the car.” Danny: “We’re trying to guess **maybe 5 litres, I don’t know**.”	North end of Spadina Station Platform

4:18 AM Leak Described

Leak thought to be only 5L at the time.

TIME	ORDER OF EVENTS ACTIONS	LOCATION
4:18 AM	Lars: “Can you estimate how many litres?” Danny: “I honestly can’t because it’s underneath the car.” Danny: “We’re trying to guess **maybe 5 litres, I don’t know**.”	North end of Spadina Station Platform

4:33 AM Absorbent Applied

Absorbent applied to track on visible spill thought to be isolated to only that area.

TIME	ORDER OF EVENTS ACTIONS	LOCATION
4:33 AM	Absorbent applied, clean up still required. Leak appears to be isolated at disabled RT's location Northbound Spadina YU.	North end of Spadina Station Platform

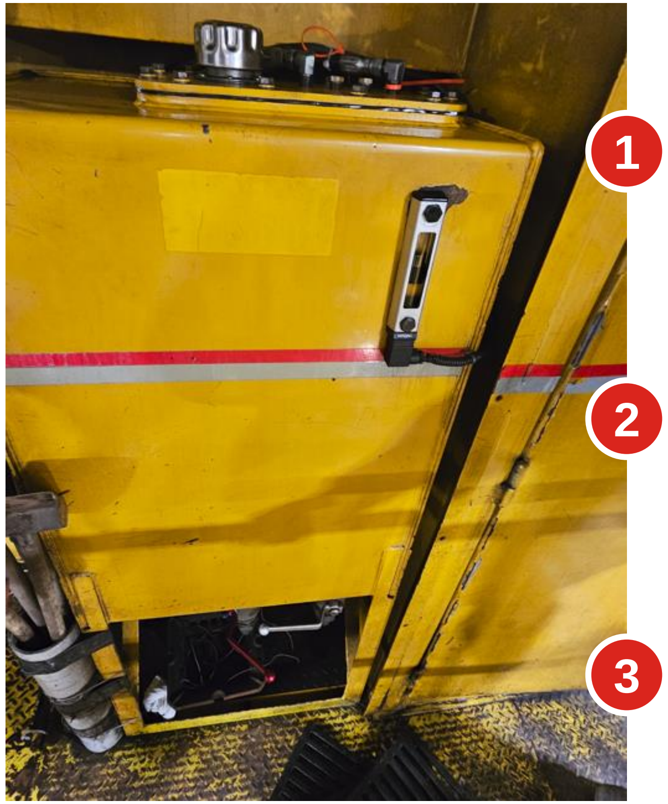
4:39 AM Leak Concern

Radio call estimates delay to be 30 minutes for clean up, and concern about moving the work car before the leak is isolated.

TIME	ORDER OF EVENTS ACTIONS	LOCATION
4:39 AM	Key elements of conversation: "About 5 litres leaked from RT-56. Might be half an hour late." Ramill (DM): "…my **main concern is having slippery rail conditions cause we had issues last time. I don't want this RT moved off anywhere until they isolate this leaked hose**, I don't want it pissing hydraulic fluid all over the infrastructure."	North end of Spadina Station Platform

Spill assumptions versus post-investigation facts.

Assumptions made during call to TCC:



Review & calculations establish:

- RT-56 reservoir can hold 210L of hydraulic fluid.
- 21L of hydraulic fluid remained in the reservoir.
- Adjacent "pump room" floor saturated with hydraulic fluid.
- Underside and side sills were coated with hydraulic fluid that remained adhered to the car after initial spill while RT-56 was stationary.
- It is estimated up to 140L of hydraulic fluid was leaked at the initial spill location, with most having gone into the catch basin.
- Due to height difference between reservoir and hose breach, hydraulic fluid will flow by gravity alone if it is not crimped off, regardless of if engine is off.

TIME	ORDER OF EVENTS ACTIONS	LOCATION
4:55 AM	Foreperson, 70564, advised RT-56 **only holds 5 litres of oil and it appears to have leaked out** of the RT. Crew is **unable to crimp the broken hose due to it being underneath the RT with no access**. RT will have to be addressed in Greenwood Yard. RT will have to coupled up in order to move it off and **as long it [engine] is not turned on, it will no longer leak only small drips expected between running rails**.	North end of Spadina Station Platform

4:58 AM RT-46 summoned

RT-46 was the closest available work car that could be summoned to rescue the leaking RT-56.

TIME	ORDER OF EVENTS ACTIONS	LOCATION
4:58 AM	WAC to wayside to move RT-46 into work zone. Ministry of Environment ref#: 1-604W1H.	En route to Spadina Station.

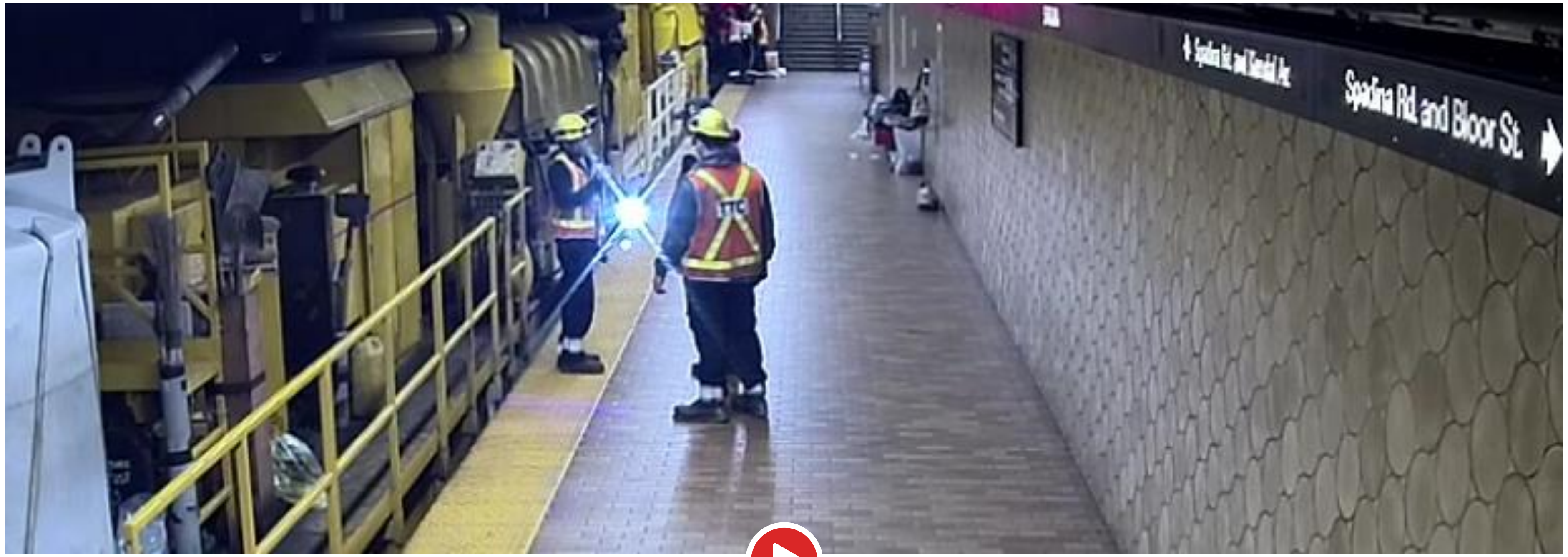
5:17 AM RT-46 coupled to RT-56

Rescue RT-46 arrives on scene and is coupled to RT-56 so it can be moved away.

TIME	ORDER OF EVENTS ACTIONS	LOCATION
5:17 AM	RT-46 and RT-56 successfully coupled together.	Middle of Spadina Station Platform

5:18 AM 69484 on Scene

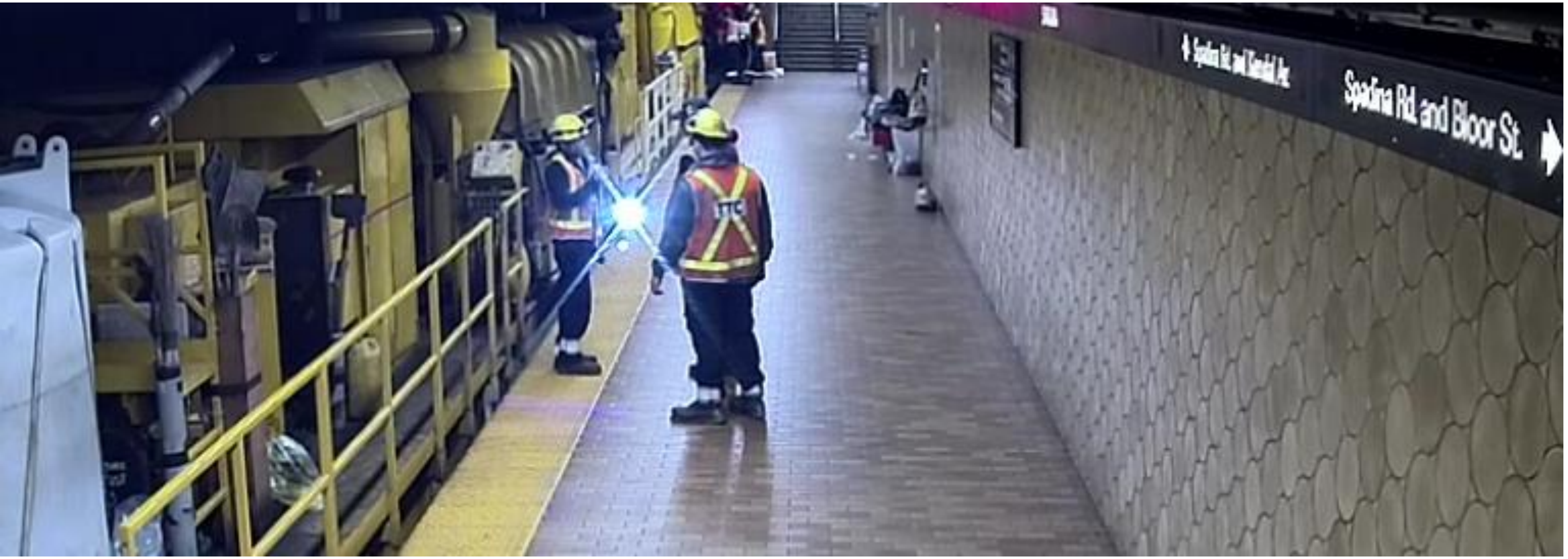
Senior management arrived on scene for further decision making while failed RT-56 and rescue RT-46 are coupled and stationary for 25 minutes in the middle of Spadina station platform.



TIME	ORDER OF EVENTS ACTIONS	LOCATION
5:18 AM	Track and Structure 69484 arrived on scene. Advised clean up can begin as soon as the RTs are moved from the affected area.	Middle of Spadina Station Platform

5:18 AM 69484 on Scene

Senior management arrived on scene for further decision making while failed RT-56 and rescue RT-46 are coupled and stationary for 25 minutes in the middle of Spadina station platform.

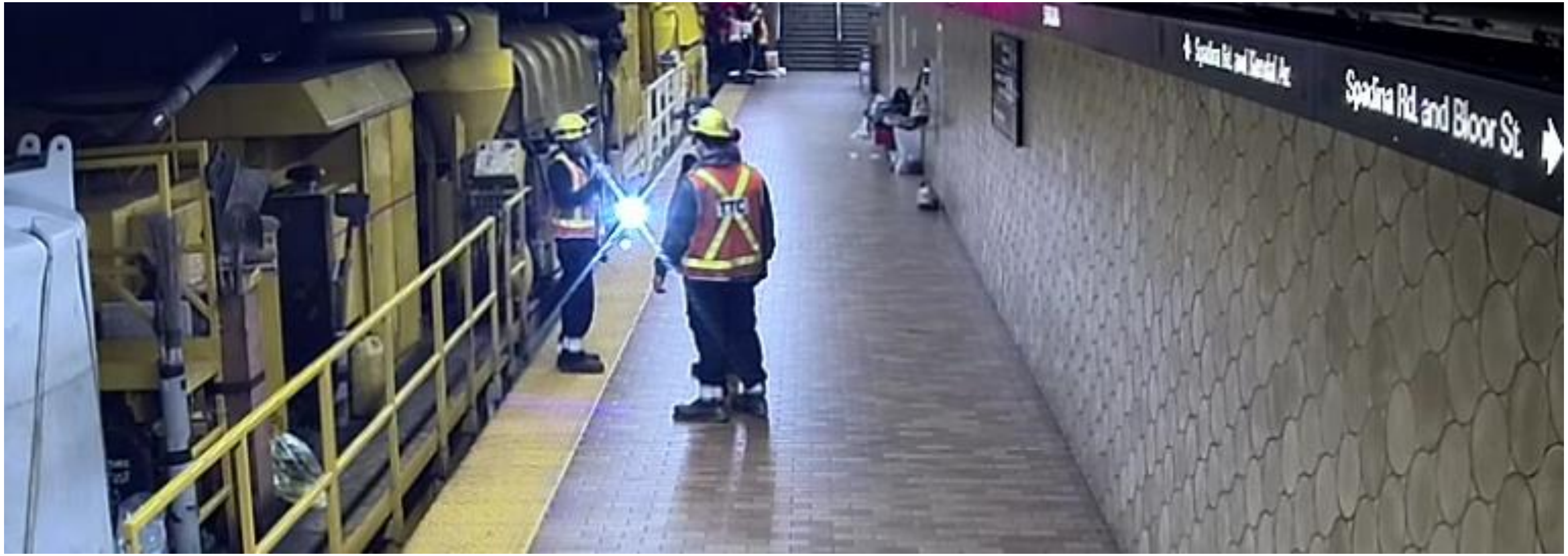


In the meantime, hydraulic fluid continued to flow through breached hose at approx. 150mL per minute (per calculation given hole size) at this new location, as observed later at track level between the running rails after the coupled work cars were moved off from this location.

TIME	ORDER OF EVENTS ACTIONS	LOCATION
5:18 AM	Track and Structure 69484 arrived on scene. Advised clean up can begin as soon as the RTs are moved from the affected area.	Middle of Spadina Station Platform

5:24 AM Suggest move to Bay Lower

Suggestion is made to move the coupled work cars to Bay Lower, presumably to stay there until it is certain there are no more hydraulic fluid leaks.



However, review of the records indicate there was no such action taken, the work cars only paused there briefly.

TIME	ORDER OF EVENTS ACTIONS	LOCATION
5:24 AM	Phone Call: Randy 143W: "Apparently the RT is still leaking." Gavin TCC: **"Maybe just put it down to Bay Lower"** ... "The biggest thing is to confirm if it's on the rail cause it looks like it's mostly in the middle of the running rail."	Middle of Spadina Station Platform

5:40 AM RTs Moved Off

Coupled RT-46 and RT-56 are given the signal to move off towards Museum Station.

RT-56 being pushed by RT-46 out of Spadina Station to Museum Station.

Marker lights and headlights are off on RT-56 indicating the engine is OFF.

There is no evidence that the engine on RT-56 was started again until it was back at Greenwood Yard.

TIME	ORDER OF EVENTS ACTIONS	LOCATION
5:40 AM	RTs moved off, travelling South on the Northbound towards Museum Station.	Middle of Spadina Station Platform

5:49 AM Spadina Cleanup

Cleanup at Spadina, including the spill created by the 25 minute pause.

TIME	ORDER OF EVENTS ACTIONS	LOCATION
5:49 AM	143 W reports that clean up in the affected area, Northbound at Spadina Station is complete. The running rail and power rail look good for service. RTs arrived at Museum Station, on route down to Bay Lower.	Middle of Spadina Station Platform

Coupled work cars move through Bloor-Yonge station after pausing only briefly at Bay Lower.

TIME	ORDER OF EVENTS ACTIONS	LOCATION
5:53 AM	RTs on route from Bay Lower unto the Bloor Danforth Line heading to Greenwood Yard.	Bloor-Yonge Station

6:13 AM Speed Reduced at Museum

Line 1 spin-slides recorded in YMSS on TR trains once revenue service began after RT-56 passed through Museum Station.

Line 2 started to experience platform overshoots starting at 6:05AM (for example, train run 223 travelling EB on Line 2) and thereafter recorded spin-slide events on several trains (train runs 226, 228, 233, 234, and 235).

Line 1 TRs were able to record detailed Spin-Slide events, as shown in the following table:

TIME	ORDER OF EVENTS ACTIONS	LOCATION
6:13 AM	YUS line PA call made at 6:12 AM advising operators of the restricted speed zone Northbound Museum to Spadina Station due to hydraulic leak that occurred prior to service start up.	Museum Station

6:13 AM Speed Reduced at Museum

Line 1 spin-slides recorded in YMSS on TR trains once revenue service began after RT-56 passed through Museum Station.

Time Range	Location (between)	Number of Spin-Slide Events per truck
6:11:14 to 6:18:36 AM	Museum & Spadina	99
6:17:40 to 6:22:32 AM	Museum & Spadina	81
6:23:56 to 6:28:39 AM	Museum & Spadina	57
6:29:45 to 6:35:07 AM	Museum & Spadina	55
6:37:54 to 6:41:12 AM	Museum & Spadina	31
6:41:37 to 6:47:32 AM	Museum & Dupont	59
6:48:27 to 6:53:49 AM	Museum & Dupont	136
6:54:15 to 7:01:02 AM	Museum & Dupont	220

TIME	ORDER OF EVENTS ACTIONS	LOCATION
6:13 AM	YUS line PA call made at 6:12 AM advising operators of the restricted speed zone Northbound Museum to Spadina Station due to hydraulic leak that occurred prior to service start up.	Museum Station

6:24 AM EB Trains Report E28's

Hydraulic fluid splatter on rails causing E28's "signal violation due to positional uncertainty".

Sherbourne Station - Before

Sherbourne Station - After

TIME	ORDER OF EVENTS ACTIONS	LOCATION
6:24 AM	Several trains Eastbound between Yonge and Broadview reporting E28's and multiple speed control issues along with spin/slide in multiple locations.	Sherbourne Station

6:24 AM EB Trains Report E28's

Hydraulic fluid splatter on rails causing E28's "signal violation due to positional uncertainty".

Sherbourne Station - Before

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Hydraulic fluid splatter on rails causing E28's "signal violation due to positional uncertainty".

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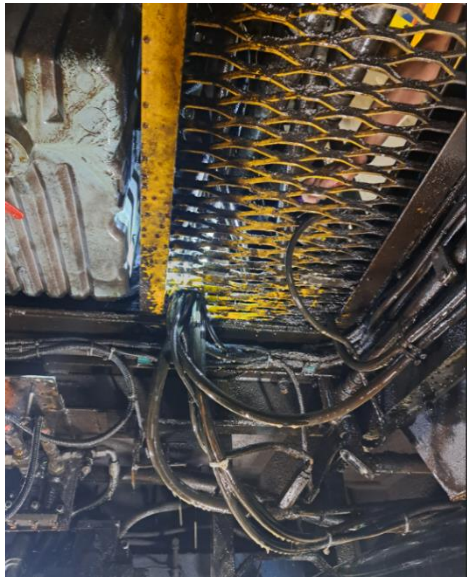
Sherbourne Station - After



Investigation reveals the hydraulic fluid coating the underside and side sills of RT-56 (because of the initial hose breach/leak under pressure at Spadina) was shaking loose and splattering due to the movement of the coupled RTs as they made their way to first Museum and then on to Greenwood at 25 km/h once they were under TCC control past Museum Station.

TIME	ORDER OF EVENTS ACTIONS	LOCATION
6:24 AM	Several trains Eastbound between Yonge and Broadview reporting E28's and multiple speed control issues along with spin/slide in multiple locations.	Sherbourne Station

Hatch recommendations based on investigation results of 8 separate hydraulic fluid leak incidents from January to May 2024

Item No.	Priority	Category	Responsible TTC Department	Recommendation
1.i	High	Work Car Recovery Procedure	Rail Cars and Shops Transit Control	TTC to update their work car recovery procedure to incorporate guidance to address hydraulic fluid leaks, including instructions that specify how to isolate a suspected hydraulic fluid leak.
1.ii	High	Work Car Recovery Procedure	Operational Safety and Planning Rail Cars and Shops Subway Infrastructure Transit Control	TTC to develop comprehensive guidelines for coordination between work crews, managers, and TCC in response to spill incidents, including the designation of roles and responsibilities.
2.i	High	Spill Incident Clean-up Protocol	Track and Structure	TTC to consider the use of work cars to deliver cleaning supplies, the storage of fluid spill kits on the work cars (particularly cars with large volume fluid tanks), and additional improvement measures to improve the efficiency of cleaning protocol for hydraulic fluid spills.
3.i	High	Maintenance Practices and Procedures	Rail Cars and Shops	TTC to improve standard maintenance practices and procedures for work car maintenance tasks such as hydraulic hose assembly and repairs.

Hatch recommendations based on investigation results of 8 separate hydraulic fluid leak incidents from January to May 2024

Item No.	Priority	Category	Responsible TTC Department	Recommendation
3.ii	High	Maintenance Practices and Procedures	Rail Cars and Shops	Identified equipment issues should be reviewed for disposition, and if necessary appropriate TTC staff should review and approve any design changes for incorporation. Further, the implementation of changes should be confirmed by quality assurance resources.
4.i	High	Inspections	Rail Cars and Shops	TTC to establish a more detailed inspection regimen for work car system components such as the hydraulic hoses that provides specific instructions to check for signs of damage (i.e., chaffing on the hose jacket, drips of fluid in the pump room, etc.). The inspection procedure should include clear pass/fail criteria for the identification of component failures.
4.ii	High	Inspections	Rail Cars and Shops	TTC to determine an appropriate inspection interval for the hydraulic hoses and other work car system components to reduce the risk of unexpected failures and unscheduled maintenance.

Hatch recommendations based on investigation results of 8 separate hydraulic fluid leak incidents from January to May 2024

Item No.	Priority	Category	Responsible TTC Department	Recommendation
5.i	High	Quality Assurance	Rail Cars and Shops	TTC to implement stronger quality assurance and control processes that flag non-compliant practices/outcomes, to confirm maintenance requirements are properly satisfied, and to identify issues before they cause equipment failures. TTC to consider the performance of regular audits to confirm recommendation is implemented.
6.i	High	Configuration Control, Documentation and Inventory Management	Rail Cars and Shops	TTC to consider supplementing OEM reference material by documenting hydraulic hose details (i.e. specification of length, construction and routing) in order to maintain consistent implementation of repairs/changes.
6.ii	High	Configuration Control, Documentation and Inventory Management	Rail Cars and Shops	TTC maintenance needs to improve their inventory management protocols and configuration control guidelines.
7.i	Medium	On-Call Work Car Technical Expert	Rail Cars and Shops	TTC to consider making a technical expert available to be on-call during non-revenue service shifts when work cars are out on the line to provide guidance to Transit Control on actions to be taken for urgencies with work cars.

Hatch recommendations based on investigation results of 8 separate hydraulic fluid leak incidents from January to May 2024

Item No.	Priority	Category	Responsible TTC Department	Recommendation
8.i	Medium	Training	Operations and Training Centre	TTC to develop training materials and provide formal training to qualify employees to perform work car maintenance tasks.
9.i	Medium	Maintenance Reporting	Rail Cars and Shops	TTC to update the SMS system in timely manner and improve the level of information in the reporting system to gather data to inform preventative maintenance practices and minimize impacts to revenue service and system maintenance.
10.i	Medium	Low Hydraulic Fluid Level Alarm	Rail Cars and Shops	TTC to consider shutting down the hydrostatic propulsion system automatically to prevent any further hydraulic fluid spill anytime the fluid drops below a predetermined level. Note: A cost and time vs. benefit analysis is needed to determine if the implementation of these features will be beneficial to TTC.
10.ii	Medium	Low Hydraulic Fluid Level Alarm	Rail Cars and Shops	TTC to also consider coupling the above new functionality with the implementation of a data logger to record activation of the low hydraulic fluid level alarm. Note: A cost and time vs. benefit analysis is needed to determine if the implementation of these features will be beneficial to TTC.
11.i	Low	Tooling and Equipment	Rail Cars and Shops	TTC to perform audit to evaluate the condition and labeling of the tooling.

AMERICAN PUBLIC TRANSPORTATION ASSOCIATION
PEER REVIEW REPORT
1300 I Street, NW, Suite 1200 East, Washington, DC 20005
Paul P. Skoutelas, president and CEO

FINDINGS OF THE APTA PEER REVIEW PANEL ON

SERVICE DISRUPTION

AT

TORONTO TRANSIT COMMISSION

July 22–26, 2024

Executive summary: The APTA Peer Review Panel was convened at the request of Rick Leary, chief executive officer of the Toronto Transit Commission, to review a series of incidents over the first six months of 2024 that impacted operations. The incidents were varying in nature and included streetcar derailments, HVAC failures on buses and eight different incidents where work cars leaked hydraulic fluid. The review was held from July 22 to 26, 2024. The observations and recommendations provided through this peer review are offered as an industry resource for TTC to consider in support of ongoing efforts to minimize service disruptions and align with industry standards.

Through this APTA peer review, a team of four transit professionals and subject matter experts spent a week at TTC facilities and conducted interviews and site visits as well as reviewed TTC documentation. The objectives of this peer review included conducting a comprehensive review of recent service disruptions to identify common root causes and the likelihood of such events occurring within six months. Other objectives included evaluating TTC's incident management, communication strategies and operational programs, as well as identifying gaps and providing recommendations to improve TTC's practices and processes. Some of the major findings in this report include recommendations and future considerations including the following:

- Continue current practices of revenue incident management.
- Nonrevenue incident management processes need to be aligned with how they are for revenue operations.
- Consider developing established communication protocols for incident notification and post-incident updates.
- Consider additional resources such as additional staff to meet public expectations for communication.
- The hydraulic leak incidents had common technical root causes however, the panel found no evidence that the hydraulic leaks were intentional or the result of sabotage.

APTA appreciates TTC having the peer review panel on-site for this endeavor and stands ready to assist with any follow-up as needed.

Table of contents

Peer review team

The APTA Peer Review Panel was convened at the request of Rick Leary, chief executive officer of Toronto Transit Commission, in support of ongoing efforts to align the safety program with industry standards.

The following panel of industry peers was assembled, composed of individuals with senior and executive industry leadership skills from within the public transit sector to provide advice, guidance, benchmarking and best practices in regards to the prevention and response to service disruptions:

STEVE REDMAN
Superintendent, Car Track Equipment Maintenance, Rail Fleet
Washington Metropolitan Area Transit Authority
Washington, D.C.

CHRYSTALLE COOPER
Assistant Chief Operating Officer, Corporate Safety
Southeastern Pennsylvania Transportation Authority
Philadelphia

DAVE JENSEN
Assistant General Manager, Rail Operations
Regional Transportation District
Denver

BRYAN SOOTER
Director – Standards
American Public Transportation Association
Washington, D.C.

The panel convened in Toronto, Ontario, from July 22 to 26, 2024.

Peer review panel biographies

Steve Redman

With over 35 years of experience in the electrical and mechanical service industry, Steve Redman has held positions to include field engineer, regional service manager and heavy equipment maintenance department superintendent. As a graduate of Lincoln Technical Institute in 1988, Redman started his career as a field service technician repairing elevators. While serving other positions in the electro-mechanical maintenance field, he quickly gained experience working on cash register systems and banking equipment to include ATMs and proofing machines. Climbing the ladder within these trades, he moved toward management positions, gaining vital experience and knowledge in maintenance contract and personnel management. In September 2002, Redman joined the Washington Metropolitan Area Transit Authority, where he is currently a superintendent charged with managing the maintenance program for over 1,000 Metro assets to include 185 pieces of rolling stock. In 2013 he completed the Maximizing Your Leadership Potential course at the University of Maryland College and in 2018 attended the Transit Maintenance Leadership Workshop hosted by the National Transit Institute in Seattle. Instrumental in supporting equipment used in WMATA's 2016-2017 SafeTrack infrastructure renewal project, participating work crews could rely on readily available and safe equipment to meet schedules and prevent injury. Redman has a passion for maintenance perfection resulting in a superb level of safe and reliable equipment for the people who use it.

Chrystalle Cooper

Chrystalle Cooper serves as assistant chief operating officer of Metro Rail for the Southeastern Pennsylvania Transportation Authority, the sixth-largest public transit agency in the country. In this role, Cooper is responsible for directing all activities and employees engaged in the provision of train, service and customer service operations for the Market-Frankford and Broad Street lines; city and suburban trolley lines; and Victory Bus Transportation operations. She oversees 1,000-plus employees who serve approximately 120,000 daily riders, and she manages Metro Rail's annual budget of more than $89 million.

Dave Jensen

Dave Jensen is a rail professional with over 37 years of rail and executive-level management experience. He is currently responsible for managing all rail operations, both commuter rail and light rail, at the Regional Transportation District in Denver. He began his management career in 1989. Jensen has extensive experience managing all levels of a passenger railroad agency. Jensen has provided consultation and assistance to numerous transit agencies in the United States and internationally, including agencies in Hong Kong, Canada, Argentina, Salt Lake City, Washington D.C., Los Angeles, New Jersey, Houston and Virginia. He has experience participating in peer reviews for APTA. He has provided assistance and consultation to streetcar new-start agencies in Kansas City, Cincinnati and Detroit. Jensen also has extensive experience with conducting and teaching rail accident investigation, critical incident management and analysis. He has testified in numerous court cases as an expert witness in California and Colorado and as a "person most knowledgeable" on railroad operations, rules, policies, procedures and training.

Bryan Sooter

Bryan Sooter serves as APTA's director of standards and manages the standards-generation process and prioritization of the standards projects at APTA. He serves as the primary engineering resource within APTA and leads APTA's rail and bus engineering initiatives. Sooter has over 17 years of experience in the transportation industry. Prior to joining APTA, he worked as a consultant for a forensic engineering firm, where his responsibilities included train operation assessments, railroad accident investigation analyses, train derailment and crossing accident investigations, evaluation of train-handling issues, and data analysis. Prior to working as a consultant, he worked for the Alaska Railroad as a train dispatcher, certified conductor and certified locomotive engineer. Sooter is a licensed professional engineer in Georgia. He holds an M.S. degree in civil engineering from the University of Illinois at Urbana-Champaign and a B.S. in civil engineering from the University of Alaska at Anchorage. In addition to his coursework in railroad track/transportation engineering and construction, he also has a strong background in structural, geotechnical and arctic engineering.

Service Disruptions at Toronto Transit Commission

1. Methodology

The APTA peer review process is well-established as a valuable resource to the public transit industry. Highly experienced and respected transit professionals voluntarily provide their time and support to address the scope required by the requesting agency. The panel conducted this peer review from July 22 to 26, 2024, through documentation review, field observations, and a series of briefings and interviews with TTC staff.

2. Scope of this report

The APTA Peer Review Panel was convened at the request of Rick Leary, chief executive officer of Toronto Transit Commission, to review service disruptions at TTC, in support of ongoing efforts to align with industry standards.

2.1 Interviews and field visits

Through this peer review at TTC, the panel conducted various interviews and field visits throughout the TTC system, including the agency's personnel responsible for the response to service disruptions. The agenda of panel interviews and field visits can be found in Appendix B and are summarized below.

Interviews:

- Introductory meeting at TTC Headquarters
    - Rick Leary
- Interviews with different departments' employees
    - Rail, Cars & Shop
    - Track & Structure
    - TCC
    - Safety
    - Operation Training Centre
    - Commission Services
    - Corporate Communication
    - Operation Safety & Planning
    - Streetcar Maintenance
    - Marketing & Customer Experience
    - Bus Maintenance

Field visits:

- Greenwood Car House
- Transit Control Center

2.2 Primary areas of focus

Based on the panel's observations and assessments from these interviews and field visits, this report's observations and recommendations are compartmentalized into the following areas:

- A review of all service disruptions at TTC and peer agencies over the past number of years (including hydraulic leaks on work cars, streetcar derailments, and HVAC failures on the conventional bus fleet), to understand the likelihood of such events all happening within six months and identifying any common root causes.
- A review of TTC's management (from the various departments involved) of these incidents and associated communications (internally and externally).
- A review of TTC's operating, maintenance, recovery, training and safety programs associated with these incidents.
- A review of industry best practices and studies, surveys and reports on operating, maintaining, recovering, etc., these vehicles.
- Recommendations to address gaps in current practices, processes, technologies, materials and training.

3. Opening comments

This peer review was convened to review recent service disruptions on the TTC in support of ongoing efforts to align TTC operations with industry standards and best practices. TTC's request for an independent review of service disruptions exemplifies its commitment to the safety of employees and customers. During the peer review, the panel conducted multiple interviews, field observations and tours. All facilities visited by the panel—including subway, streetcar and bus maintenance facilities—were clean and organized.

The team was able to bring its extensive knowledge, background and best practices to share with TTC so it can make updates and improvements to its procedures, standard operating procedures and other methodologies. Below are the major findings from the panel's observations and recommendations from this peer review.

4. Observations and recommendations

4.1 Work car hydraulic leaks and maintenance procedures

For the service disruptions reviewed during this peer review, the most significant in terms of frequency and impact were the hydraulic leaks experienced by work cars. TTC has a fleet of 75 work cars with 47 work cars that are equipped with hydraulic systems and/or equipment. The average age of TTC's work car fleet is 17 years with a life cycle of approximately 30 years depending on the specific use of the work car. The work car fleet is part of TTC's Infrastructure State of Good Repair (SOGR) Program, which covers 300 km of subway infrastructure including tracks, signals, communications, power (electrified) rail and structures. The SOGR Program is conducted seven days a week in three-hour maintenance windows with the use of 20 to 25 work cars per night on average.

Hydraulic failures present an environmental hazard but can also have a significant impact on revenue operations as hydraulic leaks on the main line affect train acceleration and braking distances. The general standard practice in response to hydraulic failures on the main line at TTC is to reduce train speeds while infrastructure crews assess track conditions. Since January 1, 2024, there have been eight incidents of hydraulic failures on work cars at TTC, as shown in **Table 1**, of which four occurred on the main line.

TABLE 1
Work Car Hydraulic Fluid Leaks

Date	Vehicle	Location	Service Disruption	Amount of Spill	Root Cause
January 14, 2024	RT-56	Sherbourne – Donlands	Y	10 L	Failed hydrostatic hose
January 17, 2024	RT-17	Eglinton W – Dupont	Y	120 L	Failed filter O-ring
February 10, 2024	RT-7	Yard (GWD)		5 L	Failed filter housing O-ring
April 22, 2024	RT-41	Yard (GWD)		50 L	Failed distribution block seal
May 13, 2024	RT-56	Spadina – Greenwood	Y	140 L	Hose abrasion, auxiliary pump pressure line
May 15, 2024	RT-84	Davisville – Eglinton	Y	200 L	Clutch failure, secondary hydraulic line damage
May 16, 2024	RT-41	Keele		0.25 L	Leaking hydrostatic pressure sensor seal
May 26, 2024	RT-18	Warden (Closure)		30 L	Failed hose crimp (new hose)

Relatively small hydraulic leaks (mostly with hoses) should be expected to occur with work cars, given the nature of the work they perform and the environment they operate in. Proper inspection and maintenance of work cars is essential to prevent larger leaks from occurring. At TTC there are only generic instructions for the periodic inspection of work cars, but vehicle specific documentation is required. At the time this peer review was conducted, the only guide for the periodic maintenance of work cars available to millwrights was the original equipment manufacturer maintenance manuals. Additionally, work car cleaning is not being performed during every scheduled service interval. This will help improve the inspection of hydraulic systems by making it easier to identify wear or damage on hoses and components prior to a catastrophic failure.

One of the hydraulic leaks reviewed by the panel were directly related to improper hose fabrication. TTC millwrights fabricate hydraulic hoses for work cars using a Gates OmniCrimp machine. The only guidance for millwrights to fabricate hydraulic hoses and use the OmniCrimp machine is the OEM manual from Gates. There are no TTC work procedures or instructions for the fabrication of hydraulic hoses or quality control procedures to ensure that they have been properly assembled. Rail Cars & Shops has purchased a new hose crimper machine, which should improve the quality control of hydraulic hose fabrication.

To improve the overall maintenance of the work car fleet, the panel suggests developing TTC maintenance instructions for work cars that are specific to the systems of the work car design. The panel also suggests including the proper cleaning of work cars prior to all periodic maintenance intervals; this will improve the inspection process and identification of work car defects. As previously stated, the new hydraulic hose crimping machine should be a major improvement in the fabrication of hydraulic hoses and the quality control process. However, the panel suggests that TTC develop procedures for the fabrication of hydraulic hoses that are in line with industry standards that include proper training and qualifications for personnel who fabricate hydraulic hoses.

4.2 Hydraulic leak on RT-56 (May 13, 2024)

The most significant hydraulic leak reviewed in terms of disruption to service occurred on the morning of May 13, 2024 when RT-56 (a vacuum work car) was performing work on the northbound track at Spadina Station. The crew operating RT-56 had noticed abnormal noises coming from the work car and activated an emergency stop button to shut down the motors on the work car. The crew then discovered that a hydraulic hose had failed and sprayed hydraulic fluid on the work car and surrounding track area, as shown in **Figure 1**.

FIGURE 1
Spadina Northbound Track Location of Initial Hydraulic Hose Failure

RT-56 remained at the Spadina Station for about an hour before it was coupled to RT-46 and towed to Bay Lower Station and then onto the Greenwood Yard. During the time the RT-56 was being towed to the Greenwood Yard, it continued to leak hydraulic fluid over the track and infrastructure it traversed. It is estimated that a total of 140 L of hydraulic fluid leaked from RT-56 with the majority of fluid spilled at the initial location of the failure, but additionally was spread across the track between the Spadina Station and the Greenwood Yard.

At the time when RT-56 experienced its hydraulic leak, there were no qualified work car maintenance personnel available to assess the condition of the hydraulic and mechanical systems on the car. This is in contrast to revenue vehicles, where qualified maintenance personnel are available during revenue service hours to assess equipment if a revenue vehicle becomes disabled on the main line. The delay in assessment by qualified work car maintenance personnel meant that RT-56 was moved without fully knowing the extent of the hydraulic fluid leak nor if the leak was contained. This ultimately resulted in a service interruption of 730 minutes (from 6:50 a.m. to 7 p.m.), including during peak revenue service operations.

TTC conducted a post-incident investigation but did not establish who authorized that RT-56 was safe for movement from the Spadina Station. The purpose of a post-incident investigation is to gather and assess facts in order to determine cause(s) and to identify corrective measures to prevent recurrence. Incident investigation is not intended to affix blame, to subject people to liability for their actions, or to recommend disciplinary action. The purpose of a post-incident investigation is to learn more about the mechanical and other failures and human factors to correct unsafe conditions.

Both nonrevenue and revenue equipment have the potential to create a major service disruption, as was evident in this incident. It is not unusual for rail-bound hydraulic powered equipment to experience hydraulic fluid leaks given the harsh environment they operate in and nature of work they perform. Response and procedures to incidents involving work cars need to be consistent with those of revenue vehicles (i.e., streetcars and subway). The panel suggests evaluating usage of work car maintenance personnel to be available to assist when track and structure work cars are operating on the main line in the event they become disabled. The panel also suggests conducting exercises/drills on work car recovery from the main line with both operators and maintenance personnel to reinforce procedures. Additionally, the panel suggests reviewing or revising the post-incident review/investigation process to ensure that key facts of the incident are captured. TTC should also consider developing a policy on who can authorize the movement of a disabled work car to ensure that it can be moved safely.

For any rail transit system, maintenance time on the alignment to meet the demands for infrastructure state of good repair is limited due to the demands of revenue service. Because of this limitation of time for infrastructure maintenance, a commitment to providing resources, financial and otherwise, to infrastructure maintenance is essential. The goal for any infrastructure maintenance program for a rail transit agency should be to maximize state of good repair resources in order to minimize revenue service disruptions.

4.3 TTC track and structure work car operator training

The track and structure work car operator training program is sufficient to properly train operators and meets the industry standard for training delivery. Generally, work car operators are not trained to assess the mechanical and hydraulic systems of the equipment they operate, as was the case with track and structure work car operators at TTC.

The overall training model for track and structure work car operators is sufficient and should continue as it is. It is recommended to reemphasize the scope of the training to students, so they know what mechanical systems they are qualified to assess upon completion of the training and when to escalate mechanical problems to work car maintenance personnel. Additionally, the panel recommends performing periodic work car recovery drills with both track and structure work car operators and maintenance personnel.

4.4 Management of incident and associated communication

In the case of the May 13 hydraulic leak, the fact that it was never established in the post-incident investigation who authorized the movement of RT-56 identifies that there was a breakdown in communication. Generally, TTC’s incident management and procedures involving revenue vehicles and streetcars are very good and meet or exceed industry standards. However, nonrevenue incident management and procedures need to be improved and aligned with that of the incident management and procedures for subway vehicles and streetcar. The peer review panel recommends continuing current practices of revenue vehicle incident management and aligning policies and procedures for incident management of nonrevenue vehicles to those of revenue vehicles, as both present the same level of service disruption risk.

The current TTC Board of Commissioners has expressed a desire to receive a higher level of operational details of events than in previous years. Generally, communication with oversight boards of transit agencies focus on several key areas to ensure that hey have the necessary information to make informed decisions, including the following:

- performance metrics and KPIs that measure operational efficiency, productivity and success
- strategic alignment of operational goals with the overall financial strategy and long-term objectives
- any operational risks and mitigation strategies for proactive management and foresight
- how resources are being utilized and any needs for additional support or investment
- ongoing initiatives for process improvements and innovation efforts that enhance operations
- challenges and opportunities for growth or improvement
- financial implications of operational performance
- update on key projects and initiatives, including progress, milestones achieved and next steps

The panel suggests developing established communication expectations and protocols for incident notification and post-incident updates. This could be accomplished by either establishing a charter or revising current bylaws for the Board of Commissioners.

Additionally, the public expectations for the timeliness of communication from public agencies has evolved significantly in recent years due to the digital transformation and increased connectivity. There is also a growing demand for transparency and accountability at transit agencies from the public, which includes the expectation to provide clear and timely updates during a service disruption. Currently, the public's expectations for information, both content and timeliness, during a major event exceed TTC's capacity. As communication expectations from the public increase in both content and frequency, TTC should consider additional resources and/or personnel to manage these expectations.

4.5 Streetcar derailments

Streetcar derailments were included in the scope of this peer review to identify any common root causes with other service disruptions. Additionally, the panel analyzed TTC's response and recovery of streetcar derailments and compared them with industry norms. TTC reported three revenue streetcar derailments in 2023 and four revenue streetcar derailments in 2024 through July. The panel reviewed TTC Streetcar Department SOPs for Mainline Response and Inspection Report for Low Floor Light Rail Vehicles.

The panel found no common root causes with streetcar derailments and other recent service disruptions. Current procedures and post-incident protocols are acceptable and accurate to identify root causes. The panel recommends continuing to follow current post-incident processes and SOPs.

TTC should consider classifying and tracking preventable vs. non-preventable derailments per vehicle revenue mile (VRM) operated to normalize the data and to help identify trends in preventable derailments. For example, in the U.S. the Federal Transit Administration tracks derailments per 100 million VRM, and the average rate of rail transit vehicle derailments in the U.S. between 2007 and 2017 was 68 per 100 million VRM.[1] Publicly available data states that TTC operated 9,210,000 vehicle revenue kilometers of streetcar service in 2022.[2] Using the FTA average rate of derailment, this would equate to four derailments per year.

TTC's streetcar rate of derailment is also generally comparable to that of the agencies of the panelists. SEPTA had four revenue derailments in 2023 and zero in 2024. RTD (light rail) had two revenue derailments in 2023 and one in 2024. The panel felt that TTC's SOPs were sufficient and in line with industry norms to safely recover derailed streetcars on the main line.

4.6 Bus HVAC failures

It was reported that two bus facilities each had approximately 10 buses that had the HVAC system's compressor clutch power disconnected over a two-week period. Once the HVAC systems were found inoperable, the buses were removed from service until they were repaired.

After reviewing these incidents with TTC staff, the panel believes this was an isolated incident that was resolved quickly. The panel's recommendation is to maintain current policies.

4.7 Related industry standards

APTA RT-OP-S-002-02, "Rail Transit Accident or Incident Notification and Investigation Requirements,"[3] describes requirements that a rail transit agency shall develop and implement for accident/incident

1. FTA Rail Safety Data Report, September 2021, https://www.transit.dot.gov/sites/fta.dot.gov/files/2021-09/Rail-Safety-Data-Report-2007-2018-09-23-2021.pdf
2. https://www.ttc.ca/transparency-and-accountability/Operating-Statistics/Operating-Statistics---2022/Conventional-System
3. https://www.apta.com/wp-content/uploads/Standards_Documents/APTA-RT-OP-S-002-02-Rev-3.pdf

investigation plans. The standard requires that the agency accident/incident investigation plan address policies and procedures, notification and reporting, investigation thresholds, coordination with government and regulatory agencies, formal investigation process, training, and post-accident reporting.

The American Railway Engineering and Maintenance-of-Way Association (AREMA) publishes the Manual for Railway Engineering, which contains recommended practices for the general care and maintenance of work car equipment, which is found in Chapter 27, Maintenance-of-Way Work Equipment.[4]

Guidelines for selection, routing, fabrication, installation, replacement, maintenance and storage of hose and hose assemblies for hydraulic fluid power systems can be found in ISO/TS 17165-2:2018, "Hydraulic fluid power — Hose assemblies."[5]

5. Closing remarks

The APTA peer review team commends TTC for its robust safety culture throughout the organization and its commitment to extend that culture to work train operations, emergency response protocols and training. The peer review panel hopes the recommendations presented at the closing presentation and in this document contribute positively to TTC's efforts to enhance its overall operation, including the operation of track and structure work cars moving forward.

The panel sincerely appreciates the support and assistance extended throughout the entire peer review process by all TTC management and staff and stands available to assist with any clarification or subsequent support that may be needed.

4. https://www.arema.org/AREMA_MBRR/AREMAStore/MRE.aspx
5. https://www.iso.org/standard/74155.html

Appendix A: Letter of request

Richard J. Leary
Chief Executive Officer
Toronto Transit Commission

May 31, 2024

American Public Transportation Association (APTA)
1300 I Street NW, Suite 1200 East
Washington, DC 20005
Attn: Brian Alberts, Senior Director – Safety and Advisory Services

Dear Mr. Alberts:

Re: TTC Peer Review Request – Review of Recent Service Disruptions and Failure Incidents

The Toronto Transit Commission (TTC) would like to request the American Public Transportation Association (APTA) convene a peer review panel to advise on the increase in service disruptions and failure incidents over the last six months that have impacted our operations.

The incidents are varying in nature and include, but are not limited to, the following reoccurrences: eight hydraulic leaks on work cars, two streetcar derailments and a number of HVAC failures on conventional bus fleet.

We would like an independent review to identify any common root causes and to assess how well the TTC has been managing these incidents, including but not limited to, the protocols for recovery of the vehicles, and escalation of communications to the public, customers and Board.

For our current, recently revised, and planned practices for operations, maintenance, training, and communications, we would like the APTA Peer Review panel to recommend any additional actions/improvements they believe we should consider to reduce the frequency and severity of failures, as well as improve the way such incidents are managed. The scope of the peer review would include, but not limited to, the following:

- A review of all service disruptions at TTC and peer agencies over the past number of years (including hydraulic leaks on work cars, streetcar derailments, and HVAC failures on the conventional bus fleet), to understand the likelihood of such events all happening within six months and identifying any common root causes;
- A review of TTC's management (i.e. from the various departments involved) of these incidents and associated communications (internally and externally);
- A review of TTC's operating, maintenance, recovery, training, and safety programs associated with these incidents;

- A review of industry best practices and studies, surveys and reports on operating, maintaining, recovering, etc. these vehicles and;
- Provide recommendations to address gaps in our current practices, processes, technologies, materials, and training.

The point of contact for the review is Bem Case, Executive Director – Innovation & Sustainability. Bem can be reached at (647) 393-2385.

Sincerely,

Richard J. Leary
Chief Executive Officer

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Appendix B: Agenda

Day 1 - Monday, July 22, 2024

Time	Activity	TTC Staff
8:00am - 9:00am	Travel to TTC Head Office	Roy Park
9:00am - 10:00 am	Kick-off Meeting	Rick Leary, Bruce Macgregor, Roy Park, Bem Case, Rich Wong, Harpreet Nagi, Fort Monaco
10:00am - 11:00am	Interview - CEO	Rick Leary
11:00am - 12:00pm	Lunch	
1:00pm - 2:00pm	Travel to Greenwood Carhouse	Roy Park
2:00pm - 3:00pm	Tour - Greenwood Shops	Roy Park
3:00pm - 5:00pm	Interviews - Rail, Cars & Shops (RCS)	Harpreet Nagi, Tim Cheney, AJ Spang, Avi Berger

Day 2 - Tuesday, July 23, 2024

Time	Activity	TTC Staff
8:00am - 11:00am	Interview - Track and Structure	Bryan Callaghan, Andrew Marsh, Kwame Johnson, Peter Dumitriu
11:00am - 12:00pm	Tour - Transit Control Centre	Mike Puplett
12:00pm - 1:00pm	Lunch	
1:00pm - 2:00pm	Interview - Transit Control	Andrew Dixon, Jacob Passmore, Mike Puplett
2:00pm - 3:00pm	Interview - Safety	Shaun DeSouza, Calum Frame
3:00pm - 4:00pm	Interview - Operations Training Centre (OTC)	Pablo Fernandez
4:00pm - 5:00pm	HOLD: Extra Interviews	

Day 3 - Wednesday, July 24, 2024

Time	Activity	TTC Staff
8:00am - 9:00am	Travel to TTC Bloor Street Office	Roy Park
9:00am - 10:00am	Interview - Commission Services	Chrisanne Finnerty
10:00am - 11:00am	Interview - Corporate Communications	Shabnum Durrani
11:00am - 12:00pm	Interview - Operational Safety and Planning	Steven Gehring, Gaetano Bonaiuto, Robert Poole
12:00pm - 1:00pm	Lunch	
1:00pm - 2:00pm	Interview - Streetcar Maintenance	Steve Cushieri, Damon Quan, Claire Patrigeon, Tony Isacco
2:00pm - 3:00pm	Interview - Safety Director	Scott Cameron
4:00pm - 5:00pm	HOLD: Extra Interviews	

Day 4 - Thursday, July 25, 2024

Time	Activity	TTC Staff
8:00am - 8:30am	Travel to TTC Head Office	Roy Park
8:30am - 9:30am	Interview - Marketing & Customer Experience	Nancy Ortenburg, Heather Brown, Victoria Gorobets
9:30am - 10:30am	Interview - Bus Maintenance	Scott Macgillivary, Bruce Peters, Sam Farhangi, Shiv Persaud
10:30am - 12:00pm	HOLD: Extra Interviews	
12:00pm - 1:00pm	Lunch	
1:00pm - 5:00pm	HOLD: Extra Interviews	

Day 5 - Friday, July 26, 2024

Time	Activity	TTC Staff
8:00am - 9:00am	Travel to TTC Head Office	Roy Park
9:00am - 11:00am	APTA Wrap-Up Presentation and Q&A	Rick Leary, Bruce Macgregor, Roy Park, Bem Case, Rich Wong, Harpreet Nagi, Fort Monaco