Interim Report

FOR CREATIVE SENTENCE

To Enhance Safe Work Practices for Trenching and Excavating

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INTERIM REPORT

Docket number 230255978P1; OHS-249224

5 June 2025

Executive Summary

On June 6, 2021, a worker was operating an excavator next to the Susan Lake Waterbody to build a berm when the bank slumped into the clear water system. The cab of the excavator was fully submerged and the worker was fatally injured. On April 4, 2024, Syncrude Canada Ltd., being an employer, pleaded guilty to a contravention of section 3(1)(a)(i) of the Occupational Health and Safety Act (failure to ensure, as far as reasonably practicable, the health and safety of the team leader, a worker engaged in the work of that employer, by permitting the team leader to operate a John Deere excavator on a ramp with an over-steepened slope). Syncrude agreed to a creative sentence to assist in the development of methods to prevent serious incidents and fatalities associated with trenching and excavating, particularly around water and ice. This is the purpose of this project.

The outcomes are to: 1) summarize the hazards and consequences that water can have on slope stability; 2) summarize best practices for trenching, excavating, and adjacent work; 3) convene focus groups of subject matter experts to create a job reminder checklist and 'competent person decision tree'; 4) summarize these best practices; 5) create a mobile application to presents the decision tree, checklists, and best practice guideline; 6) beta-test this app; and 7) maintain this application and make it a free downloadable version. While this project was motivated by slope stability issues in northern mining, these outcomes can be applied to broader geographies and industries.

Overview of work completed over the last year

We have completed the geotechnical literature review and case study review of incidents. We held two workshops to identify critical controls for hazards with the potential for serious incidents and fatalities for: a) working on/around water and ice and b) trenching and excavating. The resulting 'bowtie' diagrams can be used to visualize and understand the systems, causes, and consequences for trenching/excavating that are often complex and hidden. These diagrams will be further enhanced with the findings of our geotechnical review and through future workshops. This will help support additional training and critical control assurance. We also completed a survey of workers and contractors in the mining industry, specifically asking about their hazard identification / controls for trenching and excavating and water/ice. In addition, we have started scoping the requirements to develop a mobile app. We describe our previous year's activities and our next steps in the attached report.

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1. Introduction

On June 6, 2021, a worker was operating an excavator to build a berm when the bank slumped into fresh water. The cab of the excavator was fully submerged, and the worker was fatally injured. On April 4, 2024, Syncrude Canada Ltd., being an employer, pleaded guilty to a contravention of section 3(1)(a)(i) of the Occupational Health and Safety Act (failure to ensure, as far as reasonably practicable, the health and safety of the team leader, a worker engaged in the work of that employer, by permitting the team leader to operate a John Deere excavator on a ramp with an over-steepened slope).

1.1 Rationale and Outcomes

The purpose of this project is to examine the hazards and human factors in excavating, trenching, and adjacent activities; identify indicators and controls; and implement a best practice guideline and field-ready mobile application to support system-level assurance of controls. The detailed outcomes of this project are the following:

1. Summarize geotechnical investigation, Alberta OHS, WorkSafeBC, AMHSA and others' best practices for trenching, excavating, and adjacent work.
2. Summarize the hazards and consequences that the presence of water can have on the slope stability of trenches/excavations and controls for mobile equipment and people working in that vicinity.
3. Convene focus groups of subject matter experts to create a job reminder checklist and 'competent person decision tree' that sequentially steps through the workers' process for hazard identification, risk assessment, and critical controls assurance.
4. Summarize these best practices, job reminder checklists, decision tree, and schematics of controls as a user-friendly document for employers to properly assess ground conditions/to do proper geotechnical assessments. Make this publicly available on AMHSA's website, the University of Alberta's website, and Alberta OHS's website.
5. Create a mobile application that presents this decision tree, job reminder checklist(s), best practice guideline, and schematics of controls (setbacks, shoring, tiebacks, and other controls).
6. Beta-test this application and fine-tune to enhance accessibility, functionality, and adoption.
7. Maintain the mobile application and make it a downloadable application on App Stores. We intend to make it free. However, if there are costs to maintain it (i.e., graduate student review/revise annually), then, we will examine how these costs could be covered by the David and Joan Lynch School of Engineering Safety and Risk Management (ESRM), University of Alberta Geotechnical Centre, and/or a nominal user fee.

1.2 Project Team

The following is a list of members of the project team based at the University of Alberta, AMHSA, and the University of Calgary.

Project team at the University of Alberta:

- Lianne Lefsrud, Ph.D., PEng. Principal Investigator. ESRM, Chemical and Materials Engineering.
- Fereshteh Sattari, Ph.D., ESRM.
- Renato Macciotta, Ph.D., University of Alberta Geotechnical Centre, ESRM.
- Michael Hendry, Ph.D., University of Alberta Geotechnical Centre
- Albert (Fangzhou) Liu, University of Alberta Geotechnical Centre
- Julian Solano, MSc. student, University of Alberta Geotechnical Centre, ESRM.
- Abigail Paul, MSc., student, University of Alberta Geotechnical Centre, ESRM.
- Rose Marie Charuvil Elizabeth, MSc., ESRM, Chemical and Materials Engineering.

Project team at AMHSA:

- Juliet Goodwin
- Craig Hrynchuk

Project team at the University of Calgary:

- Thomas O’Neill, Ph.D., Department of Psychology.
- Samantha Jones, MSc., Ph.D., Department of Psychology.

1.3 Schedule and Budget

As this research is funded by a creative sentence, tracking expenses is paramount. As of 25 March 2025, we are on track with our expenditures. Details are given in Table 1.

Table 1. Expenditures as of 31 March 2025

Funds available before expenditures (A):		**$390,000.00**
Expenditures		
Salaries and Benefits-BL	$158,868.19	
Supplies and Other-BL	$110,261.37	
Travel-BL	$2,481.92	
Capital Assets-BL	$1,737.99	
Total Direct Expenses (B)		**$273,349.47**
Funds Available before Indirect Costs as of 03/31/2025 (A-B):		**$116,650.53**

* Includes $109,000 subgrant transfer to University of Calgary to cover graduate student research support and other research-related expenses completed to date and for the remainder of Phases 1-2, by Dr. O'Neill's group. It does not yet include a transfer of $x to AMHSA for Phase 4 activities.

We are on schedule as per what we proposed. See Table 2.

- Phase 1 – Summarize geotechnical 'best practices'. There was some delay in recruiting graduate students; however, we completed this work as of February 2025.
- Phase 2 – We convened two focus groups in September and November 2024 with subject matter experts in heavy industry to summarize the hazards and controls for workers in northern mining. We will convene more in 2025, to review/develop best practices, tools, and training for broader geographies and industries..
- Phase 3 – We recruited a graduate student in September 2024 to start creating a mobile app.
- Phase 4 – following our September and November workshops, we started to share learnings with industry. This will be our priority for the remainder of 2025 and early 2026, led by AMHSA.

Table 2. Project Schedule.

	2024									2025												2026			
Phase	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
1) Summarize geotechnical investigation, regulators' and others' best practices for trenching and excavating	▓	▓	▓	▓	▓	▓	░	░	░	░	░														
2) Convene focus groups of subject matter experts to create a job reminder checklist and 'competent person decision tree'			▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓◆	▓	▓	▓	▓	▓	▓	▓	▓				
3) Create a mobile application that presents this decision tree, job reminder checklist, and schematics of controls						░	░	░	░	░	░	░	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	
4 - Industry sharing and education						░		░					▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓◆

◆ Reporting includes an interim report submitted to OHS email JEND.OHS-IRU@gov.ab.ca at one year from the date of the Order and include project status, preliminary findings, financials, and next steps. The final report will be submitted two years from the date of the Order and will include all findings, financials, outputs, and an evaluation of the project.

We describe each of these research activities in more detail in the following sections.

2. Literature Review of Geotechnical Best Practices for Trenching and Excavating Around Water

Julian Solano, Abigal Paul, Renato Macciotta, Michael Hendry, Albert Liu, Lianne Lefsrud

2.1 Purpose and Objectives

The purpose of this section is to summarize best practices for trenching, excavating, and adjacent work. For this, we completed a literature review of academic research, regulatory guidelines, and industry best practices for larger mobile equipment for trenching, excavating, and adjacent work – including the impact of water on slope stability and bearing capacity.[1]

2.2 Regulations

A review of regulations and regulatory guidance documents was undertaken to identify legislated requirements for trenching and evaluate the differences between jurisdictions. Sources from Alberta (AB), Ontario (ON), British Columbia (BC), Saskatchewan (SK), Manitoba (MB), the United States (Occupational Safety and Health Administration, "OSHA"), Michigan (MI), and the Canadian Centre for Occupational Health and Safety (CCOHS). References are listed in section 2.2.1 . The literature review was structured around guiding questions developed in an initial brainstorming session. The preliminary findings of the regulatory review are summarized as:

1. How is a trench defined?

   The most general definition is an excavation where the depth is greater than the width (ON, CCOHS, SK, MI, MB). Some jurisdictions specify measurements such as "an excavation less than 3.7 m (12 ft) wide at the bottom, over 1.2 m (4 ft) deep, and of any length" (BC) or that the width at the bottom is less than 4.6 m (OSHA).

2. What soil classification system is used to assess site conditions?

   3-4 types based on consistency (stiff/soft), density, ease of penetration, strength, seepage, cracking, water content, appearance, cohesiveness, and previous excavation history. Definitions and criteria differ slightly by jurisdiction.

3. Under what circumstances is shoring/benching/additional support required?

   Critical depths for shoring, sloping, benching, and temporary support structures are either 1.2 m (ON, BC, CCOHS) or 1.5 m (AB, MB, USA). Specific requirements regarding the geometries and allowable materials of support structures have not been included in the current review.

4. Under what circumstances is work required to be supervised by an engineer/professional?

   Critical depths vary between 3m and 6m. Some jurisdictions distinguish between supervision for a trench and an excavation. Key factors include: proximity to other structures; deviations from sloping/support systems specified by regulations; influence of nearby loads, vibrations, hydrostatic pressure, etc.; slope of ground above excavation.

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[1] A recent example of a related best practice is AMHSA's recent guideline, calculator, and other tools for landscaping, https://www.amhsa.net/resources/lawn-maintenance-safety-toolkit/

5. When should the trench be inspected? Under what conditions is an inspection triggered? Is a frequency of inspection specified?

   CCOHS and ON recommends inspection before every shift and after any event that may impact stability (checklist provided by CCOHS). US regulations specify daily (OSHA) or ongoing (MI) inspections and specifically require inspections after rainstorms.

6. What setback distances are specified for equipment, soil piles, etc.?

   The setback distance is generally 1m, some jurisdictions use 0.6m. MB takes most conservative approach and recommends that material is not closer to the edge than the depth of the excavation, Jurisdictions vary in the type of material and equipment (soil piles, heavy equipment, pipes, etc.) that is subject to this setback distance.

7. Are there any specific considerations for water? What actions are required in the case of adverse weather conditions, such as heavy rain or freezing?

   Water should not be allowed to accumulate to a level that presents a hazard. Prevent erosion of slopes from surface water (BC) and divert surface water from entering excavation (OSHA). Water removal equipment must be monitored by a competent person (OSHA, MI). Excavations below the groundwater table in cohesionless soil require water removal equipment (MB). Water table should be lowered by a minimum of 2ft (0.6m) below the base of the excavation. Emergency evacuation plan (harness, communication) is required if flooding is considered a risk (MB). AB and SK specifically prohibit the use of natural freezing as a full or partial alternative to temporary protection structures.

8. What are the requirements for marking the excavation (e.g. with flagging tape or barriers) to make workers above the excavation aware of the hazard?

   Some jurisdictions have no specific requirements for marking (OSHA, MI, MB). Where there are requirement: marking is required where there is a danger of a worker falling in (AB), a barrier greater than 1.1m is required for excavations greater than 2.4m deep (ON), barriers should stop equipment from rolling in (AB), barriers are required when the excavation is open for a “long time” (note that this duration is not specified by regulations) and by placed to prevent tripping over the barrier into the trench (SK).

9. What exceptions exist for excavations that are not required to comply with certain sections of the applicable regulation in the jurisdiction?

   AB has exceptions for if a professional engineer (P. Eng.) certifies that the ground is stable. These sections pertain to protection methods (cutting back and/or temporary protective structures), specified dimensions for cutting back walls, trimming loose materials from the side of the wall, placement and management of spoil piles, supporting overhead power lines, safe entry and exit requirements, and providing barriers for mobile equipment operating above the excavation. SK also regulates trenches and excavations on mine sites separately. All other jurisdictions have no stated exceptions.

10. Are there any parameters that must be continuously or initially measured in the workplace? (e.g. carbon monoxide, noise, air quality, weather)

    OHSA and MI require atmospheric testing before a worker enters a trench greater than 4ft deep. Specific considerations for oxygen deficiency and flammable gases. Ventilation and PPE required where hazard does or may exist. Re-testing is done as often as is necessary. MB requires atmospheric testing before entering the excavation where hazardous atmospheres may be present. Ventilation or PPE is required where a hazard does or may exist. Tests must be conducted periodically by a qualified professional and records must be available on-site. No other Canadian jurisdiction has monitoring requirements. There are no legislated requirements for monitoring noise or weather (e.g. precipitation and temperature forecast) for any jurisdiction that are specifically related to excavations.

11. What are the provisions for underground utilities?

    AB has the most prescriptive requirements for underground utilities. Overall regulatory requirements include locating all buried services prior to excavating by contacting the utility owner, hand exposing, and supporting utility pipelines and conduits after exposing.

12. What are the trench entrance and exit requirements?

    Critical depth of excavation that requires a ladder, ramp, or staircase is either 1.5m (AB, MB) or 1.2m (ON, MI). Where regulations specify a distance, most jurisdictions specify that a worker must be within 8m of an entry or exit while working in an excavation 8m (AB BC, SK). MB takes a more conservative approach and specifies that workers must be within 3m of an entry or exit. Ladders should be secured and sufficiently long (CCOHS), and must extend at least 1m above trench (MI, MB). OSHA and MI also specify requirements for structural ramps.

Future work included within the scope of this regulatory review will focus on reviewing additional relevant sources from each jurisdiction, including regulations specifically related to mining, and adding questions based on the results of the review of case studies and safety research (e.g. how does the regulation aim to prevent workers from being struck by falling objects while working in a trench or excavation?)

2.2.1 Regulatory sources currently included

Alberta - OHS code (Alberta Regulation 191/2012). Part 32 Excavating and Tunnelling
    https://kings-printer.alberta.ca/1266.cfm?page=2021_191.cfm&leg_type=Regs&isbncln=9780779852352
Ontario - Ontario Regulation 213/91: Construction Projects
    https://www.ontario.ca/laws/regulation/910213#BK41
British Columbia - OHS Regulation Part 20: Construction, Excavation and Demolition
    https://www.worksafebc.com/en/law-policy/occupational-health-safety/searchable-ohs-regulation/ohs-regulation/part-20-construction-excavation-and-demolition#SectionNumber:20.78
Saskatchewan - OHS Regulation
    https://publications.saskatchewan.ca/#/products/112399

Saskatchewan - Safety in Excavations and Trenches
https://www.worksafesask.ca/wp-content/uploads/2023/06/23-08_CR8992_PRV_Safety-in-excavations-and-trenches_FINAL.pdf
Manitoba - Guide for Excavation Work
https://www.safemanitoba.com/Page%20Related%20Documents/resources/GD_ExcavationWork_21SWMB.pdf
United States - OSHA Title 29, Subtitle B, Chapter XVII, Part 1926, Subpart P
https://www.ecfr.gov/current/title-29/subtitle-B/chapter-XVII/part-1926/subpart-P
Michigan - Construction Standard, Part 9 - Excavation, Trenching, and Shoring
https://www.michigan.gov/leo/-/media/Project/Websites/leo/Documents/MIOSHA/Standards/Construction/CS_09/CS_09__03-14-2013.pdf
Canadian Centre for Occupational Health and Safety - Trenching and Excavation
https://www.ccohs.ca/oshanswers/hsprograms/trenching_excavation.html

2.3 Analysis of Case Histories of Incidents in Construction and Mining

Safety in the construction and mining industries remains a critical concern due to the high-risk nature of excavation activities. Structural failures, wall collapses, and falling objects pose significant threats to workers, often leading to severe injuries or fatalities. This analysis aims to provide insights into the most frequent types of incidents and their contributing factors across Canada and the U.S. to emphasize the need for improved workplace safety measures.

This study is based on official reports from **WorkSafeBC, the Government of Alberta, the Centers for Disease Control and Prevention (CDC - NIOSH), Michigan State University (OEM), the University of Kentucky (KIPRC), and the California Department of Public Health (CDPH)**, as well as media reports from **CBC News** and **CTV News**, which served as supplementary references to highlight specific high profile incidents that received public attention. These sources provide detailed investigations into workplace incidents and serve as a foundation for understanding safety gaps in excavation-related work environments.

Analysis of Incidents

A review of reported incidents highlights that excavation-related accidents generally stem from one or more of the following factors, all of which will be explored in further detail below:

- **Insufficient soil support and trench reinforcement**: Many collapses occur due to unstable soil conditions without adequate shoring systems.
- **Lack of compliance with safety regulations**: Failure to follow OSHA and local safety guidelines contributes to preventable incidents.
- **Improper handling of heavy equipment**: Machinery-related accidents often result from poor maintenance, lack of training, or inadequate worksite supervision near open excavations.
- **Unstable excavation environments**: Water infiltration, weather conditions, and excavation depth significantly impact soil stability and lead to worker exposure near collapse zones.

By understanding these root causes, companies and regulatory bodies can prioritize interventions that directly address preventable hazards in construction and mining sites.

Wall Collapses in Excavations (27 reported cases)

Wall collapses account for the majority of excavation-related fatalities. In many instances, workers were buried under soil and debris due to inadequate reinforcement or unexpected soil instability.

- **Example:** In **Alberta (2018)**, a temporary retaining wall failed, causing a worker to be trapped. Investigators cited excessive soil pressure, lack of proper shoring, and failure to assess soil conditions beforehand (Government of Alberta, 2024).
- **Example:** Similar cases occurred in **California (2019, 2020, 2023)**, where multiple fatalities resulted from the absence of trench boxes and over-excavation beyond safe depth limits (CDC-NIOSH, 2024).

Struck by Excavator Bucket (3 cases)

Improperly maintained heavy machinery and unsafe worker positioning near active excavators have resulted in fatal accidents.

- Example: A worker in British Columbia (2019) was fatally struck when an excavator bucket detached unexpectedly due to mechanical failure and inadequate maintenance checks (WorkSafeBC, 2024).

Falling into Trenches (1 case)

Falls into open excavations are often caused by insufficient protective barriers, unstable ground, and poor site planning.

- **Example:** In **Alberta (2020)**, a worker fell into an unprotected trench and suffered fatal injuries. The investigation found that there were no safety barriers or soil assessments to prevent such incidents (Government of Alberta, 2024).

Struck by Falling Objects (1 case)

Material handling errors and unsecured loads contribute to accidents involving falling objects.

- **Example:** A worker in **Alberta (2013)** was crushed when a rolling pipe entered a trench unexpectedly. Reports indicate that unsecured materials and poor hazard assessment were primary factors (Government of Alberta, 2024).

Key findings include:

- Inadequate trench support leading to collapses.
- Lack of proper training in handling heavy machinery.
- Failure to conduct geotechnical assessments before excavation.

Reports from **CDC-NIOSH, KIPRC, and OEM Michigan** suggest that inadequate regulatory enforcement and lack of worker safety training are persistent factors in U.S. trenching and excavating incidents. The findings highlight that wall collapses in excavations are the consequence of recurring factors such as Non-compliance with safety regulations, insufficient trench reinforcement, inadequate worker training, and economic pressures that prioritize cost savings over safety. The findings of this research align with CPRW's conclusion (https://www.cpwr.com/wp-content/uploads/krtrenching.pdf), which underscores the broad consensus among experts on the importance of consistently implementing the requirements of the OSHA excavation standard (Subpart P, Excavations, of 29 CFR Part 1926.650, .651, and .652) to prevent most trench-related deaths and serious injuries. In particular, the presence of a properly trained competent person at every excavation site is crucial to assessing hazards and ensuring the appropriate use of trench protective systems.

To address these risks and reduce fatalities, regulatory agencies, construction firms, and industry stakeholders must focus on:

- Enhancing trench shoring and soil stabilization measures.
- Strengthening compliance and enforcement of excavation safety regulations.
- Providing mandatory safety training and site assessments before excavation begins.
- Implementing real-time geotechnical monitoring to assess soil conditions.

Moreover, smaller companies with limited resources are particularly vulnerable, as they are more likely to lack proper training and protective equipment. Weak enforcement and penalty reductions further contribute to the inadequate implementation of safe practices. In conclusion, improving competent-person training, adopting more effective teaching methods, and strengthening the enforcement of safety regulations are essential steps to mitigating risks in excavation operations. By addressing these safety gaps, the industry can significantly reduce fatalities and injuries, fostering a safer working environment for excavation and trenching activities.

Sources of Information

1. **Government of Alberta** – Excavation and mining safety reports.
    a. Worker fatally injured in trench collapse
    b. Investigation report: worker fatally injured falling into an excavation
2. **WorkSafeBC (British Columbia, Canada)** – Incident investigation report summaries.
    a. Incident Investigation Report Summaries
3. **Centers for Disease Control and Prevention (CDC - NIOSH)** – Occupational safety reports in the U.S.
    a. Cases in California, Michigan, Oregon, Kentucky, Massachusetts, Texas, and New York
4. **Michigan State University - Occupational & Environmental Medicine (OEM)**
    a. Incident investigations in Michigan
5. **University of Kentucky - Kentucky Injury Prevention and Research Center (KIPRC)**
    a. Incident reports in Kentucky
6. **Media sources**
    a. CBC News - Incidents in Alberta
    b. CTV News - Accident reports

2.4 Soil Conditions, Water, Weather, and Adjacent Activities

Excavation and trenches are a common element of construction and infrastructure projects across the United States and Canada. While they play a vital role in laying the foundation for utilities, pipelines, and other projects, they also pose significant safety risks if not managed properly. OSHA has established guidelines (under the OSHA 1926 Subpart P standards) to ensure the safety of workers involved in excavation activities. (NAXSA, 2023)

Trenching and excavation are among the most dangerous activities in construction, an industry that continues to be one of the most hazardous in the United States. With construction workers experiencing approximately 1,000 fatal and 70,000 nonfatal injuries annually since 2016, monitoring these trends and enforcing safety requirements at trenching and excavation sites is crucial. An overwhelming majority of trenching and excavation injuries in the United States occurred among construction workers, accounting for 85% of fatal trenching injuries from 2011-2021 and 90% of nonfatal trenching injuries from 2011-2022. It was found that nearly 4% of all OSHA construction citations were for trenching, with over half of those occurring in Heavy and Civil Engineering Construction in 2023. (CPWR, 2024).

From 2013-2017 there were 97 trenching fatalities in the construction industry – an average of 19 per year, from a low of 10 deaths in 2014 to a high of 33 in 2016. While the total number of 85 construction-trenching deaths in the previous five years, 2008-2012, was lower, the average of 17 construction-trenching deaths during that five-year period is not significantly different (BLS, 2019). Furthermore, there was no trend in the number of deaths over the 10-year period 2008-2018. From 2018 to 2020, the numbers remained in the range of 20-25 deaths annually in the U.S. (CPWR, 2024).

However, headlines from July 2022 read “Alarming rise in trench-related fatalities spurs US Dept. of Labor to announce enhanced nationwide enforcement and additional oversight.” In the first half of 2022, 22 workers were fatally injured in trench-related workplace incidents. Additional research will be conducted to integrate relevant statistics and incident trends from the mining sector and contrast them with those from the construction industry.

“By January 2023, the deputy regional director of OSHA Region 6 reported that 39 workers had lost their lives in Fiscal Year (FY) 2022. That number has been used by industry professionals since it emanated from OSHA. Eight more fatalities have been added to FY2022 statistics since January 2023, since OSHA has now completed several investigations. So, the final number for that year is 47” (NAXSA, 2024).

Table 3. A four-year summary of 2020-2023 incidents adds additional context (Extracted from NAXSA, 2024)

FY 2020	33
FY 2021	25
FY 2022	47
FY 2023	29

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A sharp increase in fatalities coming out of COVID is clear. Last year may suggest a return to more "normal" incident levels, if any fatalities can be called "normal." (NAXSA, 2024)

Further analysis on FY 2022 shows a large increase in construction spending in Q4 2021, coming out of COVID. It appears that crews hired may have lacked training, experience, and possibly, maturity, to navigate the requirements of the Excavation Standard safely. Fatalities in FY2022 include one 17-year-old, one 19-year-old, and nine individuals in their 20s. This suggests a lack of training and proper understanding of the risks. (NAXSA, 2024)

The reduction in deaths from 2022 to 2023 has coincided with stepped up enforcement and public outreach by the U.S. OSHA, as well as increased publicity efforts by trade associations.

"One hopes that all the attention paid to, especially the 2022 fatalities, sent a message to the industry that they need to pay more attention to this, and maybe we saw the effect of that in 2023. And hopefully, that'll continue into 2024," says Jordan Barab, former OSHA deputy assistant secretary. "It's always hard to tell with these things." (NAXSA, 2024)

However, the author of the "Confined Space" newsletter about work safety sees some issues that continue to lead to deaths that he and other safety advocates view as entirely preventable if trench boxes were only used properly. (NAXSA, 2024)

"Unfortunately," Barab says, "a lot of these are relatively small construction companies that kind of escape the oversight of OSHA."(NAXSA, 2024)

He notes that the large construction projects, which have substantial oversight, mostly have trench boxes in use. But he and other safety advocates point out that most jobs where workers die in trenches are small ones in residential areas where it's unlikely OSHA inspectors will be driving by or that people will notice a violation and call OSHA. (NAXSA, 2024)

In Canada, the number of fatal accidents from excavation collapses is lower but not negligible, given the smaller population and construction activity. There is no consolidated national public count, but provincial data provides context. For example, in Ontario (Canada's most populated province), 4 workers died in excavation or improper leveling incidents between 2017 and 2021, along with 26 critical injuries in trenches during that period. (Construct Connect, 2022)

Geotechnical factors affecting trench stability (emphasis on water and soil conditions)

Trenching is a high-risk work activity. Workers continue to be seriously or fatally injured because proper procedures were not put in place or followed. Listed below are the main causes of lost-time injuries in the sewer and watermain industry that are directly related to trenching (IHSA, 2019).

- Being struck by materials and equipment falling into the trench
- Slips and falls as workers climb on and off equipment
- Injuries while unloading, handling, and placing pipe and other materials
- Injuries while handling and placing frames and covers for manholes and catch basins
- Being struck by moving equipment

- Falls as workers climb in or out of an excavation
- Falling over equipment or excavated material
- Falling into the trench
- Exposure to toxic, irritating, or flammable gases.

Trenching fatalities are mainly caused by cave-ins (IHSA, 2019). Death occurs by suffocation or crushing when a worker is buried by falling soil. The following figure shows some typical causes of cave-ins (IHSA, 2019)

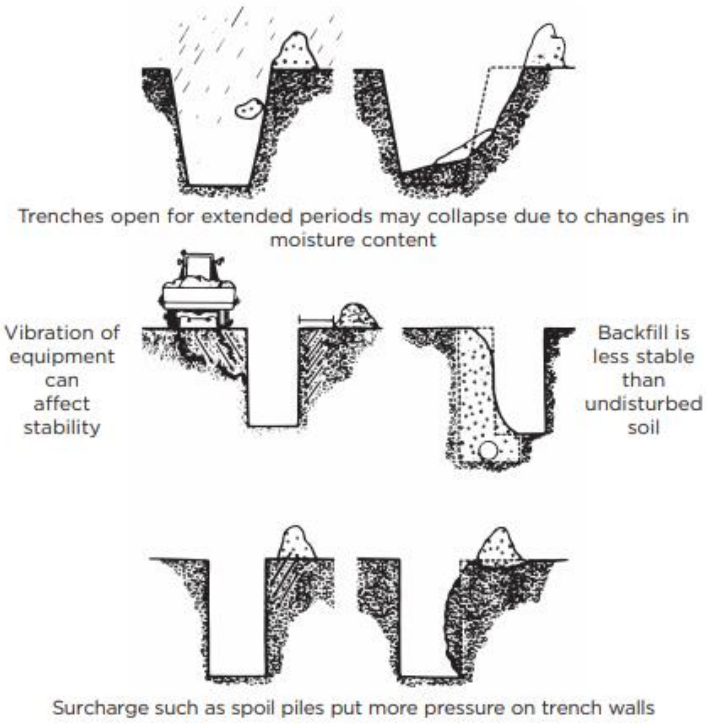

Fig 1. Typical Causes of Cave-ins. Source: https://www.ihsa.ca/PDFs/Products/Id/M026.pdf

Common Soil Problems in Trenches Works

The Guide to OSHA Excavations Standard highlights the requirements in the updated standard for excavation and trenching operations, provides methods for protecting employees against cave-ins, and describes safe work practices for employees. A necessary first step in planning the approach to any trenching or other excavation project is to understand what could go wrong. This understanding can help avoid many of the safety risks associated with excavation. (Duke University, 2009)

According to IHSA (2019), many factors can affect trench stability and cause cave-ins. Soil properties can vary widely from the top to the bottom and along the length of a trench. Time is also a critical factor. Trenches that remain open for a long period can collapse suddenly due to changes in the soil's moisture content. Other factors such as cracks, water, vibration, weather, insufficient shoring, and previous excavation can affect trench stability (Figure 2). The main factors affecting trench stability are:

- Soil type
- Moisture content
- Vibration
- Surcharge

- Previous excavation
- Existing foundations
- Weather

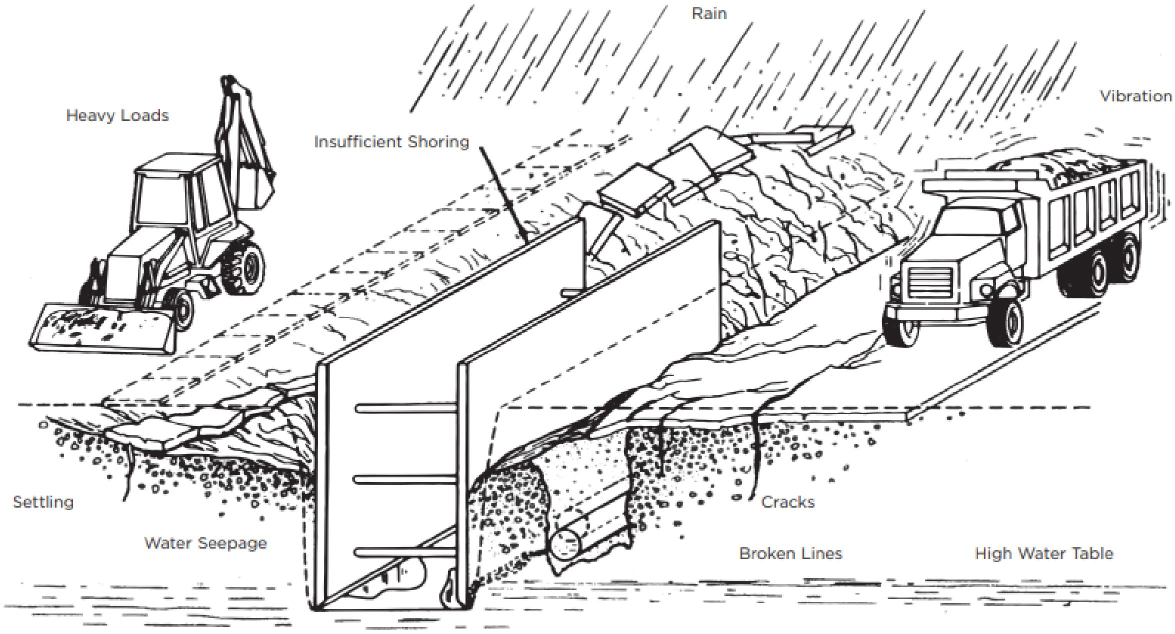

Fig 2. Factors Affecting Trench Stability. Source: https://www.ihsa.ca/PDFs/Products/Id/M026.pdf

Soil mechanics

According to Duke University (2009), a number of stresses and deformations can occur in an open cut or trench. For example, increases or decreases in moisture content can adversely affect the stability of a trench or excavation. The following diagrams show some of the more frequently identified causes of trench failure.

- Tension Cracks: Tension cracks usually form at a horizontal distance of one-half to three-quarters times the depth of the trench, measured from the top of the vertical face of the trench. See Figure 3 for additional details.

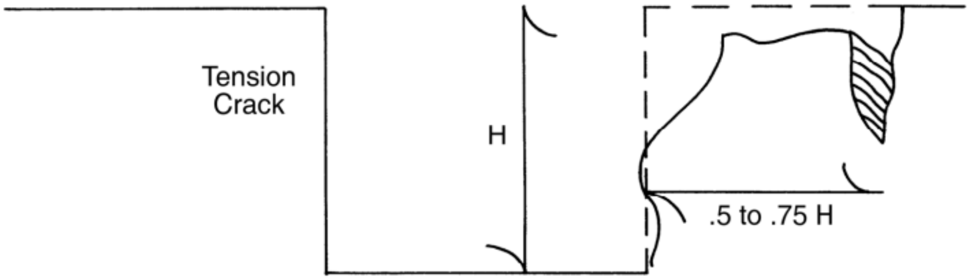

Fig. 3 Tension Crack. Source: https://www.safety.duke.edu/sites/default/files/ig14.pdf

- Sliding or Sluffing: This may occur as a result of tension cracks, as illustrated in the following figure.

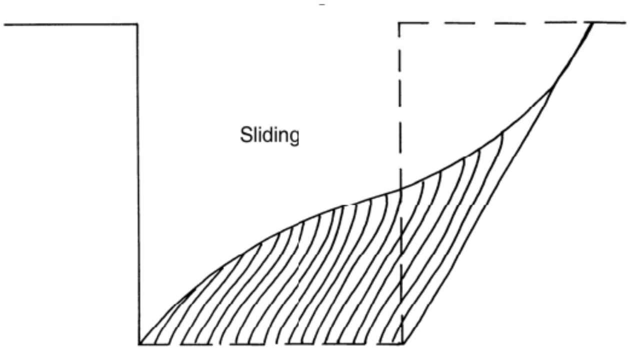

Fig 4. Sliding. Source: https://www.safety.duke.edu/sites/default/files/ig14.pdf

- Toppling: In addition to sliding, tension cracks can cause toppling. Toppling occurs when the trench's vertical face shears along the tension crack line and topples into the excavation. See the following picture.

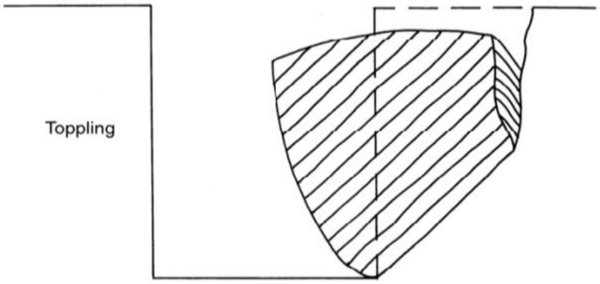

Fig 5. Toppling. Source: https://www.safety.duke.edu/sites/default/files/ig14.pdf

- Subsidence and Bulging: An unsupported excavation can create unbalanced stress in the soil, which, in turn, causes subsidence at the surface and bulging of the vertical face of the trench. If uncorrected, this condition can cause face failure and entrapment of workers in the trench (Figure 6).

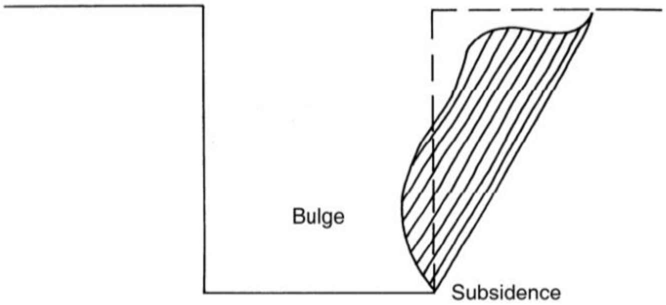

Fig 6. Subsidence and Bulging. Source: https://www.safety.duke.edu/sites/default/files/ig14.pdf

- Heaving or Squeezing: Bottom heaving or squeezing is caused by the downward pressure created by the weight of the adjoining soil. This pressure causes a bulge in the bottom of the cut, as illustrated in the following figure. Heaving and squeezing can occur even when shoring or shielding has been properly installed.

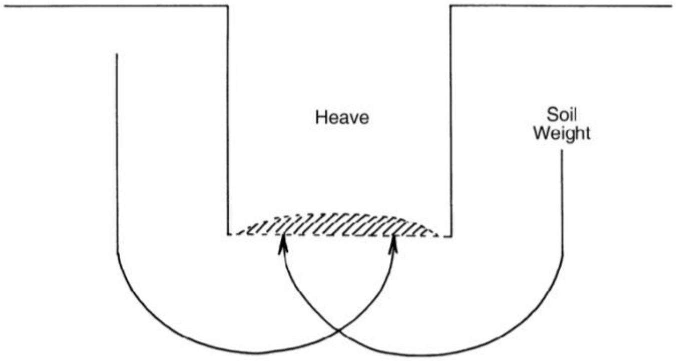

Fig 7. Heaving and Squeezing. Source: https://www.safety.duke.edu/sites/default/files/ig14.pdf

- Boiling: This is evidenced by an upward water flow into the bottom of the cut. A high-water table is one of the causes of boiling. Boiling produces a "quick" condition in the bottom of the cut and can occur even when shoring or trench boxes are used (Figure 8).

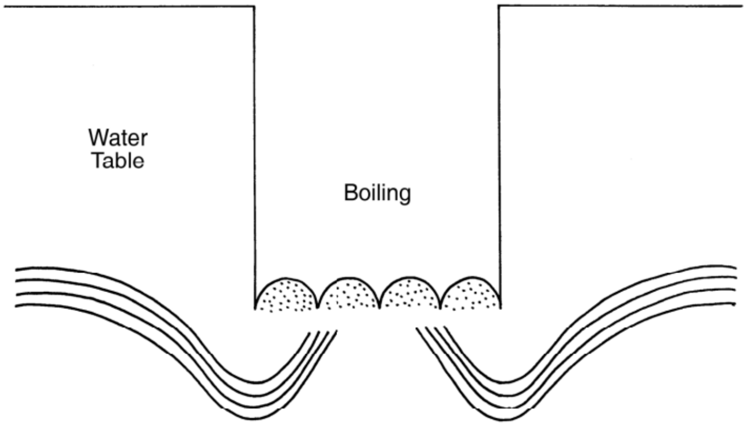

Fig 8. Boiling. Source: https://www.safety.duke.edu/sites/default/files/ig14.pdf

Vibrations near excavations

Any large, heavy movement near an excavation will result in vibration of the surrounding soils. This movement can result in soil failure. Moving machinery, nearby traffic, pile driving and blasting all cause vibration in surrounding soils.

Vibration-related soil failures can occur in all types of soil. However, certain types of soils are more susceptible to vibration failures than others. For example, sandy soils tolerate less vibration than clay soils.

Since actual soil conditions may be a mixture of more than one soil type, it is better to play it safe when planning the slope of an excavation. Figure 9 shows typical situations where vibrations can result in soil failure.

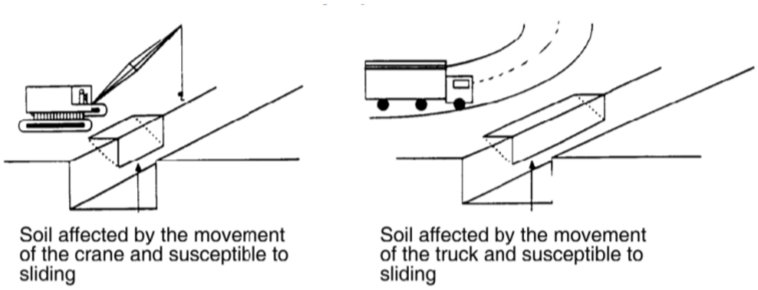

Fig 9. Examples of vibration failures. Source: https://www.safety.duke.edu/sites/default/files/ig14.pdf

Surface Encumbrances

Heavy loads such as large equipment, heavy materials or large spoil piles can be too heavy for the soil to support, resulting in a cave-in. These loads are referred to as surface encumbrances. They pose different types of dangers (see Figure 10). For example, large spoil piles may hide tension cracks that would otherwise signal that a sliding soil failure may occur.

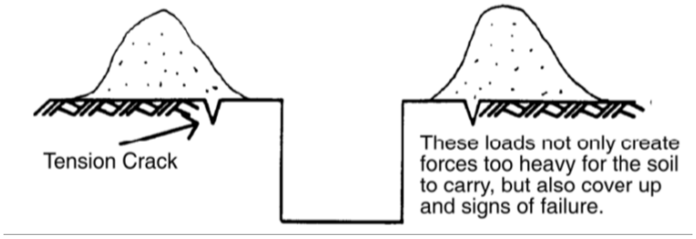

Fig 10. Surface encumbrances. Source: https://www.safety.duke.edu/sites/default/files/ig14.pdf

Mobile equipment and other material stored close to the trench also add a surcharge that will affect trench stability. One metre from the edge to the toe of the spoil pile is the minimum distance required. The distance should be greater for deeper trenches (IHSA, 2019)

Previous Excavation

Old utility trenches either crossing or running parallel to the new trench can affect their strength and stability. The soil around and between these old excavations is backfilled soil, which is usually less stable than undisturbed soil. This kind of soil will not stand up unless it is sloped or shored. (IHSA, 2019)

Fig 11. Unstable soil near old utility trenches. Source: https://www.ihsa.ca/PDFs/Products/Id/M026.pdf

Existing Foundations

Around most trenches and excavations, there is a failure zone where surcharges, changes in soil condition, or other disruptions can cause collapse. When the foundation of a building adjacent to the trench or excavation extends into this failure zone, the result can be a cave-in (IHSA, 2019)

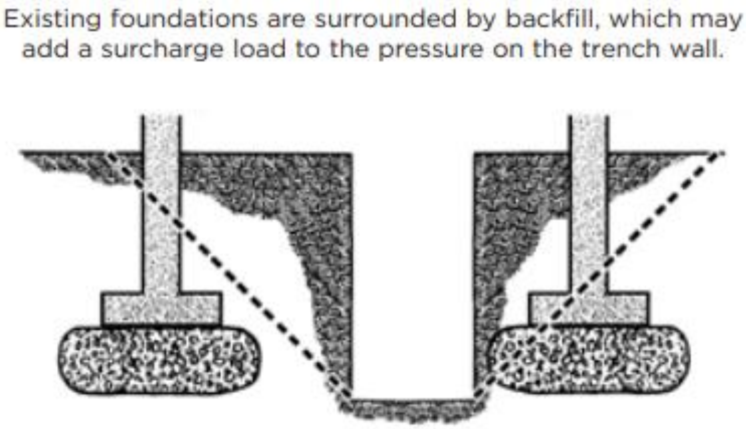

Fig 12. Unstable soil near previous excavations. Source: https://www.ihsa.ca/PDFs/Products/Id/M026.pdf

Weather conditions

Weather is an important factor in determining soil conditions. More importantly, changing weather conditions may signal a change in the pressures exerted by the soil on the side walls of a trench (Duke University, 2009).

Excess water from rain or melting snow interacts with the soil, increasing the pressure on the excavation and shoring system. For instance, a rainstorm can turn a stable trench wall that requires only light bracing into a mass of loose soil that requires heavy bracing. Freezing usually indicates a rather stable ground condition, unless the frost line is exceeded during excavation. The frost line phenomenon is depicted in the following figure. If you excavate or shore frozen ground, be aware that another potential problem exists—thawing. A sudden thaw can be as dangerous as a rainstorm. Duke University (2009).

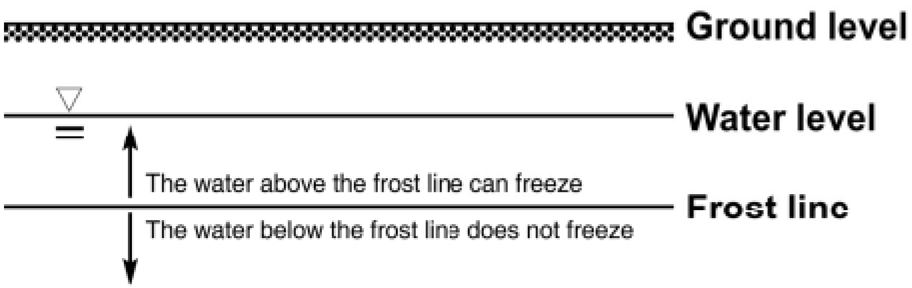

Fig 13. Region of soil freezing. Source: https://www.safety.duke.edu/sites/default/files/ig14.pdf

Excessively dry conditions can also be dangerous. As moisture content decreases, some dry soils lose their ability to stick together. This lack of cohesion may result in a sliding type of soil failure. In many of the situations described above, dewatering or extra shoring may be required as necessary to ensure the safety of your workers. Duke University (2009).

Effect of water and remedies

According to Duke University (2009), the natural water table can cause many types of problems. For example, trenches excavated below the natural water table in sandy soils and soft clay are highly susceptible to heaving, as illustrated in the following. Heaving is the seepage of water at the bottom of the trench causing the soil to be pushed upward. This heaving is a signal that a failure may occur.

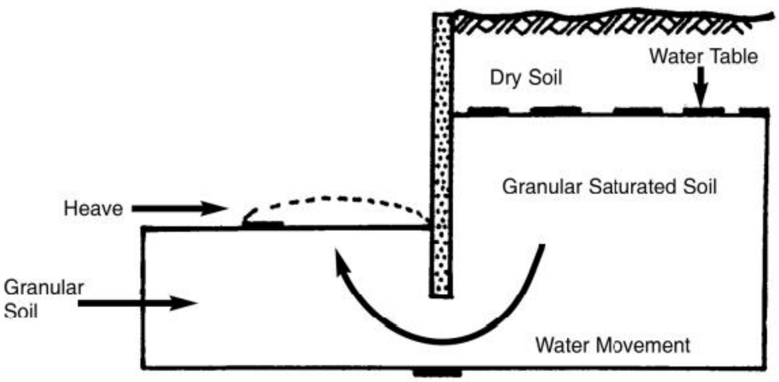

Fig 14. *Heaving. Source: https://www.safety.duke.edu/sites/default/files/ig14.pdf*

Wet conditions at the bottom of a trench may present another problem. If the bottom of the trench begins to puff and bubble and the earth rises, a quicksand condition occurs. This is also a signal that a failure may occur.

If heaving or quicksand conditions are expected, dewatering should be considered before beginning an excavation. Dewatering drastically reduces the presence of water and the additional pressure it causes. Without dewatering, heavier timbers would be needed to support the extra pressures caused by the water. The two most frequently used dewatering systems are well-points and sump pumps.

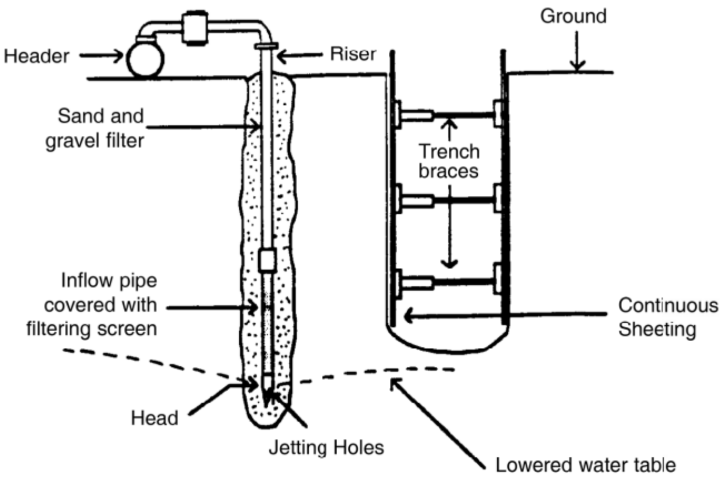

Fig 15. *Well - Point. Source: https://www.safety.duke.edu/sites/default/files/ig14.pdf*

Well-points are pipes with a point at the lower end and a screen or filter over perforations along 3 or 4 feet of the lower ends of the pipes. There are two types of well-points:

- hose driven with a maul
- those that are jetted in

The selection of the size of the well-points and the required spacing are based upon site conditions and the type of excavation to be accomplished. Above the ground, well-point pipes are connected by piping to a high-capacity pump. Pumping keeps the water level below the bottom of the excavation so that only a moist soil condition will be encountered within the excavation.

The well-point system should have a capacity sufficient to remove any inflow of water as quickly as it occurs. The depth limit of this method's practical effectiveness is approximately 15–20 feet, although the theoretical limit is just under 34 feet since the method depends upon pumping suction. Greater depths can be achieved by arranging well-points into two or more vertical stages, or by deep-well pumping, that is, locating the pump at a lower elevation.

Dewatering does not permit any substantial excavation without providing ground support. Although the dewatered soil will usually be firmer than it was before dewatering, working conditions may still be unsafe. Shoring, or bank walls at a safe slope, should be used in dewatered ground in the same manner as in any other excavation. The second common type of dewatering system is the sump pump.

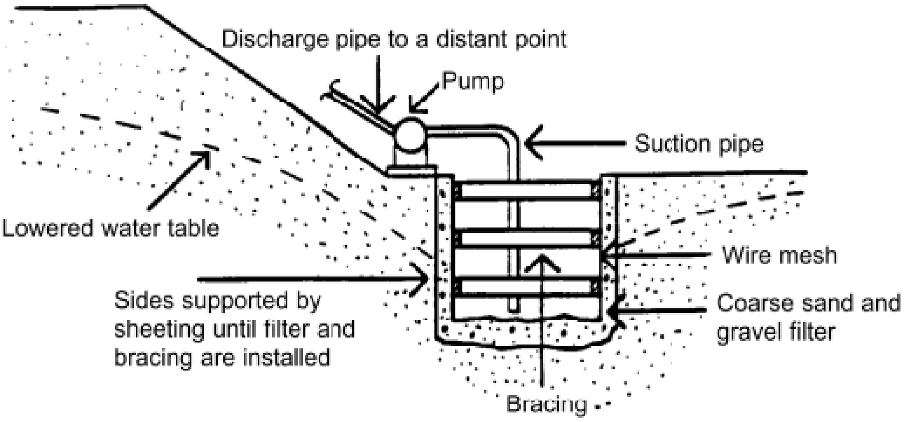

Fig 16. *Sump Pump. Source: https://www.safety.duke.edu/sites/default/files/ig14.pdf*

However, According to NAXSA (2023), Rapid water drawdown in a shored excavation can cause excessive loading on the shoring system and cause it to collapse.

After a storm or inundation due to some other source like broken water lines, the water level inside the excavation becomes the water level in the surrounding soil. Pumping will draw out the water inside the excavation faster than it will flow out of the soil. The difference between the two water levels creates a force on the shoring, or the bank of soil, causing it to want to collapse.

The following is a general rule for pumping out a flooded excavation:

a) Do not pump out excavations faster than two feet per hour, or faster than it takes to maintain a 2-foot differential between the outside and inside water levels.
b) After drawdown is complete, and before workers enter the excavation, conduct a hazard analysis focusing on safe access and egress, continued control of the dewatering system and slipping and falling due to muddy surfaces.

2.5 Preventing Trench Collapses

Experience demonstrates that every trench collapse is preventable through planning, protection systems, training, and supervision. Below is a summary of the best practices used by companies and industry associations to minimize the risk in excavations, beyond mere regulatory compliance. These strategies, promoted by organizations such as the OSHA in the U.S., NIOSH, CPWR, and industry associations (NUCA, NAXSA, etc.), have proven effective in preventing tragedies in trenches.

One of the key strategies to prevent trench collapses is adhering to five fundamental safety measures that OSHA mandates for all excavation and trenching activities.

1. Proper Planning and Hazard Analysis:

    a. A fundamental principle of excavation safety is thorough planning and analysis before any excavation work begins. OSHA 1926.651(c)(1) emphasizes the importance of assessing the soil, structure, and environmental conditions of excavations to identify potential hazards. A Competent Person, as defined by OSHA, must conduct these inspections before work starts, and as necessary while the work is being performed.
    b. Excavations and trenches at any depth can pose hazards or potential for injury. OSHA 1926.652(a)(1) emphasizes the use of protective systems at 5' deep or deeper (4' in the State of Washington) in any excavation where work will be performed.
    c. Soil analysis is a critical component of planning. Different types of soil present different risks, and understanding them is crucial. OSHA classifies soils into three main types: Type A (stable), Type B (less stable), and Type C (unstable). The classification determines the protective measures required to ensure worker safety during excavation.

2. Trench Protection Systems:

    a. OSHA 1926.652(a)(1)) mandates the use of protective systems, such as sloping, shoring, and shielding, designed to protect employees working in excavations.
    b. Sloping: This involves cutting back the trench wall at a designated angle inclined away from the excavation. The angle is determined by the soil type and other factors such as moisture.
    c. Benching: Instead of a continuous slope, benches or steps are created in the trench walls. The designs of benches are guided by soil classification. Benches are not typically allowed in certain soil types such as Type C.
    d. Shoring: This involves installing supports, such as aluminum hydraulic vertical shores, aluminum walers, or timbershoring, to prevent unexpected soil movement and protect workers.
    e. Shielding: Trench boxes or shields are used to provide a barrier between workers and the trench wall. They are designed to withstand soil movement and cave-ins. Trench boxes or shields are typically a proactive system supporting the excavation.

It is essential to select the appropriate protective system based on the specific conditions of the trench. The design and installation of these systems should be overseen and monitored regularly by a Competent Person to ensure their effectiveness.

3. Trench Protection Systems:

Ensuring quick, easy, and safe access to and from a trench is crucial, especially in case of emergency. Adequate training for workers on the proper use of access and egress points is essential to minimize the risk of accidents. OSHA 1926.651(c)(2) outlines specific requirements for access and egress in trenches deeper than 4'.

a) Ladders or Ramps: Trenches of 4’ or more in depth must have a designated means of access, such as portable stairways, ladders, or ramps, within 25’of each employee. The ladder should extend a minimum of 3’ above the trench edge to facilitate safe entry and exit. Training and review of OSHA ladder standards ensures proper use.
b) A safe exit must be provided for workers in case of an emergency, regardless if equipment is used in the excavation, and should not be impeded by materials or equipment.

1. Utilities Identification and Protection:

Excavation work often involves digging in areas where underground utilities are present. Accidental strikes on utility lines can lead to severe injuries, utility service disruptions, community damage, and costly repairs. OSHA 1926.651(c)(3) addresses the importance of identifying and protecting utilities during excavation activities.

a) Utility Locating Services: Before excavation begins, contact the relevant utility locating services to identify the location of underground utilities. This includes gas lines, water pipes, electrical cables, and communication lines. Call811.com is a great resource for this information.
    i. While the excavations are open, ensure that underground installations are protected, supported, or removed, as necessary, to safeguard workers.
b) Safe Clearance Distances: OSHA recommends non-destructive digging or vacuum excavation in the vicinity of utilities to minimize the risk of strikes. Overhead power lines are also topics of review, to ensure that safe clearance distances are maintained.
c) Utility Marking: Clearly mark the locations of utilities to ensure that workers are aware of their presence. Use color codes and other industry-standard markings for easy identification. Consult the damage prevention regulations in your area for appropriate details.

2. Continuous Monitoring, Training and Competent Person Duties:

a) Effective trench safety goes beyond initial planning and implementation of safety measures. OSHA 1926.651(k) emphasizes the need for continuous awareness and training throughout the excavation project.
    i. Monitoring: A competent person MUST regularly inspect the excavation site, including soil conditions, protective systems, and access points before any work is done, after a rainstorm, during Spring or Fall freeze/thaw cycles, and under any other hazardous conditions.
    ii. Training programs: All workers involved in excavation activities must receive training on trench safety. This includes understanding the hazards associated with excavation work, recognizing the sign of soil instability, and knowing how to use protective systems and equipment. Guidance can be found in subpart C and the compliance directive in subpart P.

2.6 Conclusions

Excavation trench safety is paramount in the construction industry, and adherence to Canadian regulations as cross-referenced with OSHA 1926 Subpart P standards, as well as other required OSHA standards, is essential to prevent accidents and protect the lives of workers.

By incorporating proper planning, trench protective systems, access and egress measures, utilities identification, and continuous monitoring and training, we can create safer construction working environment. Prioritizing trench safety is not only a requirement, but compliance with regulations also contributes to the overall success of all construction projects with trenches and excavations. (NAXSA, 2023)

Nonetheless these tragedies are preventable. Lack of compliance with OSHA regulations is by far the most comprehensive reason for these deaths. Enforcement remains weak. Penalties for OSHA violations, while they have risen, are still low and usually lack criminal consequences. Lack of experience by both new workers and new companies post-Recession probably contributes to the increase in fatalities. A growth in the percentage of trench work related to repairs and emergencies, which disrupt, often with hand tools, already-disturbed soil is another likely cause for the increase in workplace fatalities. (CPWR, 2019). Analysis of Canadian incidents will determine if these economic conditions also affect our industry fatality rates.

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3. Workshops: Building Resilience to Serious Injuries and Fatalities (SIFs)

3.1 Purpose and Objectives

We held two workshops, with industry subject matter experts in oilsands mining and industrial construction to examine hazards. Of the eight hazards we analyzed, two were related to this creative sentence: trenching/excavating and working around water/ice. These workshops included:

1. 112 participants (from 37 organizations) in-person at the Quality Hotel and Conference Centre in Fort McMurray, Alberta, hosted by Energy Safety Canada (ESC) on November 21, 2023, from 7:30 a.m. to 12:00 p.m.
2. 91 registered with (from 61 organizations in the oilsands, construction and safety management sectors), in person at the Alberta Construction Safety Association (ACSA) in Edmonton, Alberta on November 26, 2024, from 9:00 a.m. to 1:00 p.m.

The overarching objective of these workshops was to examine high hazard work, human and organizational performance, and critical controls assurance using bowtie analyses.

What is a bowtie and why do we use them? Bowties are a method used to visualize, communicate, and better control high-energy ("stuff that can kill you" – STCKY) hazards to prevent SIFs, causes, and consequences and strengthen controls. It helps us to understand what can go wrong (See Fig 16). If we can see hazards and agree how to effectively control them, we are more likely to work safely and prevent workplace incidents.

UNDERSTAND WHAT CAN GO WRONG

Bowties are a visualization technique to illustrate:

1. Loss of control over STKY hazards
2. potential causes
3. potential outcomes
4. prevention controls
5. mitigation/recovery controls

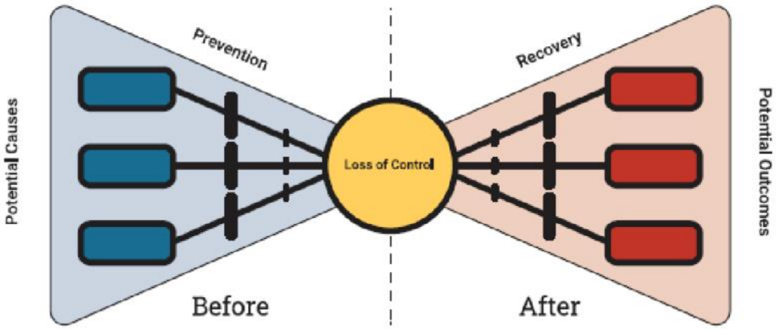


Fig 16. Elements of a Bowtie.

Bowties also illustrate that safety is the presence of layered controls rather than an absence of serious consequences. If you have greater 'depth of protection' from additional layers of controls to help you prevent and recover from an incident – e.g. a resilient safety management system - then you are more likely to fail safe than fail lucky. These layers are aligned with the hierarchy of controls (See Fig 3). Elimination, substitution, and isolation often prevent a loss of control and, thus, are most effective. If you **eliminate** work from heights by building modules on the ground, then you cannot fall to your death. If you **substitute** non-toxics for highly toxic chemicals, then a burst pipe will not harm workers. If you **isolate** workers from hazards, for example by separating workers from moving equipment, then workers cannot get hit.

Conversely, controls that are lower on the hierarchy are less effective. **Administrative controls**, such as work permits, are easy to bypass. **Personal Protective Equipment (PPE)**, such as hard hats or hearing protection, will not save workers from being run over by equipment.

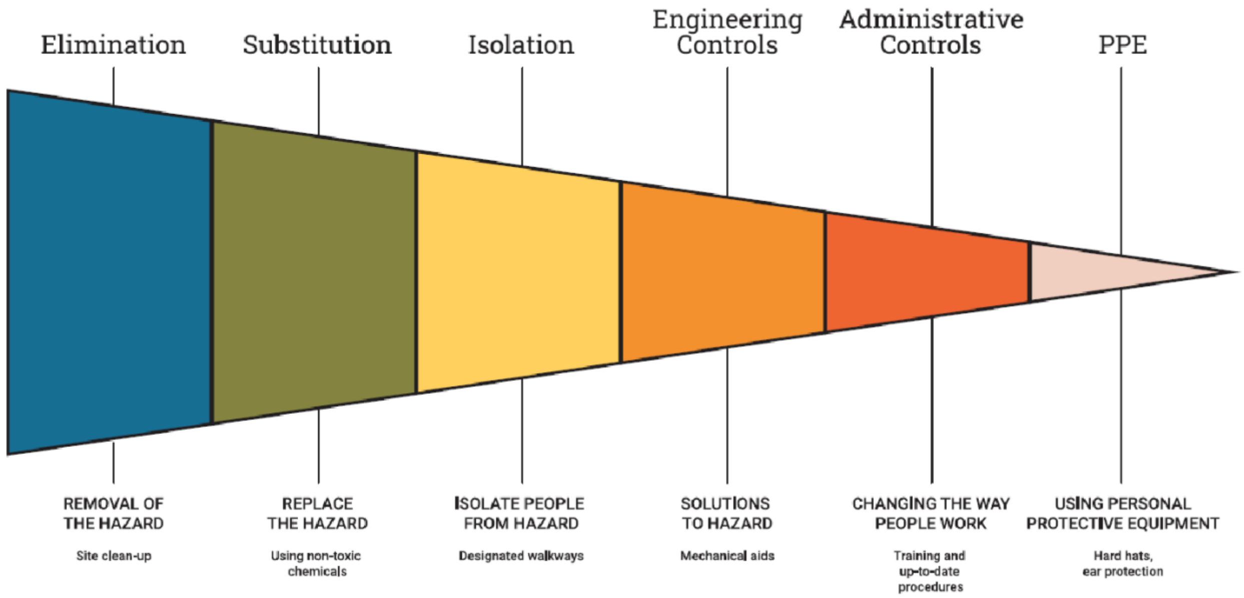


Fig 17. Hierarchy of controls as layers of protection in a bowtie.

Bowties are a useful communication tool – to make the invisible visible and the unspeakable discussable. Engaging frontline personnel in bowtie discussions can enhance awareness, promote accountability, and provide opportunities to identify potential gaps in controls. They can be used effectively during safety meetings or toolbox talks with crews to visually communicate hazards, controls, and their roles in maintaining safety. If we understand which controls are critical, then we can assure that they are in place, functional, and non-bypassable – before work starts and as it unfolds.

Lastly, bowties show that if controls are degraded by human and organizational factors, it compromises the resilience of the system to ‘fail safely’. Thus, our workshop included defining and understanding the ideas of psychological safety, trust, team learning, and safety culture. We invited participants to consider what variables should be measured and how, as well as the challenges of measuring such variables. We explored how to optimize the human and organizational factors linked to safety and how owners may support or undermine these actions.

In this workshop, we created a psychologically safe space to discuss human dynamics, leadership, and organizational factors potentially related to SIFs. We aimed to understand how employees experienced and understood various factors, including psychological safety, trust, motivation, appropriate training, peer-to-peer relationships, team dynamics and norms, leader and manager styles, organizational pressures, policies, (safety) cultures, and business drivers of safe and unsafe practices.

3.2 Participants

Two months prior, an invitation for the symposiums was circulated through industry partners. We made it clear in the invitation that all information shared during the event would be used to develop the research program and not attributed to any one person or company. Suggestions for who should attend the symposium were included on the invite: Oilsands Contractors, Subcontractors and Suppliers: Senior Leaders, Project Managers, Project Safety Personnel, Operational Risk Management. In Ft. McMurray, most attendees worked in tailings operations and in Edmonton, most attendees identified themselves as safety professionals (e.g., safety manager/coordinator/officer) or in a specialized safety role (e.g., HSEQ advisor, QA analyst), followed by management and leadership roles (e.g., manager/director).

The session included information presented and facilitated by six subject matter experts:

- Dr. Lianne Lefsrud (University of Alberta, ESRM)
- Dr. Fereshteh Sattari (University of Alberta, ESRM)
- Rose Marie Charuvil Elizabeth, MSc. (University of Alberta, ESRM)
- Dr. Thomas O'Neill (University of Calgary, Department of Psychology)
- Dr. Samanthan Jones (University of Calgary, Department of Psychology)
- Jessica Wilkins, MSc. (University of Calgary, Department of Psychology)

3.3 Workshop Agenda

Understanding and creating bowties as visualizations of high-energy hazards, causes, consequences, and controls

To start, the participants were welcomed, oriented to the space, and a land acknowledgement was conducted. We then began with a short presentation that described what bowties are and how these tools can be used to mitigate SIFs. Once the purpose and process of creating a technical bowtie was explained, the floor was open to questions. Several bowtie frameworks were displayed on posters in an adjacent room that contained pre-populated critical controls and serious incidents. Serious incidents, for which controls were developed, included dropped objects, confined space, excavation and trenching, control of hazardous energy, working in or around water/ice/hazardous grounds, and lifting and hoisting.

In groups, participants chose a bowtie framework poster and gathered at their table to work on identifying controls for each hazard (Part 1), followed by identifying which controls were *critical controls* and what could be done to assure they were in place (i.e., critical controls assurance) (Part 2). Each part of the activity was followed by a short discussion. Markers and various sizes and colours of sticky pad notes were placed at each table for the participants to use to populate the bowtie poster. Facilitators circled the room to clarify questions, ensure everyone had the opportunity to participate, and that instructions were followed correctly. Facilitation was used to ensure that the voices of all individuals were heard and accounted for, creating an inclusive environment. Feedback from this exercise was positive, with participants expressing statements such as how their combined intelligence enabled the generation of more ideas than would have been possible alone. Participants also noticed that it was beneficial to include operations personnel in the group as they provided an integral perspective. A brief group discussion on the experience of creating bowties concluded the exercise, and photographs were taken of all the bowtie posters to ensure no data was lost (see Fig 4).

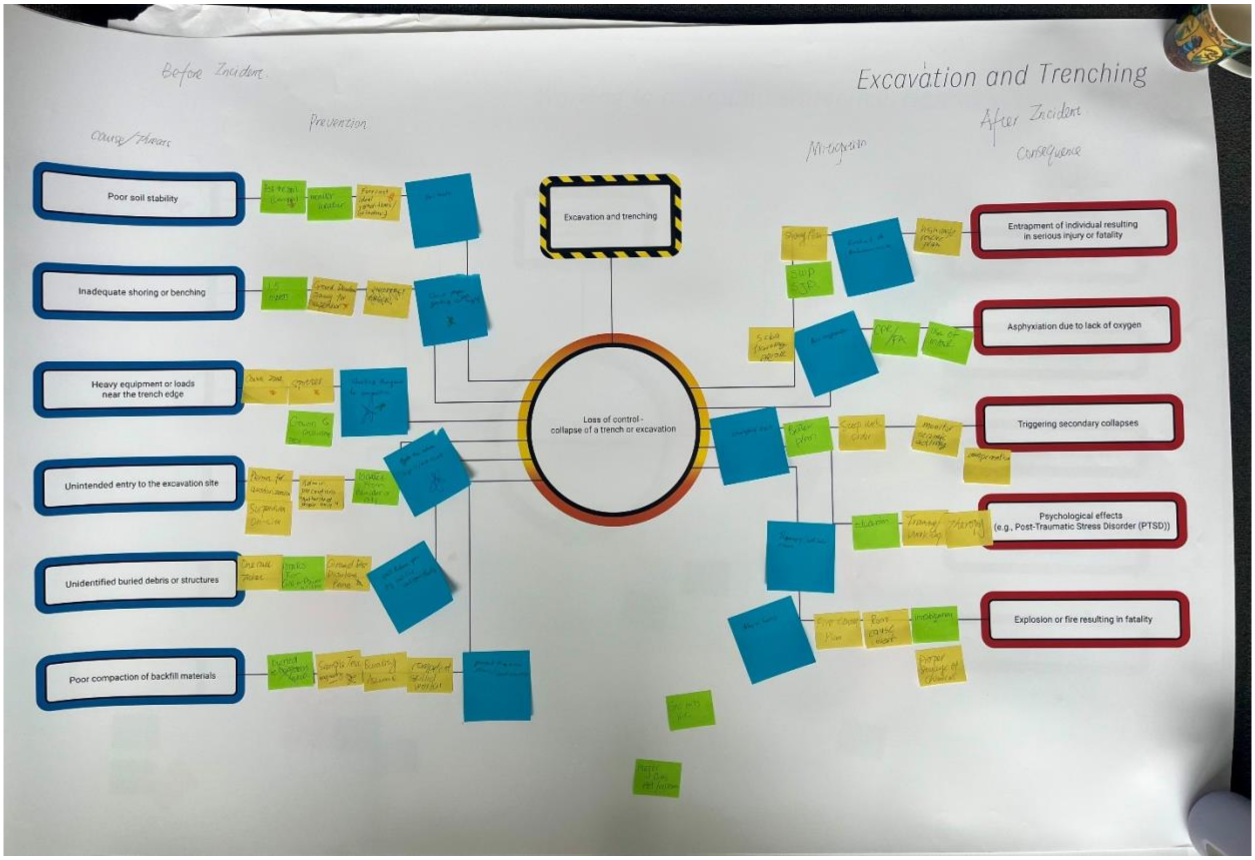


Fig 18. Sample Bowtie exercise with sticky notes for Excavations and Trenching

These bowties were then amalgamated into a single bowtie that included all subject matter experts' insights. See Fig 19 for Working on/around Water and Ice and Fig.20 for Trenching and Excavating.

Where several hazards ae present, like excavating and trenching AND water, working around mobile equipment, or dropped objects, there is value in combining bowties. This will be considered in our revision to the decision tree.

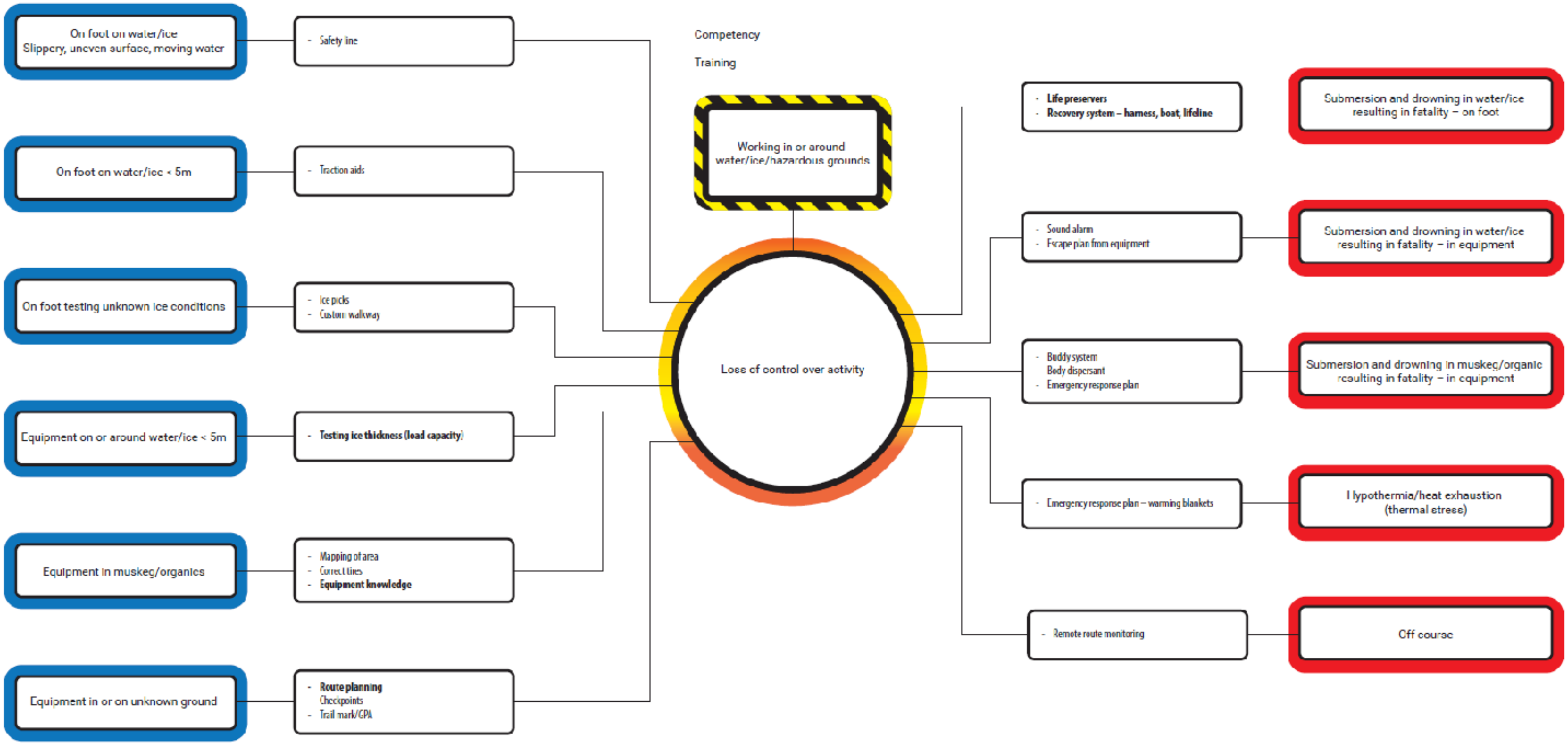


Figure 19 Bowtie for Working on/around Water and Ice

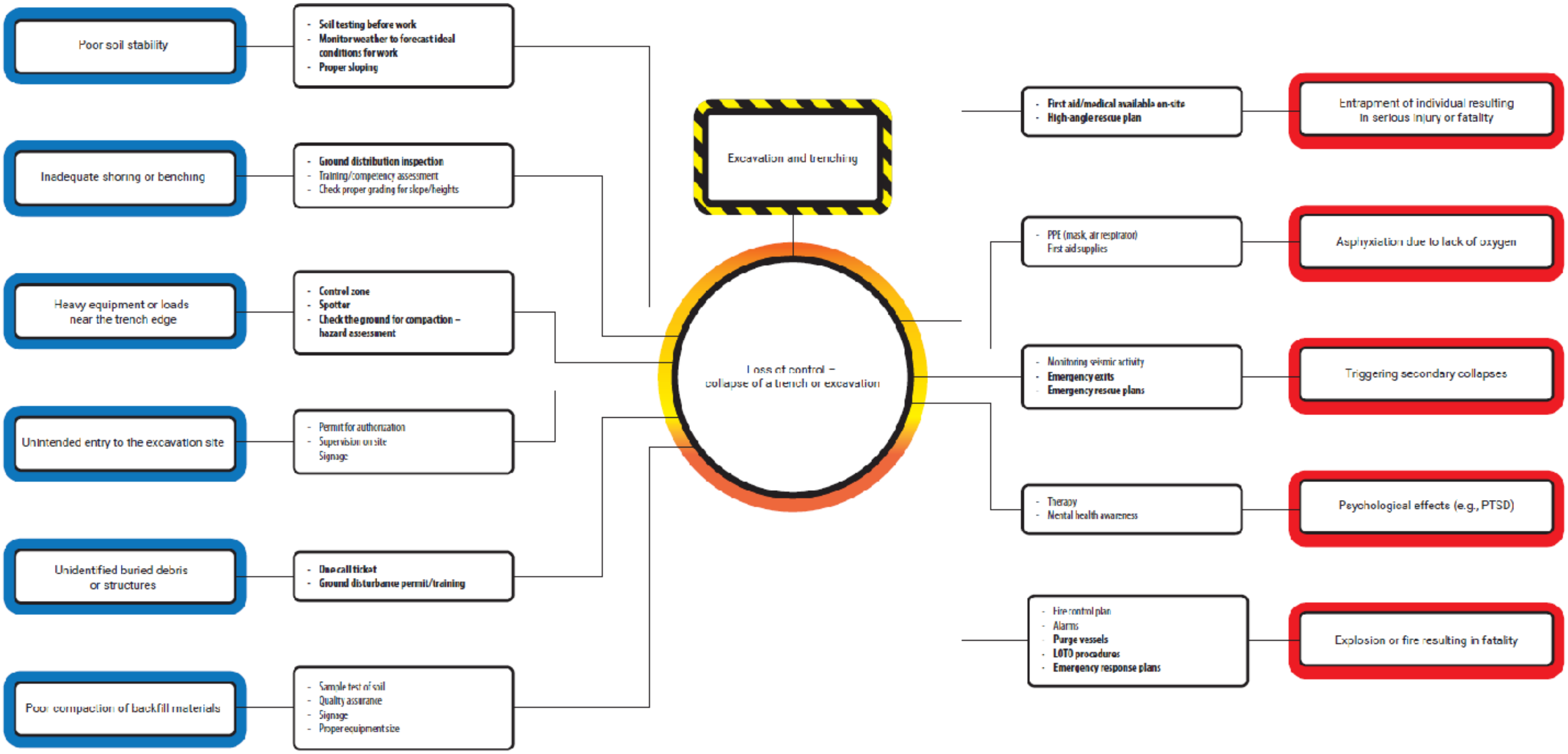


Figure 20 Bowtie for Trenching and Excavating

After the workshop, all participants from all three workshops were sent:

- A copy of the workshop slides – for participants to take back to their organizations.
- A 'business case for risk management' document – for participants whose leadership might potentially see safety as a 'cost' rather than as an investment.
- A 'bowtie primer' which describes how/when bowties could be used along with nine bowties that summarize the causes, consequences, and controls for nine major incident hazards.

Follow-up analysis will connect these bowties to the trenching/excavating best practices (Section 2) and hazard identification and human factors from the employee survey (Section 4) in a series of focus groups over the next year. This will help us to develop the mobile application (Section 5).

4. The Human and Organizational Factors of Safety: Identifying and Assessing Key Social-Psychological Predictors

Samantha Jones, Thomas O'Neill, Jessica Wilkins, Ian R. Gellatly, Lianne M. Lefsrud, Fereshteh Sattari

4.1 Summary

Accident rates in the heavy mining industry are among the highest across all sectors in Canada, with the Mining Association of Canada stating a yearly average of 2.7 fatal injuries and 269 non-fatal injuries per 10,000 employees (Mining Association of Canada, 2024). Further, trenching and excavating continues to be a factor in numerous SIF incidents (CDC/NIOSH, 2018; Yohannes et al., 2024) despite the existence of recommended policies and procedures for conducting the work safety (e.g., OHS code, WorkSafe BC). While significant progress has been made in safety science, primarily through identifying hazards and managing controls to reduce risks and consequences, the field remains overly focused on technical factors rather than human factors. This focus may stem from the ease of identifying equipment malfunctions or technical deficiencies associated with high-risk activities such as trenching and excavating. However, it may also indicate that current safety approaches are incomplete, requiring a shift towards models like the Human and Organizational Performance movement (e.g., Conklin, 2019).

Despite extensive research and efforts to improve safety, accidents, particularly those resulting in SIFs, continue to occur (Hofmann et al., 2017; Yohannes et al., 2024). Our research aims to move beyond a focus on technical factors by incorporating human and social elements. Research findings (e.g., Derdowski & Mathisen, 2023), symposium results, and conversations with experts emphasize the need to identify and measure key social-psychological factors (such as emotions, safety attitudes and norms, and psychological safety) that shape safety decisions and behaviours in the workplace, helping predict and prevent SIFs. This research will help us better understand which human and organizational factors most strongly influence employee behaviour while trenching and excavating and inform the development of tools and resources for employees conducting the work safely.

To support this objective, we are in the process of conducting research utilizing a mix of social scientific research designs and data sources. Leveraging these complimentary approaches will allow us to gain a more holistic picture of the constituent factors that lead to SIFs in trenching and excavating and consider important contextual factors and employee's personal experiences when developing resources and making recommendations.

5. An Intelligent Mobile Application to Monitor Safety of Trenching Operations

Abass Abaie, Fereshteh Sattari, and Lianne Lefsrud

5.1 Purpose

Trenching operations pose significant safety hazards, including cave-ins, equipment-related injuries, and hazardous atmospheric conditions. This study presents a novel method for enhancing safety in trenching operations by developing a customized safety evaluation decision tree for an artificial intelligence (AI)-based application. To achieve a user-friendly product, the algorithm is presented as a mobile application that analyzes the user response and returns appropriate recommendations to prevent potential risks. We will also create an electronic/laptop version and an offline paper-based version, for workers without access to mobile devices and/or wifi/internet.

5.2 Introduction

Trenching is a standard operation in mining and construction sites, involving the excavation of a specific depth for pipelines, cables, and foundations. Due to the nature of trenching, workers are at risk of severe incidents, which can result in injuries and fatalities. According to OSHA, the fatality rate of excavation work in the U.S. is 112% higher than that of general construction (Arboleda & Abraham, 2004). Furthermore, the Center for Construction Research and Training (CPWR) reported 63 fatalities across the U.S. related to trench collapses between 2011-2016 (Akboga-Kale, 2021).

Trenching accidents often occur due to unstable soil conditions, resulting in cave-ins that pose a prevalent and hazardous threat and frequently leading to serious injuries or fatalities. In addition, risks from falling objects, equipment failures, and exposure to dangerous gases pose a threat to the health of workers (Kartik, 2023). Despite the technological advancements and strict regulations, trenching incidents result in injuries and fatalities. Therefore, improving the monitoring methods requires integrating more advanced approaches into trenching safety frameworks.

Recent technological advancements have focused on AI to transform safety frameworks by reducing human errors, analyzing large amounts of data promptly, handling different input types simultaneously, and operating continuously. AI methods can be utilized to improve safety through real-time hazard detection (Javid et al., 2025), risk assessment (Banerjee-Chattapadhyay et al., 2021), automated monitoring (Mariano et al., 2024), and risk control strategies (Sattari et al., 2021). As a result, an AI-based approach is designed to evaluate the safety conditions of trenching in this study. The method utilizes natural language processing (NLP) to analyze the user's response regarding safety criteria, employing a decision tree approach as determined by experts.

Designing a straightforward user interface (UI) to introduce technologies can increase the likelihood of widespread adoption. According to Chung et al. (2023), workers are intentionally willing to utilize technology to enhance safety. Hence, the final interface of the proposed methods is implemented in a smartphone application, providing a user-friendly approach for frontline workers and supervisors to evaluate safety conditions with the assistance of AI.

In summary, this research aims to introduce a novel approach to enhance trenching safety through a mobile application. The main contributions of this study are the design of a safety evaluation decision tree based on key risk factors and the implementation of the developed algorithm in a mobile application.

5.3 Literature Review

In recent years, there has been an increasing number of studies focused on enhancing the safety of industrial operations using AI-based systems. This is because traditional safety assessment methods, such as manual inspections, can be time-consuming and prone to human error. On the other hand, AI-based systems can offer a transformative approach by leveraging techniques such as NLP and machine learning (ML) to enhance risk identification and incident prediction. This section provides a comprehensive review of existing AI-based approaches designed to improve safety in the mining industry.

To analyze historical incident reports, NLP is an effective method for extracting patterns and predicting the characteristics of future hazards. For instance, NLP can be used to extract incident patterns (Yang & Lu, 2023), identify leading indicators (Ebrahimi et al., 2021), predict injury severity (Baker et al., 2020), and estimate severity based on incident databases (Ebrahimi et al., 2023). Similarly, studies have also used this technique to categorize incident narrative reports into different mining accident types automatically (Pothina & Ganguli, 2023). NLP methods can also facilitate real-time monitoring of workplace communications, such as safety logs and maintenance reports, to identify potential risks (Zhong et al., 2024).

While NLP is effective in extracting valuable insights from textual data, ML methods offer a broader range of predictive capabilities by analyzing sensor data and other structured datasets to assess risks and prevent workplace accidents. For example, You et al. (2021) utilized an optimized support vector machine (an ML model) to identify potential risks at a mining site based on historical accident data. Their algorithm predicts the severity of incidents with an accuracy of 89%. To identify the most hazardous acts of workers on mine sites, Niu et al. (2021) utilized Bayesian networks to determine the leading indicators by analyzing risk paths. Based on the review of 22 risk factors, the mental state of workers was found to be the most influential in causing habitual violation of workplace standards, procedures, and job aids. Another study by Xu et al. (2023) identified uncertainty in the entire risk assessment process using the Decision-making Trial and Evaluation Laboratory (DEMATEL).

The application of AI in extraction operations can further expand to monitoring systems using multi-sensor data fusion (Wang et al., 2024). Developing monitoring tools for the Internet of Things (IoT) provides more features for controlling the parameters of the sites. For example, Dey et al. (2021) introduced an integration of IoT and convolutional neural networks to transmit measured data wirelessly, enabling the prediction of the miner's health quality index (MHQI) and the concentration of methane gas. In another study, Jo & Khan (2018) predicted the air quality of an underground mine through artificial neural networks. They define the mine environment index (MEI) as a combination of the most significant gases that significantly affect mine air quality.

5.4 Methodology

In this study, an AI-based method is employed to support the safety monitoring of trenching operations in the mining industry. The technique involves designing a novel decision tree based on safety protocols and NLP algorithms to assess the current site condition and integrate it into a mobile application. The following sections provide a detailed discussion of the steps.

5.5 Decision Tree

The backbone of the proposed application is the designed decision tree. Since comprehensive reviewing of safety protocols for trenching is time-consuming for supervisors, a novel decision tree has been developed in this study to identify potential risks during trenching operations.

The decision tree was designed based on trenching incident reports, and will be further developed in consultation with industry subject matter experts. The algorithm prompts the user about potential risks and provides tailored recommendations based on their responses. The supervisor uses this tree before starting the trenching as part of the pre-task plan, to detect hazards and ensure controls are in place. Additionally, it considers schematics of controls, such as shoring, to prevent hazards from occurring at trenching sites. In other words, it is an AI-integrated checklist of safety actions ensure the presence of safeguards and controls to mitigate incidents.

Fig 1 illustrates the proposed decision algorithm for addressing safety issues in trenching. From this depiction, it can be observed that the algorithm comprises two types of elements: Evaluation and Recommendation. The Evaluation elements contain questions about the current condition of the operation, and the Recommendation element provides any necessary actions that should be taken to enhance safety. To make the application more user-friendly, the supervisor responds in a yes/no format instead of providing a brief text about the condition. These kinds of answers not only make the application more user-friendly but also increase the accuracy of decision-making. The decision-making accuracy will increase since typing a report by a supervisor may not be comprehensive or may contain errors leading to incorrect decisions regarding safety issues.

The application saves the user's response in cloud storage, providing access to previous reports through their account. Additionally, the application can send a brief reporting SMS and Email to supervisors about the operation condition. These reports provide a quick overview for further manual consideration, and they serve as an alarm assistance system. The supervisor’s SMS and email information will be collected during the user registration process.

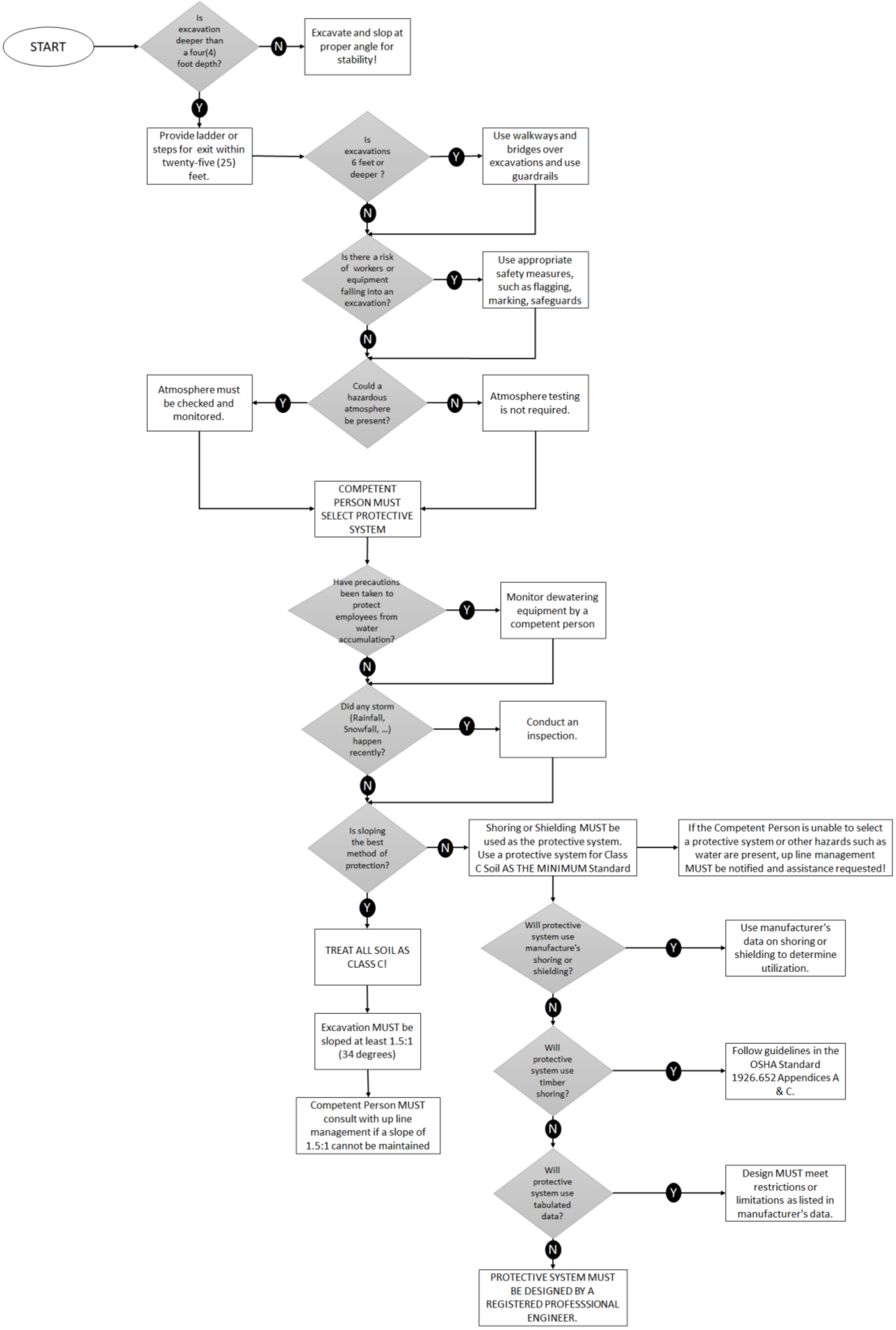


Fig 21.The novel decision tree algorithm developed for the mobile application.

Collecting the operation conditions in digital format offers numerous advantages for further safety research. Digital condition reports enable the collection and integration of real-time data with other safety systems, allowing researchers to analyze trends and correlations more effectively. These digital records can be categorized, filtered, and searched automatically, which reduces the time required for review. Fig 22 illustrates the application's interaction with the storage component to save the user's response history and notification systems.

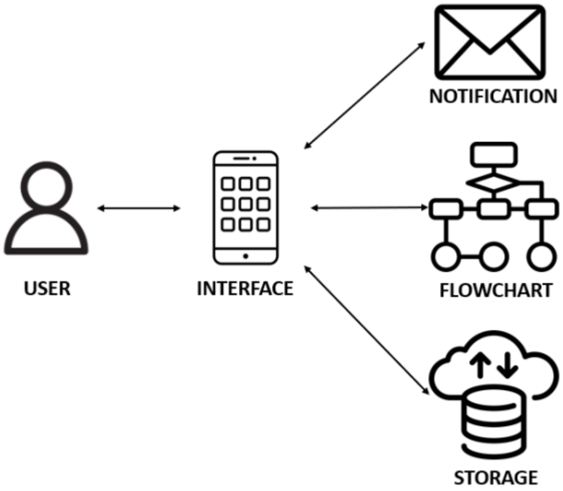


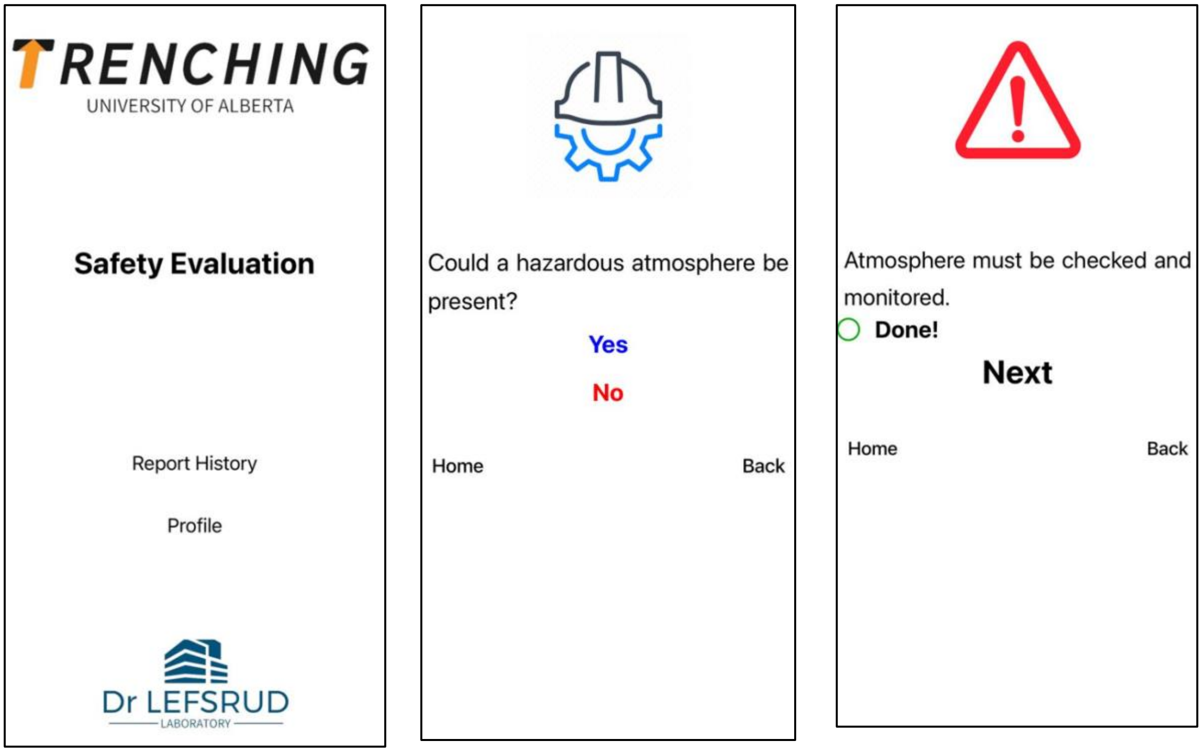
Fig 22. Interaction between various parts of the systems.

5.6 Mobile Application

Having a user-friendly interface is a significant characteristic of systems. In contrast to the complicated decision algorithm of the application, a simple and straightforward UI is effective. The front end of the application has been implemented using React Native to provide a smartphone application. Due to the popularity of mobile applications, offering a smartphone-based product reduces the training time required for the application and minimizes potential human error when using it.

After registering and logging in to the application, the home page is displayed (Fig 23a). This page includes three sections: Safety Evaluation, Report History, and Profile. The Safety Evaluation section is the heart of the application, consisting of a designed decision tree that assesses the working site's safety conditions in terms of protocols and suggests beneficial actions to mitigate risks. Selecting this option reveals the evaluation parts of the algorithm, along with the yes and no options that the supervisor should decide upon (Fig. 23b). Based on the response to the question, the application may display suggestions that include recommended parts, accompanied by a checkbox and a next button. The check box is designed to prevent it from being skipped by accident or due to distraction. As it is demonstrated in Fig. 23c, the user should check the button to pass the recommendations.

The report's History section contains all the previous reports the user has submitted in response to the questions. This feature ensures that users can access, review, and track their past responses whenever needed. Additionally, the Profile section allows users to view and update their registration information. This section includes personal information, the supervisor's email address, and the supervisor's phone number. This mobile application will be available for both IOS and Android phones, with an off-line version.



Could a hazardous atmosphere be present?

Atmosphere must be checked and monitored.

(a) (b) (c)

Fig 23. a) the Home page of the application, b) an example of the Evaluation part of the flowchart, and c) an example of the Recommendation part of the flowchart.

5.7 Conclusion and Next Steps

Enhancing safety in trenching operations is crucial to minimizing risks and protecting people on-site. This study aims to develop a mobile application that collects input from frontline staff through a structured set of yes/no questions regarding site conditions. The users can fill in and evaluate the safety checklist independently, reducing the need for numerous on-site experts and potential human errors. By leveraging real-time data, the system not only stores critical safety information but also provides automated recommendations tailored to enhance site safety. Furthermore, the proposed system makes the evaluation process for supervisors more straightforward, allowing them to remotely monitor the operational condition and trigger alarms.

The integration of this technology fosters a proactive approach to hazard identification and mitigation, ensuring compliance with safety standards while empowering workers to participate actively in risk assessment. By continuously analyzing responses, the system can help identify recurring safety issues, allowing for data-driven decision-making and targeted interventions. Moving forward, refining the system with advanced analytics and predictive safety measures could further improve its effectiveness. Additionally, designing an algorithm for operations other than trenching or excavation could be considered. Adding more sensors and actuators to an IoT board-based system can help consider additional safety issues.

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6. Conclusions and Next Steps

Over the past year, we have completed our preliminary literature review and data collection. Our geotechnical team reviewed the literature for trenching and excavating, the effect of water and weather, and the best practices to prevent a trench collapse. In workshops with construction/mining personnel, we developed a visualized 'bowtie' summary of causes, consequences, and controls for trenching/excavating and working around water/ice. These diagrams will be further enhanced with the findings of our geotechnical review and through future workshops. This will help support additional training and critical control assurance.

We surveyed workers for their perceptions of hazards and the human factors that affect their ability to recognize and control these hazards. And we have enhanced the decision tree for trenching/excavating to develop the mobile app.

In sum, we are on schedule as per our proposed deliverables:

In the second and final year of this project, we will 'ground truth' these materials with industry subject matter experts.

- How do we best use the data that we have collected to enhance safety practices for trenching and excavating?
- What (other) information do workers and their supervisors need – to make the best real-time decisions about trenching and excavating?
- How can this information be best delivered? As a mobile app? As laminated job aids? As materials to enhance a Job Hazard Assessment (JHA) or Field-Level Risk Assessment (FLRA)? As enhancements to existing training?

This will be our priority for the remainder of 2025 and early 2026, through workshops with subject matter experts, led by AMHSA.