

A COMPARATIVE ANALYSIS OF HYDRO EXCAVATION AND VACUUM TRUCK TECHNOLOGY VERSUS TRADITIONAL METHODS

Jennie Prange, Mark C. Tatum

Auburn University, Auburn Alabama, USA

Abstract

This study explores the comparative advantages of hydro excavation and vacuum truck technology over traditional excavation methods in the construction industry, focusing on environmental impact, risk management, and cost-benefit analysis. The research employs a mixed-methods approach, including case studies from recent construction projects, interviews with industry professionals, and a review of existing literature. Key findings indicate that hydro excavation and vacuum trucks minimize environmental disruption, particularly in urban and ecologically sensitive areas, by reducing soil displacement and waste. In terms of risk management, these technologies significantly lower the likelihood of utility strikes and worker injuries, enhancing overall site safety. While hydro excavation involves higher initial costs, it demonstrates superior cost efficiency in the long term, driven by faster project completion, reduced damage repair costs, and fewer environmental penalties. This study underscores the need for broader adoption of hydro excavation and vacuum truck technology to promote sustainable, efficient, and safer excavation practices in construction.

Keywords: excavation, hydro excavation, vacuum truck.

© 2025 The Authors. Published by the International Association for Automation and Robotics in Construction (IAARC) and Diamond Congress Ltd.

Peer-review under responsibility of the scientific committee of the Creative Construction Conference 2025.

1. Introduction

Construction excavation as the process of removing earth materials to create spaces required for construction activities. Excavation is a cornerstone of construction, enabling the development of infrastructure, utilities, and foundations. However, traditional excavation methods often lead to significant environmental damage, safety risks, and inefficiencies. Traditional excavation methods, such as manual digging and mechanical trenching, have been the industry standard for decades. Despite their widespread use, these methods are often associated with unintended consequences, including soil erosion, damage to underground utilities, and hazardous working conditions.

In recent years, hydro excavation and vacuum truck technology have emerged as innovative alternatives, offering a cleaner, safer, and more efficient solution. While hydro excavation and vacuum trucks have gained traction in the industry, a comprehensive analysis of their advantages compared to traditional methods remains limited. Specifically, their environmental impact, safety benefits, and cost-effectiveness warrant further exploration to guide decision-making in construction projects. This study aims to compare the environmental impact, risk management, and cost-benefit analysis of hydro excavation and vacuum truck technology versus traditional excavation methods. By examining these factors, the study seeks to highlight the potential of modern excavation technologies to transform construction practices. The following sections will explore the literature on excavation techniques, describe the methodology used for analysis, present key findings, and discuss their implications for construction practices and industry adoption.

2. Literature Review

2.1. Overview of traditional excavation

Excavation has long been a critical component of construction, employing traditional methods such as manual digging and mechanical tools like backhoes and trenchers. These methods have been in the

industry standard due to their accessibility and proven utility in various applications, including trenching for pipelines, foundations, and utilities. Manual excavation involves the use of hand tools such as shovels and picks. While it allows for precise control in small-scale projects or areas with limited access, it is labor-intensive and time-consuming. Mechanical methods utilize heavy equipment such as backhoes, excavators, and trenchers. Backhoes are versatile and widely used, backhoes combine digging capabilities with material handling, making them suitable for various excavation projects. Trenchers are designed specifically for digging narrow trenches, trenchers are commonly used for laying pipes, cables, or drainage systems.

Traditional excavation methods pose several challenges: Environmental Disruption, Safety Hazards, Operation Inefficiencies. Traditional excavation methods, such as using mechanical diggers, backhoes, and hand tools are effective for moving large amounts of earth quickly. However, they come with a set of limitations like high risk of damage to utilities, environmental impacts, and safety concerns. It often causes significant soil disturbance, leading to issues such as erosion, waste generation, and vegetation damage. Workers and communities face numerous risks associated with these methods like utility strikes, trench collapses, and equipment related injuries. Traditional methods are often slower and require more labor, which can increase project timelines and costs. Additionally, delays caused by environmental remediation or utility repairs can further exacerbate cost.

2.2. Development of Hydro excavation and vacuum truck technology

Hydro excavation and vacuum truck technology emerged as innovative alternatives to traditional excavation methods, driven by the need for safer, more efficient, and environmentally friendly excavation solutions. Hydro excavation began in the mid-20th century as a method for safely exposing underground utilities. Early systems utilized pressurized water to break apart soil, which was then removed using a suction device. These methods gained popularity in industries where precision was critical, such as oil and gas pipeline installation. Over time significant advancements have improved the efficiency and versatility of hydro excavation and vacuum trucks. This includes the development of high-pressure water systems for faster soil loosening. Integration of powerful vacuum systems capable of handling wet and dry debris. Enhanced filtration systems to separate excavated materials from reusable water, reducing waste. Modern vacuum trucks equipped with advance controls, GPS systems, and automated features for precision and ease of operation.

Hydro excavation and vacuum trucks are particularly beneficial in scenarios requiring precision, environmental care, and safety. Urban areas often have dense underground utility networks, including gas lines, water mains, and fiber optic cables. Hydro excavation allows for accurate and safe utility location without causing damage or service interruptions. Hydro excavation is extensively used for tasks such as pipeline installation, maintenance, and repair. By exposing utilities with minimal disruption, it reduces the risk of costly utility strikes. Vacuum trucks are essential for clearing debris and accessing utilities in confined spaces, ensuring a clean and safe work environment. In ecologically sensitive areas, such as wetlands or near water bodies, hydro excavation minimizes soil disturbance and prevents contamination of nearby ecosystems. Hydro excavation is adaptable to various soil types and can even handle frozen ground when heated water is used. The process creates minimal disruption to the environment, making it an ideal choice for projects where traditional excavation could cause extensive damage or where a more "surgical" approach is needed. (ACE Environmental 2023)

Hydro excavation and vacuum truck technology continue to expand in scope, offering solutions for a variety of industries and addressing challenges that traditional excavation methods struggle to overcome. This section outlines the history, technical advancements, and real-world applications of hydro excavation and vacuum trucks, positioning them as essential tools for modern construction and infrastructure projects.

2.3. Existing studies on environmental impacts, safety and risk mitigation with comparative cost analyses

Research on environmental impacts indicates that hydro excavation and vacuum excavation methods are recognized for causing significantly less environmental disruption when compared to traditional excavation techniques. They also reduce noise, dust, and vibrations, critical in urban areas or sensitive

environments. Traditional methods, such as backhoes and trenchers, often disturb ecosystems, displace more soil, and increase the risk of water contamination. Soil compaction and erosion are common issues, leading to long-term impacts on soil health and vegetation.

Hydro/Air excavation significantly improves safety by reducing the risk of underground utility strikes, which are a common hazard with traditional digging methods. Traditional techniques involving mechanical equipment can inadvertently damage buried cables or pipes, leading to safety hazards and costly repairs shown in figure 1. Traditional methods are associated with higher risks of accidents according to a 2019 Occupational Safety and Health Administration (OSHA) analysis found that trench collapses and equipment-related incidents accounted for 60% of excavation-related fatalities in the construction sector. Utility strikes are also a significant hazard, leading to costly repairs and, in severe cases, life-threatening accidents. Modern techniques like vacuum excavation are praised for their precision and reduced chances of accidental utility damage.

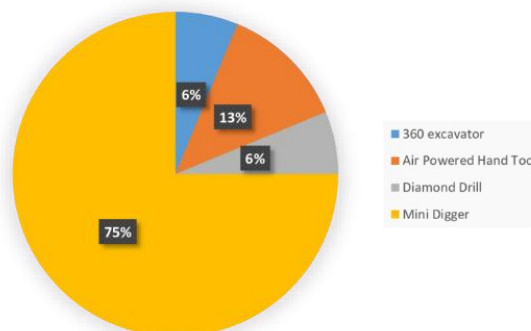


Fig. 1. Percentage of utility strikes per excavation tool.

While hydro excavation equipment can be more expensive upfront, its efficiency often translates to lower labor costs and project timelines, and we all know time is one of the biggest costs on a construction project. Additionally, avoiding damages to utilities and the surrounding environment reduces liability and long-term repair costs, making hydro excavation cost-effective in many scenarios. Its precision reduces the need for post-project remediation, contributing to long-term savings. Conversely, traditional excavation might appear cheaper initially but can incur higher indirect costs due to potential damages and longer project durations. Hidden costs, such as utility damage, environmental fines, and project delays, can significantly increase overall expenditures. For example, a 2019 industry report by the National Construction Institute estimated that utility strikes in mechanical excavation projects result in average repair costs of \$100,000 per incident. It's also noted that in 2021 there were 549 excavation safety violations worth \$2.5 million in penalties (Levelset).

3. Methodology

To evaluate the comparative effectiveness of hydro excavation and vacuum truck technology versus traditional excavation methods, this study employs a mixed-methods approach combining quantitative and qualitative analyses. The methodology is structured to address three key areas: environmental impact, safety and risk mitigation, and cost-benefit analysis.

3.1. Case Studies of construction projects and which technique was used

A case study from ACE Environmental (ACE Environmental 2023) highlights the use of hydro excavation in a contaminated soil removal project in Hagerstown, MD. The hydro excavation process enabled the team to efficiently remove impacted soil from a wetland area with minimal disruption to the surrounding vegetation, completing the task in just 12 days instead of the expected 30. This case showcases the advantages of using hydro excavation for projects requiring careful, precise work in delicate or congested areas. The site is illustrated in Figure 2.



Fig. 2. Wetland area – Hagerstown, MD, USA.

TRUVAC's vacuum hydro excavation technology has been employed across industries such as construction, oil and gas, and utilities. One such project involved a construction site where precision excavation was needed near utility lines shown in Figure 3. By using hydro excavation, the team was able to safeguard existing infrastructure, accelerating the project timeline, and reducing potential risks, while traditional methods posed a significant risk of damaging the vital infrastructure. By employing advanced hydro excavation technology, the project team executed precise digging while safeguarding the underground utilities. (Hydrodig 2023)



Fig. 3. Utilities and telecommunications.

3.2. Interviews with industry professionals

A conducive interview was completed with (L. Mendez, ECOTECH Hydro Excavation, a certified Women Owned Small Business, October 16, 2024). This interview helped me gain insight into practical applications, challenges, and innovations in the field of hydro excavation. ECOTECH's expertise provided valuable real-world context to my research. ECOTECH has two locations, Quarryville, PA, and Gaithersburg, MD. Mrs. Mendez stated the following when asked, why does ECOTECH suggest using air/hydro excavation over traditional excavation? "Water is a lubricant so it can be less abrasive to utility coatings and safer to dig around the existing utilities than traditional excavation. With water we can dig in frozen ground because the trucks we use are equipped with 5000,000 BTU boiler which heats the water, traditional excavation sometimes is placed on hold until after the winter months in northeastern states. Precise digging with water ensures minimal disruption allowing for cleaner work areas. Air has a lower operating pressure for when underground utilities are old and brittle. With air, material stays dry and can be used for backfilling or disposal immediately. Both types are ideal when access to the dig site is restricted due to overhead clearances, structural congestion, physical obstruction, narrow access road or unstable soil conditions."

The company has multiple types of trucks, the Lightweight truck which is small enough to get into the tight areas or offroad but built to have all the power of a full-size truck. This truck is light enough to haul material offsite legally and safely to disposal locations eliminating the need for a separate dump truck. (Figure 4)



Fig. 4. Ecotech's Gap Vax HV series.

The VAC Boxes (Shown in Figure 5) which sometimes are used with the trucks to help them keep working all day. The trucks pull a vacuum through the box which in turn drops the material that is being excavated directly into the box rather than into the truck. This allows for a much less expensive roll off truck to haul the material offsite and is the preferred method if the material is contaminated or if there is no available dumpsite on the project site.



Fig. 5. VAC boxes.

3.3. Hydro Excavation vs. Traditional Excavation: A Detailed Comparison

Hydro excavation is recognized for its minimal environmental impact. By using pressurized water to break up soil and a vacuum system to remove debris, this method reduces soil displacement and prevents damage to underground ecosystems. Additionally, it produces less noise and airborne dust compared to mechanical excavation. Traditional excavation methods, such as backhoes and trenchers, can cause significant soil erosion and environmental disruption. These methods often generate more debris, increase the risk of contaminating nearby water sources, and result in higher levels of greenhouse gas emissions due to the use of heavy machinery.

Hydro excavation offers enhanced safety by minimizing the likelihood of accidental utility strikes, which can lead to service interruptions, financial losses, or hazardous incidents. Its non-mechanical process reduces risks to workers, such as injuries caused by machine malfunctions or debris handling. A report by the American Society of Civil Engineers (2021) found that projects using hydro excavation had a 75% lower incidence of utility strikes. By eliminating the need for heavy machinery in confined spaces, hydro excavation reduces the risk of equipment-related injuries and trench collapses. Traditional methods carry higher risks, including accidental damage to underground utilities and increased potential for worker injuries due to manual digging or heavy machinery operation. These methods also lack the precision necessary to avoid critical infrastructure. Four deaths were recorded by Occupational Safety and Health Administration (OSHA) due to shoring in 2023, all sites utilized traditional excavation (osha.gov). OSHA has created a National Emphasis Program on Trenching and Excavation. OSHA Directive CPL 02-00-161, (October 1, 2018). It describes policies and procedures for continued implementation of an OSHA National Emphasis Program (NEP) to identify and to reduce hazards which are causing or likely to cause serious injuries and fatalities during trenching and excavation operations. (Occupational Safety and Health Administration, 2018). In this directive is states trench collapses, or cave-ins, pose the greatest risk to workers' lives.

3.4. Economic Comparison of Excavation Methods

Table 1 below shows a side-by-side comparison using 2023 rates (Northeastern US) of the exact same work utilizing an air excavation and traditional excavation method to complete a test hole to locate a gas line in blacktop in the city 6' deep.

Table 1. Side-by-side comparison.

Hydro Excavation		Traditional Excavation	
Time to Complete	2 hours	Time to Complete	7 hours
Core Drill	\$150	Saw Cut	\$75
Vacuum Truck	\$260	Minihoe and Labor	\$675
Labor to Backfill and Replace Core	\$100	Dump Truck	\$450
Material to Backfill and Replace Core	\$100	Backfill	\$250
Skid Steer	\$200	Material	\$100
		Blacktop	\$50
Total	\$810	Total	\$1,600.00

This table does not represent all cost, with hydro excavation there would be less disruption to traffic, excludes mobilization cost which most of the time is included in the hourly rental of the hydro truck. There is less fuel cost, due to less equipment needed to perform this task. With the traditional method, shoring is needed, a larger footprint is dug and must be replaced. Larger patches with a higher change of settling latter in time. To prevent damage to underground utilities, hand digging is required once a certain level is reached. This requires more manpower and more time.

An article published in digdifferent magazine September/October 2016 edition, by Cory Dellenback – showcases the need for thinking outside the box. In downtown Philadelphia the need to remove 3,000 cubic yards of fill from below a hospital for an expansion project was completed by ECOTECH. A total of 3,000 cubic yards of dirt, rocks and bricks had to be removed. The estimate from ECOTECH for the job was around \$650,000 and the bid for doing it with the manpower and drums came in at \$1.3 million, just to get the material out of the hospital.



Fig. 6. Site setup of the Philadelphia Hospital project (USA).

4. Results and Discussion

In this section, the environmental impacts, risk management strategies, cost-effectiveness, and emerging trends in hydro excavation technology are compared with traditional excavation methods. The purpose of this analysis is to provide a comprehensive understanding of how hydro excavation and vacuum truck technologies perform in terms of ecological sustainability, safety, financial implications, and their potential for future advancements. The findings discussed here offer valuable insights into the practical benefits of adopting hydro excavation methods in construction projects, particularly in terms of minimizing environmental disruption, enhancing worker safety, and improving overall cost-effectiveness.

4.1. Environmental Impact

Hydro excavation offers a more environmentally friendly alternative to traditional excavation methods by minimizing soil and ecosystem disruption. This method helps maintain soil integrity and reduces the risk of erosion, particularly in sensitive areas such as wetlands and near waterways. One of the key

advantages of hydro excavation is its efficient use of water, especially when compared to the water-intensive nature of traditional excavation methods. In comparison, traditional methods can create more debris and waste material that often requires additional disposal or cleanup efforts, leading to higher environmental management costs. Hydro excavation generally produces fewer emissions compared to traditional excavation methods. While both methods rely on mechanical equipment, traditional machines like diesel-powered backhoes contribute to higher levels of greenhouse gas emissions, air pollution, and noise. Additionally, the reduced need for extensive equipment operation in hydro leads to lower fuel consumption and overall carbon footprint.

4.2. Risk Management

According to industry data, the rate of utility strikes is significantly lower in hydro excavation projects due to the precision of the water and suction process, which allows workers to excavate around utilities safely. This reduction in damage not only saves money but also enhances worker and public safety. Hydro excavation offers several built-in safety advantages. The method uses non-invasive technology that reduces worker exposure to dangerous conditions, such as falling debris or cave-ins. The vacuum trucks also provide a safer alternative to manual excavation by removing debris quickly, thus reducing the time workers spend in potentially hazardous areas.

4.3. Cost-Benefit

Hydro excavation requires a higher initial investment due to the specialized equipment involved. The cost of a vacuum truck can range from \$200,000 to \$500,000, which is significantly higher than the initial cost of traditional excavation machinery such as backhoes or trenchers. However, the operational costs of hydro excavation tend to be more efficient in certain contexts. With traditional methods, the fuel consumption of large machines, the need for additional labor, and the higher risk of equipment breakdowns can contribute to ongoing costs. Hydro excavation, though more expensive upfront, often reduces the need for multiple equipment operators and minimizes downtime due to its precision and efficiency. The precision of hydro excavation reduces the amount of time spent correcting errors or repairing utility damage, which is common in traditional excavation. For example, hydro excavation's ability to work in tighter spaces or near sensitive utilities results in fewer project delays and faster completion times.

5. Conclusion

This comparative analysis demonstrates that hydro excavation and vacuum truck technology offer significant advantages over traditional excavation methods in construction. By minimizing environmental disruption, these modern technologies reduce soil erosion, waste generation, and damage to local ecosystems. Moreover, they enhance risk management by lowering the likelihood of utility strikes, improving worker safety, and preventing trench collapses. Although hydro excavation may involve higher upfront costs, its long-term benefits such as reduced project delays, lower remediation expenses, and improved operational efficiency make it a cost-effective solution. The findings suggest that integrating hydro excavation and vacuum trucks into standard construction practices can lead to more sustainable, efficient, and safer excavation processes. For policymakers, these technologies present an opportunity to establish guidelines and incentives that promote environmentally friendly and low risk excavation methods. Mandating the use of hydro excavation in sensitive areas or near utility lines could significantly reduce environmental and social risks associated with traditional techniques. To facilitate widespread adoption, industry stakeholders should focus on, education and training, cost management, technology integration. By embracing these technologies and addressing the remaining barriers to adoption, the construction industry can pave the way for a safer, more efficient, and environmentally responsible future.

References

- ACE Environmental. (2023). Your guide to hydro excavation. ACE Environmental. Retrieved from <https://www.aceenvironmental.net>
- Cory Dellenbach, Hydroexcavation Contractor Gets Creative on Project in Downtown Philadelphia, September/October 2016, retrieved from https://www.digdifferent.com/editorial/2016/09/hydroexcavation_contractor_gets_creative_on_project_in_downtown_philadelphia, 2024-11-03

Global Excavation Safety Conference. (2023, March 15). 2023 Global Excavation Safety Conference proceedings. Global Excavation Safety. Retrieved from <https://www.globalexceptionsafety.com>

Huadmin; TRUVAC Hydro Excavation Truck Redefines Safe Digging in California, Nevada & Arizona, HAAKER Underground Equipment; <https://haakerunderground.com/truvac-hydro-excavation-truck-redefines-safe-digging-in-california-nevada-arizona/> accessed 2024-10-25

Hydro Excavation vs Traditional Digging Methods: A comparison, 4 Warriors Hydro Excavating; <https://4warriorshydroexcavation.com/hydro-excavation-vs-traditional-digging-methods-a-comparison/> accessed 2024-10-25

Hydro-Excavation Case Study: Contaminated Soil Removal in Hagerstown, MD. ACE Environmental. Retrieved from <https://www.aceenvironmental.net>

Jet News, Hydro-Excavation White Paper published by Vactor Manufacturing, Inc, Hydro-Excavation: Digging with Precision and Safety, August 2012, 2-21

Levelset, Christopher Bokum, US Construction By the Numbers: 100+ Construction Statistice You Need to Know in 2023, November 13, 2020, updated January 19, 2023, Retrieved from levelset.com/blog/us-construction-statistics-you-need-to-know/#OSHA_Violations

OSHA, Trenching and Excavation, <https://www.osha.gov/trenching-excavation> October 20, 2024.

Occupational Safety and Health Administration. (2018, October 1). National emphasis program on trenching and excavation (Directive No. CPL 02-00-161). U.S. Department of Labor. Retrieved from <https://www.osha.gov>

Peurifoy, R. L., Schexnayder, C. J., and Shapira, A. (2010). Construction planning, equipment, and methods (8th ed.). McGraw-Hill Education, New York

Tisyn Milne, Uncovering the Benefits of Hydro Excavation, August 24, 2015, Retrieved from <https://trenchlesstechnology.com/uncovering-benefits-hydro-excavation/>, 2024-11-18

Zhou, J., Tang, Q. Zhang J., Dynamic Risk Assessment for Excavation Engineering Based on Human Factors2009 First International Conference on Information Science and Engineering, <https://ieeexplore.ieee.org/document/5455234>, October 25, 2024.