conditions can cause localized liquefaction and consolidation. Hydraulic conductivity of water-bearing strata can be estimated using grain-size correlations or measured by borehole permeability tests. Pump tests may be warranted for larger projects if highly permeable soils with significant groundwater control issues are anticipated during construction. Hydrologists that specialize in groundwater characterization for trenchless construction should be consulted if groundwater is considered a significant project risk.

Dewatering in the immediate vicinity of active pipe ramming operations can be an effective way to improve the ground and facilitate construction. However, dewatering may have unintended consequences such as increased friction on the casing, resulting in higher ramming forces because of increases in effective stress and loss of lubrication.

Potential Buried Objects The likelihood of buried objects, their nature, and relative sizes should be evaluated by the desktop study and site investigation. Pipe ramming can be stopped by buried objects in the path of the ram depending on the composition, orientation, and size of the buried object. Known objects should be avoided if possible. Examples of buried objects from past construction include foundations, old pile-supported structures, cisterns, slurry walls, drain fields, bulkheads, and wells. The potential for buried objects and an understanding of their nature should be determined early in the planning phase to minimize the risk of encountering them. To increase the likelihood of engulfing or breaking up the buried object, consider using a cutting shoe and enlarging the diameter of the casing.

Contaminated or Hazardous Ground or Groundwater Encountering soil and/or groundwater contamination has health and safety, cost, and schedule impacts on projects. Hazardous conditions can include naturally occurring hydrocarbons and asbestos. Other hazards can include naturally occurring gases such as methane and hydrogen sulfide. Careful planning, research, and execution may minimize these impacts during construction. Determination of the potential for encountering contaminants and hazardous substances should be completed during the planning phase. If contaminants are found, then determination of their nature and extent must be undertaken during the site investigation. Even if contaminants are not identified during the planning phase, the site investigations should screen for contaminants. One inexpensive approach is to sample the headspace above the samples with a photoionization detector (PID) and to record the readings. Consult an environmental professional for additional information regarding detecting the potential presence of contaminants in the ground and possible effects on the project.

Other Considerations Other important information to characterize includes environmentally sensitive surface features, biological entities, and the potential for cemented soils/caliche. Environmentally sensitive areas can include wetlands, riparian corridors, or environmentally protected areas such as a nesting habitat. In some areas of the country, environmentally sensitive areas are seasonal. It is important to understand noise, vibration, and construction windows for the project location.

Biological entities can be sensitive to pipe ramming. Examples include sensitive plants, roots, birds, small mammals, and marine animals.

Additional information about environmentally sensitive areas and contaminated soils is provided in Section 4.5.

Cemented soils and caliche are regionally specific soil concerns in arid environments. It is important to consult geologists or geotechnical engineers familiar with local geology to assess the potential for this risk.

4.2.3 Geotechnical Reports

All relevant subsurface data collected during the geotechnical desktop study and site investigations, professional interpretations thereof, and design and construction considerations should be summarized in project reports. The geotechnical data report (GDR) contains all the factual geotechnical information for the project, including explorations, laboratory and field testing results, and geophysical and historical geotechnical data. The GDR does not include interpretations or recommendations and should be included in the contract documents.

Geotechnical design memoranda and/or a geotechnical interpretive report (GIR) should be prepared to present summaries of the geotechnical data, interpretation of the data, earth pressures to be used for design, discussions of the expected behavior of the ground, and other geotechnical design recommendations such as dewatering, pipe ramming, shaft types, and support systems. Because the GIR and design memoranda are typically prepared prior to design, the information presented in these memoranda and reports with respect to the project may not be applicable to the contractor at the time of bid. These design documents should be disclosed to the bidders but are typically not provided to the bidders, nor should they be included with the contract documents.

Increasingly, another stand-alone report is also prepared, known as a geotechnical baseline report (GBR). The GBR is typically prepared with the owner's input as the design is being completed and serves as the definitive geotechnical baseline for use in the resolution of disagreements, disputes, or claims related to differing subsurface conditions. The GBR presents contractual interpretations of the data to be used for bidding and construction, as well as baseline expected behavior of the ground and other geotechnical construction considerations, such as appropriate shaft types and systems.

See *Geotechnical Baseline Reports for Construction: Suggested Guidelines* (ASCE Technical Committee for the Underground Technology Research Council 2007). The GBR should be included in the contract documents and prepared by a qualified geotechnical engineer or engineering geologist experienced in underground construction.

4.2.4 Applicability of Pipe Ramming Based on Subsurface Conditions and Classification

The information in Table 4-2 can be used to determine whether pipe ramming is an appropriate method for the identified or anticipated geotechnical conditions, or whether pipe ramming in general is a feasible method for the project.

Because pipe ramming is typically an open-faced trenchless method, it is not considered applicable for use in ground conditions that classify as flowing (according to terminology used in Table 4-1). Ground improvement (e.g., dewatering) can be implemented to change the ground classification, or modifications to the construction approach (e.g., constructed soil/sandbag plugs) can be used to reduce the risks associated with flowing ground. Similarly, squeezing ground can result in high ramming forces, which may exceed the capacity of the chosen equipment. Identification and mitigation of the risks associated with these ground types can be key to successful completion of a drive.

4.3 UTILITY SURVEYS

It is important that the locations of existing and abandoned utilities be reliably established as early as possible during planning to determine the feasibility of implementing pipe ramming. Existing utilities should be identified in an iterative manner whereby each level of survey builds on the prior study and identifies data gaps to be filled in a subsequent study. Existing utilities should be avoided, or the utility should be relocated before construction. Abandoned utilities should be identified and avoided or removed before construction.

All utility information (aerial and subsurface) should be collected in connection with the project alignment(s) and presented in accordance with ASCE 38 (2002). It is recommended that QLB and QLA utility data be obtained, especially if the utility expectancy is complex and/or risky. Note that using a *design ticket* from a state's on-call service can result in only QLC or QLD information.

During the planning and design phase, it may be possible to make changes to the pipe ram alignment and shaft locations to avoid conflict and the necessity for potentially costly and time-consuming utility relocations.

Table 4-2. Applicability of Pipe Ramming for Identified Geotechnical Conditions.

SPT N-value	Geotechnical condition	Applicability
0–1[a]	Very soft clays, silt, and organic deposits	Depends[b]
2–4	Soft clays, silt, and organic deposits or very loose sands	Yes
5–10	Medium stiff clays and silts or loose sands	Yes
11–30	Stiff to very stiff clays and silts or medium dense sands	Yes
11–30	Soil with gravels [1 to 3 in. (25 to 75 mm)]	Yes
11–30	Soils with occasional cobbles [3 to 12 in. (75 to 305 mm)], boulders (>12 in.)	Depends[c]
11–30	Soils with significant cobbles, boulders, and obstructions larger than 4 in. (100 mm)	Depends[c,d,e]
31–50	Hard clays or dense sands	Depends[e]
>50	Very hard clays, very dense sands, or rock	No

Note: In general, larger diameters have a better success rate in more complicated geotechnical conditions.

[a]Also referred to as *weight of hammer material*.

[b]The ground conditions are likely too weak to maintain line and grade.

[c]Likelihood of completion depends on diameter of the pipe as compared to the size of the buried object hit, whether the buried object can be engulfed or if the pipe hits the buried object.

[d]Pipe ram will require heavier walled casing, a robust cutting shoe, and may not achieve line and grade.

[e]Pipe ram may be able to penetrate a portion of the ground with this N-value but not for an extended distance.

If conflicts cannot be avoided, relocation plans for the utilities should be prepared. Relocation of the utilities can be done either in advance of the project or as part of the project and can be of either a temporary or permanent nature. The utility owner must be engaged as early as possible for input and review. It is beneficial to contact the local community for input and information. All known existing and abandoned utilities should be shown in the contract drawings. Information such as utility quality level, diameter, depth, pipe material type, owner, trenched cross section, and backfill material used (according to ASCE 38) should be identified, if available.

Utilities that will remain in place and are in proximity to the project may require protection and monitoring during construction. Evaluation of settlement and heave risks may be appropriate depending on type and age of the utility, clearances, and ground conditions. Real-time settlement monitoring and vibration monitoring of critical utilities may be required by the utility owner if the utility cannot be relocated.

4.4 TRAFFIC FLOW AND ACCESS FOR VEHICLES AND PEDESTRIANS

Traffic control measures taken or traffic control or calming devices installed to alert drivers or modify the overall flow of traffic should be planned and approved in advance with the agency responsible for maintaining unimpeded traffic flow and according to the Federal Highway Administration's *Manual on Uniform Traffic Control Devices* (MUTCD) (FHWA 2012).

If the proposed pipe ram alignment or shaft location affects traffic, it may be important to collect and evaluate traffic information. The traffic information can be used to determine the feasibility of implementing pipe ramming; to develop alignment alternatives; to plan shaft locations, staging areas, and drive lengths; and to develop means to minimize disruption to vehicles and pedestrians. As a general statement, pipe ramming is used as a crossing method, whereby the casing is installed perpendicular to the roadway as opposed to along the roadway. The extent of the traffic data requirements is dependent on the nature, complexity, and setting of the proposed construction. The presence of individual facilities with unique access demands (such as schools, hospitals, fire stations, post offices, distribution centers, and bus depots) must also be considered.

During planning and route selection the alternatives analysis should include the real costs and the social costs (see Chapter 3 for social cost discussion). Real cost impacts include design and construction costs. Design costs include preparation of maintenance of traffic plans. Construction costs can include traffic control and enforcement. Alternative traffic management strategies through work zones may have substantial project cost consequences. For example, if pipe ramming requires time restrictions, such as construction during off-peak hours only, the effective workday may be reduced significantly. Thus, the overall duration of project construction increases, substantially affecting project costs. Similarly, other requirements may influence the available work area during certain phases of construction, such as workspace limitations that may be caused by parallel or adjacent construction activities with potential increased project cost consequences.

For most projects, traffic impacts cannot be completely eliminated. Even when the route is fixed, the selection of shaft locations and workspaces can have a significant impact on traffic.

4.5 ENVIRONMENTAL CONDITIONS

Environmental conditions can be naturally occurring or the result of human activity. Some naturally occurring conditions are naturally occurring hydrocarbons and asbestos as well as active or dormant landslides, active erosional features, and corrosive soils. Some human-created conditions are places of historical and cultural significance as well as landfills and contaminated ground and groundwater. Environmentally sensitive areas can include

- Sources of water supply;
- Islands and island corridors;
- Beaches;
- Dunes;
- Wetlands and wetland transition areas;
- Breeding, nesting, and spawning areas;
- Migratory stopover areas;
- Wintering areas;
- Prime fishing areas;
- Migratory pathways;
- Water areas supporting submerged vegetation;
- Shellfish harvesting waters;
- Forest areas;
- Habitat for federal and state endangered or threatened plant and animal species;
- Federal and state wilderness areas; and
- Areas designated as wild, scenic, recreational, or developed recreational rivers.

Properly planned pipe ramming can reduce or eliminate the effect of construction on these environmental conditions by undercrossing the features or by scheduling construction during nonpeak hours or inside specific construction-time windows.

Existing site features that could be affected by shaft construction and pipe ramming operations should be identified during the site investigation. Historic buildings and environmentally sensitive areas usually require evaluation on a case-by-case basis to ensure protection.

Effects to the surface or the near surface environment can be reduced by locating launching and receiving shafts outside the sensitive area and pipe ramming under it. In this case, the effects are avoided by simply passing under the sensitive area. If the distance is too great for a single drive, then consider either (1) using a pilot tube for guidance, pipe ramming from two different directions, and meeting in the middle, or (2) using a different trenchless method.

For contaminated ground, if the affected area cannot be avoided during planning-level route selection, then the volume of contaminated spoils generated can be reduced by locating the shafts outside the contaminated area and then advancing the casing though the affected area. In this case, the volume of contaminated ground is reduced to the excavated casing volume. When excavating contaminated ground, always consider the total excavated volume (shafts and pipe rammed casing) in arriving at a final design.

Consult an environmental professional for assistance in development of contract requirements related to such issues as handling and disposing of the spoils, decontamination of equipment before and after construction, and personnel health and safety. The availability of contractors qualified to perform work at contaminated sites may be reduced.

4.6 FLOOD ZONES

The potential for flood hazards should be considered during design when identifying and selecting shaft locations and pipe ram alignments in low lying areas or areas prone to sudden floods, storm surges, and flash flood conditions. Designing for potential high water conditions can minimize flooding of shafts, reduce damage to pipe ramming equipment, prevent pollution from petroleum products, mitigate cost and schedule impacts, and protect personnel. In addition, locating work areas and shafts within designated flood zones may require additional permitting effort, which can delay design activities.

Assessment of flooding risk during planning should include review of information from FEMA, the National Oceanic and Atmospheric Administration (NOAA), and USACE. Such assessment should also include local knowledge to determine whether storm impacts are probable, along with expected seasonality and frequency of storm occurrence. In some locations, flooding may last for weeks and affect the project duration. The ground conditions may become saturated and can affect the shafts and ramming operation.

If flooding conditions are a significant risk, the design may need to consider the following:

- Design shafts to address the full hydrostatic pressure condition (i.e., increase pressure to the top of the shaft or plan to flood the shaft to eliminate unbalanced hydrostatic pressures).

- Design for fully saturated ground conditions.
- Temporarily raise the site grade, if permittable, to provide better access.
- Design for increased uplift that may occur during flooding or determine maximum groundwater level and method of monitoring that is allowed before flooding occurs.
- Increase pipe joint pressure ratings to accommodate installation and operational high water pressures due to flooding. Design may need to consider 10-, 50-, 100-, or even 500-year flood frequency events.
- Develop plans for evacuation and note that access roads may flood before the project site floods.
- Protect or remove sensitive equipment, oils, and fuels.
- Develop plans to protect the project site from flooding when not occupied, including weekends and holidays.
- Develop plans to monitor water levels in advance and during large rainstorm events.
- Design shafts, casings, and operations that prevent destabilization of flood control levees and embankments. Recognize that localized levee slope failures can occur during floods.
- Plan construction operations to avoid periods with a high potential for flooding (i.e., hurricane season, rainy season).
- Develop start-up plans after a flood event. Plans should include mobilization of pumps; disposal of water from the shaft; and cleanup of the surface, shaft walls, and equipment within the shaft.

In areas prone to flooding, the owner should consider including allowances or contingencies in the contract to compensate the contractor for this event, associated cleanup, and loss of time to the construction schedule. A major unexpected flood event may be considered a differing site condition. It is recommended that flood events be defined in reference to specific water surface elevation and recurrence intervals (e.g., 1 in 100 years) and the anticipated baseline conditions identified in the contract documents.

4.7 SEISMIC CONSIDERATIONS

In projects for which the rammed casing is the final carrier pipe, seismic factors (including liquefaction, embankment instability, ground shaking, fault offset, and related ground responses) should be considered. For temporary contractor designed structures such as launching and receiving shafts and for sacrificial pipe rammed casings, seismic considerations are less critical.

For permanent structures, it is also important to consider the anticipated postseismic event level of service and the consequences of failure for the pipeline or casing (i.e., flooding or gas release and fire). The seismic considerations include protection of personnel and minimization of damage from fault offset, ground shaking, landslide, liquefaction, lateral spreading, and tsunamis. Seismic experts should be consulted for design recommendations for permanent structures in seismic hazard areas.

In areas prone to seismic events, the engineer should consider the need for mitigation measures such as ground improvement, oversized casings around product pipes to allow fault offset/creep deformation to be accommodated by the casing, and placement of annular space (air or crushable material) between casing and product utility. The project could also be affected and delayed if an earthquake occurs during construction. For additional information on seismic design of pipelines, consult O'Rourke (2002) and the Technical Council on Lifeline Earthquake Engineering (TCLEE) monographs (https://ascelibrary.org/page/books/s-tclee).

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