1 INTRODUCTION

This paper provides information regarding selection, installation and bracing of various earth retention systems.

2 SHORING TYPES

2.1 Soldier Pile and Lagging System

A common method of shoring used in southern Ontario is the soldier pile and lagging soil retention system. Movements of a lagged shoring system during excavation are typically in the order of $\frac{1}{2}$”. The main components of this system are vertical steel wide flange beams known as soldier piles and horizontal timber lagging. Figure 1 illustrates a typical plan of a pile and lagged system.

The portion of the pile which extends below the base of the excavation is known as the pile toe. The depth of toe is determined based on the lateral force it is required to resist. This is a function of the height of excavation, hole diameter and the soil properties. If the pile toe will be subject to vertical load it will typically be backfilled with 20 Mpa concrete. The portion of the hole above the toe is backfilled with 0.4 Mpa lean mix concrete.

The timber lagging is installed behind the flanges of the soldier piles. Excavation for installation of the lagging is done in maximum lifts of 4 feet in conjunction with the general excavation. The backhoe excavates to 4” behind the face of the piles. The material trapped between the flanges of each pile is removed by labourers using spaders powered by an air compressor. The lagging boards are then placed horizontally between the piles starting from the base of each 4-foot lift and continuing to the underside of the bay above. The soil must have sufficient cohesion and stability to retain a vertical face until the lagging can be installed. Backfill is placed behind
SOLDIER PILE & LAGGING
PLAN
Figure 1

CAISSON WALL
PLAN
Figure 2
the lagging boards during installation. The boards are wedged in place using timber wedges. This sequence of 4-foot lifts continues until the final excavation level is reached.

A Pile and lagging system is not normally considered suitable for use alongside existing buildings or through ground conditions which will not maintain stability for a sufficient length of time to allow the timber lagging to be installed between the pile flanges. In these situations a caisson wall would be specified.

![Figure 3: Pile and Lagging braced with rock anchors.](image)

### 2.2 Contiguous Caisson Wall

This method provides a more rigid system of excavation support than a soldier pile and lagging wall and is therefore a more suitable choice adjacent to existing buildings or structures sensitive to movement. Caisson walls typically have movements less than \( \frac{1}{4} \)”. It is also specified in areas with poor or wet ground conditions where it would not be possible to install wood
lagging without loss of ground such as areas below the water table.

A caisson wall is composed of a series of vertically drilled holes which are interlocked. The designed interlock varies from 3” to 6” depending on the ground conditions and degree of water tightness required. The drilled hole diameters normally range from 24” to 36”. A steel beam or soldier pile is typically placed in every third or fourth hole. The intermediate holes are referred to as “filler holes”. All drill holes in a temporary wall are backfilled with lean mix concrete immediately upon completion. Structural concrete can be used if a permanent wall is required. Figure 2 illustrates a typical plan layout of a caisson wall.

There is a specific sequence of drilling which is normally required to achieve a proper interlock. Initially every other hole is drilled and backfilled with lean mix concrete. One to three days later the remaining holes are drilled. The timing of this last phase is normally dependant on the strength that the concrete placed in the initial drilling has attained. The strength should still be low enough to allow the infill holes to be drilled easily yet high enough that the concrete in the initial holes doesn’t cave during drilling of the infill holes. It is important to ensure that a proper interlock is formed during this final phase of drilling.

The face of the soldier piles is normally set along the line of the proposed foundation wall. The front of the drill holes will encroach beyond the line of the future foundation wall. The excavation subcontractor would remove this portion of the caisson wall during the general excavation.

A caisson wall is normally braced using tiebacks, rakers or struts. These supports can be preloaded to minimize potential movements of the shoring system.

A caisson wall can also be designed to act as a permanent load-bearing wall. In this application the drill holes and soldier piles must be designed to carry the loads of the permanent structure.
2.3 Soil Nailing

Soil nailing can be used to stabilize existing slopes or to support excavations. Closely spaced passive inclusions known as nails are installed as the excavation progresses. These nails are not pre-tensioned. They mobilize their resistance as the excavation progresses and deformation develops. In a properly designed soil nailed structure, the mobilization of nail resistance will increase soil resistance to shear.

The excavation is normally carried out in 1 to 2 metre lifts using light construction equipment. The soil must remain stable during the excavation. This requires that the soil have a certain degree of short-term cohesion and that the groundwater table be below the final excavation level.
The process of nailing normally involves the installation of driven steel sections, or the placement of steel reinforcing material within drilled holes which are subsequently grouted. Reinforced shotcrete facing may be installed immediately after excavation, or after soil nail installation has been completed depending upon the stability of the excavated soil face. After completion of each lift the sequence continues downwards until the final excavation level has been reached. Geotextile backed drainage may be placed at regular intervals and weep holes may be added during excavation if groundwater conditions warrant.

2.4  Slurry Walls

Slurry walls can be used as either cut off walls or excavation support systems. They are not commonly used in the Toronto area. A slurry wall is constructed by first excavating a trench. A slurry mixture is added as the excavation progresses to ensure that caving or sloughing of the walls does not occur. Reinforcing cages can be installed in the wall to provide a permanent support system. The system would then be braced similar to a soldier pile and lagging or caisson wall shoring system.

3  BRACING OF SHORING SYSTEMS

Shoring systems require bracing to resist the lateral loads exerted by soil pressure. Several possible methods of support are described below. If it is critical that movements of the shoring are minimized than preloading or prestressing of the bracing system can be specified. An example of where preloading would be required is adjacent to existing buildings or structures.

3.1 Tiebacks

Tiebacks are drilled at an angle to the horizontal and extend beyond the perimeter walls of the site. Therefore, their interference with subsequent construction is minimal. They can be anchored in soil or if bedrock is located sufficiently close to the base of the excavation the tiebacks could be anchored in rock. Typically rock anchors are drilled at 45 degrees (see figure 7). Soil anchors are normally drilled at 20 to 30 degrees from the horizontal.

High strength steel tendons or steel bar are placed in the drilled holes. Grout or concrete is then placed in the anchor
zone. The tieback is later post tensioned and the load locked into the shoring at the tieback connection. This process minimizes future movements of the shoring system. Tiebacks can be fabricated with corrosion protection if they are required for permanent support of the excavation.

The design of the soldier piles and the pile toes must consider the vertical component of the tieback load in the design.

Tiebacks are typically installed below roadways or on neighboring properties. As a result it is necessary for the owner of the building under construction to obtain permission for encroachment of tiebacks on the adjacent properties. It is also extremely important that a thorough investigation be completed prior to design to ensure that there are no existing utilities or structures present which may interfere with installation of the proposed tiebacks.

Figure 5: Drilling soil anchors with hollow stem auger for bracing of caisson wall.

3.2 Rakers
Rakers can be used to provide lateral support to brace a shoring system. A raker is a steel member installed at 45 degrees to the shoring. The base of the raker is seated in a concrete footing and the top is welded to a soldier pile. The steel section can be a wide flange beam or HSS steel pipe. In order to minimize interference with excavation and future construction of the structure rakers are normally installed at alternate
piles and a continuous waler is installed along the face or top of the shoring.

An earth berm is left in front of the shoring to provide temporary support until the rakers can be installed. Slots are excavated in the berm and a footing excavated at each raker location. The raker is lifted into location with a crane and is welded in place. After the concrete in the footing has reached adequate strength and the welding of the rakers and waler is complete the excavation can continue to the next level of rakers where the process of slotting the berm is repeated. The raker locations for the second row are staggered from the top row to simplify placing and handling.

There is a potential for some movement of the system to occur while the earth berm is providing support to the shoring prior to installation of the rakers. For this reason rakers are not recommended when poor ground conditions exist, as the earth berm would not provide adequate temporary support to the shoring.

![Figure 6: Pile and lagged shoring system. The left wall is braced by 2 rows of rakers with walers. The right wall is braced by 2 rows of rock anchors.](image-url)
ROCK ANCHOR SECTION

Figure 7

RAKER SECTION

Figure 8
As shown in figure 6 a raker system can severely restrict access, particularly on tight sites. This increases the cost of bulk excavation and lagging installation. The bracing also interferes with future construction and the costs of removing the rakers and walers after slabs and walls are complete can be considerable. For these reasons the majority of owners and contractors prefer to use a tieback support system rather than rakers.

3.3 Struts

Struts are horizontal steel members. They can be used to brace opposing lines of shoring or brace a line of shoring against an existing structure such as a bridge abutment. Struts are often used in subway or utility trench construction. They can be steel pipes or wide flange sections. They can be preloaded to minimize potential movements of the shoring if required.

4 DRILLING TOOLS

Drilling for soldier piles and caisson walls is normally done with an auger (figure 9). There is a cutting edge at the base of the auger. As the auger is turned the cutting edge breaks the soil and the drill spoil travels up the auger flights. After the soil fills the flights the auger is removed from the hole and is emptied by spinning. Auger design and construction varies depending on the drilling conditions it is to be used for.

Core barrels are used when it is necessary to penetrate through concrete, hard layers of rock, or obstructions. The core barrel is a cylindrical tube with hard metal teeth welded along the bottom of the tool (figure 10). As the core barrel is turned the teeth cut evenly to penetrate the layer.

It is not possible to describe all the tooling available as contractors may develop or modify tools to suit a particular task or soils condition.
5 DRILLING EQUIPMENT

Drilled shafts for shoring are normally constructed using rotary drilling equipment. The three most common types of drill rigs used in Canada are truck mounted, track mounted and crane mounted. There are various manufacturers that construct each of these rig types.

5.1 Truck Mounted Drill Rigs

Truck mounted drill rigs are economical to move between sites as they can be driven on the road. They do not require floats for transportation to the site and set up time upon arrival is minimal. The working surface must be firm and level for this machine to be used efficiently.

5.2 Track Mounted Drill Rigs

Track mounted drill rigs are moved between sites on a single float (figure 4). There is minimal set up of the machine required when it arrives at the site. This rig is an excellent choice on sites with difficult or tight access. It is very
compact. Soft working platforms are less of a problem for this machine than the other two rig types.

5.3 Crane Mounted Drill Rigs

These machines consist of a drill attachment mounted on a crane (figure 11). The various components are moved to the site using several floats and trailers. These rigs also require considerably more set up time then the other two alternatives. Due to the size of a crane mount a larger work area is also required. One advantage of a crane mounted drill rig is that it is capable of drilling large diameter holes. It is also able to lift and place liners to case the holes it has drilled. The track and truck drills often require a separate service crane to handle liners or long soldier piles.

![Crane Mounted Drill Rig](image)

**Figure 11**: Crane Mounted Drill Rig

6 INSTALLATION METHODS

The installation methods used for drilling are primarily dependent upon the soil conditions. It is very important to the
structural engineers and caisson contractors that a complete
gеotechnical investigation is completed prior to design and
tendering. This will allow development of the most cost
effective design and installation solution.

6.1 Open Hole Drilling

The simplest method of drilling occurs in dry cohesive soil
conditions. In this situation it is possible to drill an open
hole to the required depth without use of a liner or slurry to
stabilize the hole.

6.2 Lined or Cased Holes

Temporary steel liners are typically installed to stabilize the
sides of holes which must be drilled through non-cohesive or
caving materials. The hole is drilled without lining until the
wet or non-cohesive layer is encountered. If the layer is
relatively thin and is underlain by a cohesive layer the drill
rig will push an oversized liner through the wet layer and into
the cohesive layer below to provide a seal. If the layer is too
thick to allow the liner to be advanced in this manner then
other methods must be used to stabilize the sides of the shaft.
These methods are described briefly in the following sections.

6.2.1 Vibratory Equipment

A vibratory hammer is mounted on a service crane. The vibratory
hammer is connected to the top of the steel liner with “steel
jaws”. This temporary liner is vibrated through the non-
cohesive material into a cohesive soil below to provide a seal.
The larger hammers are capable of advancing liners into
weathered shale or dense tills.

Once the liner has been installed the soil within the liner is
removed by augering. The steel beam and concrete are placed in
the hole and the temporary liner is extracted using the
vibratory hammer.

In figure 12 a vibratory Hammer is mounted on a service crane.
The hammer is clamped to the top of a temporary steel liner to
advance the liner through the non-cohesive material. Two crane
mounted drill rigs are visible at the rear of the photograph.
These drilling rigs are augering inside liners that had been
previously installed by the vibratory hammer. After a liner has
been “drilled out” concrete will be placed in the steel casing
using the free fall method. The casing will then be extracted
using the vibratory hammer.
Figure 12: Installation of a contiguous caisson wall. A vibratory hammer mounted on a service crane is installing steel casing. Top portions of previously installed casings are also visible. Two crane mounted drill rigs are located at rear of photograph.

6.3 Slurry Drilling

In non-cohesive soils below the water table bentonite slurry or drilling mud can be used to stabilize the sides and base of drilled shafts.

Drilling mud is composed of a stabilizing polymer and there are several manufacturers of this product. A mix of water and drilling fluid is then added to the drill hole before the hole is advanced below the water table. A sufficient head of the water/fluid mixture should be present to ensure that collapse of
the sides of the hole does not occur when drilling continues below the water table. Additional water and drilling fluids should be added as the hole is advanced to maintain the balance of pressure below the water table. The drilling fluids increase the viscosity of the mixture and encapsulate the outer grains of sand or gravel to ensure clean removal from the hole. Flocculent can be added to the mixture to ensure rapid settling of fine silts if required. A similar procedure is used for shafts drilled using a bentonite slurry for stabilization.

After drilling is complete the concrete is placed in the shaft using tremie methods or by concrete pump. During pouring it is important to ensure that the base of the pipe is kept an adequate distance below the top of concrete to ensure that contamination of the concrete cannot occur.

7 INSTALLATION TOLERANCES AND MONITORING

The normal placement tolerances for soldier piles are plumbness to 0.5% of height and within 1.5 inches of design location at the top of pile. If the soldier piles are long or liners are required during drilling it is standard practice to set the pile line back 0.5” to 1” from the proposed outside face of wall to minimize the possibility of pile encroachment into the future foundation wall.

It is important that the face of pile is surveyed at regular intervals as the excavation progresses to allow adjustment in the lagging placement or trimming of caisson wall as required. If the pile encroaches into the proposed foundation wall the lagging is set back using timber blocking or steel angle to provide the proper wall face. Similarly if this occurs with a caisson wall the filler caissons can be trimmed back to the proper wall line.

It is standard practice to monitor shoring for potential movements on a weekly basis. Readings should be taken at the tops of piles and at each support level. Regular monitoring allows detection of any movements at an early stage. This is particularly important during winter months when frost action can severely damage a shoring system.

8 BOULDERS AND OBSTRUCTIONS

An obstruction is defined as a cobble or boulder, or any other natural or man-made object that cannot be removed using normal drilling procedures or which interferes with progress within a drilled shaft. It is impossible to accurately quantify the number of obstructions or the time required to remove them. As
a result of these unknowns it is normal industry practice to remove these obstructions on a time and material basis. Typically the owners’ site representative or the soils inspector documents this additional work in the daily reports to verify the quantities for payment. This method ensures that the owner is only charged for the actual cost of the work and that the contractor does not add a risk contingency for this item in the bid.

9 CONCLUSION

The two most commonly used earth retention systems used in Southern Ontario are soldier piles and lagging and caisson walls. The soldier pile and lagging system is less costly to install than a caisson wall, however it is not normally used to shore adjacent to existing structures or below the watertable.

A bracing system of rakers and walers can restrict access and present difficulties to the excavation, lagging and concrete phases of a project. Tiebacks result in minimal interference to other phases of the construction however; permission to encroach on adjacent properties is required for work beyond the site property lines. It is also necessary to ensure that there are no existing utilities or structures present which may interfere with installation of the proposed tiebacks.

Regular monitoring of shoring for movement is important to provide an early indicator of potential problems or overloading of the system. This is particularly important during the winter months to ensure that frost damage is not occurring.

There are several design and installation solutions possible for any shoring project. It is important to retain an experienced designer and contractor for this work to ensure that adequate protection to adjacent structures and properties is provided during construction.