

# Substructure Guidelines

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Bridge substructure types are determined during the preliminary design phase of the bridge design. There are many factors to consider when deciding on the most appropriate substructure: soil type, skew, superstructure type, vicinity of a roadway/railroad tracks, cost, etc.

This guide is intended to describe the basic types of substructures and when/where they are used.

## Foundations

In order for bridges to serve a long service life they need to be founded properly. The foundation type will depend on several factors: soil profile beneath the substructure units, bridge length, bridge type, proximity to water, etc.

Early in the design phase a geotechnical firm will perform soil borings and provide a foundations report that will recommend one or more foundation options.

The presence of solid rock near the surface may call for a spread footing keyed into the rock (or poured on an engineered fill material if the rock is a couple feet below the footing). If the rock is further down then driven Steel H-Piles, Drilled Shafts, Rock Sockets, or another pre-bore method may be needed to embed the pile into the rock layer.

In locations where rock is not encountered, Cast-In-Place Piles (C-I-P's) will likely be used.

Driven pile foundations are the most common foundation type used for Minnesota bridges. They make the bridge less susceptible to scour failures and have performed well.

It is worth noting that in the recent past there have been bridge failures due to pile corrosion below the footings. Some areas have caustic/corrosive soils and this should be noted in the geotechnical report.

### Cast-In-Place Concrete Piles

Cast-In-Place (or C-I-P) Piles are essentially steel pipes which are driven into the ground and then filled with concrete to give them additional strength/stability. The ends of the piles are typically covered with a welded steel plate or a pointed end cap depending on the anticipated soils they will be driven through. The end plate can also give them some end bearing depending on the soil type.

These piles are generally used when rock is not present. They get their bearing capacity through skin friction and/or end bearing. The presence of rock or boulders can sometimes damage the pile or redirect it and weaken the pile.

They come in several diameters and wall thicknesses depending where they are used and what loads they need to support. 12" diameter piles are commonly used in abutments, while 16" or 20" diameter piles are used in pile bent piers, where they provide additional support against ice and debris loads. Occasionally, larger diameter piles (or thicker walled piles) are used to reduce the number of piles needed for a substructure.

Since these piles are round and concrete filled, they are stiffer than Steel H-Piles, which can make them less desirable for integral abutments where flexibility of the piles is beneficial for proper function.

C-I-P Piles are also used as shells to cover Steel H-Piles in river piers, giving greater resistance and protection to ice and debris loads.

The current Division SB Spec for Steel Piling has a provision to choose either painting or galvanizing for exposed piling (such as pile bent piers).

*Additional information in the MnDOT LRDF Bridge Design Manual (BDM)*

- [Section 3 - Loads and load factors](#) (PDF)
- [Section 10 - Foundation selection criteria](#) (PDF)
- [Section 11 - Substructure detailing and design guidance](#) (PDF)

## Steel H-Piles

Steel H-Piles are H-shaped rolled beams that are driven into the ground to support structures. In the cases where rock or boulders are present they will have special pile tips welded to the end for additional end strength and facilitate driving them into rock.

They come in different sizes and thicknesses depending on what load they need to carry as well as what soil types they are to be driven into. 10" and 12" sizes are the most common and they essentially are the same width as height.

They are quite useful for integral abutments as they offer a weak axis for bending, which is desirable for that abutment type.

Please note that when rock is near the surface there may be a need for a rock socket (or other pre-bore method) to embed the pile at least 5' into the rock. The minimum pile length should be 15' minimum. For shallow rock in streams, scour depth and competency of the rock needs to be considered. Please be aware that using these short piles will affect their flexibility, so using them on longer integral abutment bridges may affect the bridge performance.

They are also commonly used for temporary bridges, as their shape is quite useful for bolting on cross members, plates, channels and other pieces used to create a bent type pier.

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## Drilled Shafts

Drilled shafts are holes bored through soil and/or rock and are filled with concrete and a reinforcement cage. They come in different diameters, ranging from 30" to 72". Sizing is dependent on the loads needed to be carried and the availability of drilling equipment.

Drilled shafts are commonly used when proposed pile lengths would be shorter than 15 feet. This usually occurs when bedrock is close to the surface. Drilled shafts are typically socketed into the bedrock.

Due the large diameters of drilled shafts, they can be a good choice for the large span bridges where the resulting live/dead loads would require a large number of driven piles. In these cases it may be more effective to use drilled shafts.

Drilled shafts attain the majority of their load capacity by end bearing, typically ending in bedrock. They are similar to the columns of a pier. They may also use side friction to attain load bearing capacity, but piles are typically used for those designs.

The use of drilled shafts has not been prevalent in Minnesota, partially due to the fact that there aren't many contractors that provide the equipment to build them. Many of our contractors have pile driving equipment and driving piles is a more efficient process for them. As a result, drilled shafts are generally more costly when compared to piling.

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## Spread Footings

Spread footings are footings that are not supported on any piles or shafts and as a result are very dependent on the soil conditions that they bear upon. The geotechnical engineer will play a greater role to determine whether the soil conditions will permit spread footings to work properly.

Spread footings have historically been used on sound bedrock and also just above bedrock using an engineered fill material. Since they are less costly and take less construction time there is a desire to use them more often. This makes the geotechnical engineering report extremely important, as there are strict guidelines for settlements that must be adhered to. The intended use of spread footings may require approval of the MnDOT Bridge Office Construction Unit.

Spread footings are generally used in box culverts and there is an increasing desire to use them more often in 3-sided structures, which can be quite large and have greater loads applied to the soil.

Spread footings near waterways must be adequately protected against scour, as they are easily undermined.

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## Abutment Types

There are 3 main abutment types used for bridges in Minnesota: Parapet, Integral, and Semi-Integral. For local bridges the most common abutment is the integral abutment.

This section will explain each abutment type and give advantages/disadvantages to each type.

All integral abutments are founded on a single row of piles (H-Piles or C-I-P Piles) and the Parapet and Semi-Integral abutment types could be founded on multiple rows of piles (H-Piles or C-I-P Piles), drilled shafts, or spread footings.

### Integral Abutments

Integral abutments consist of a stem wall supported on a single row of piles and are integrally connected to the superstructure. This allows the stem wall to flex back and forth with the thermal expansion and contraction of the superstructure.

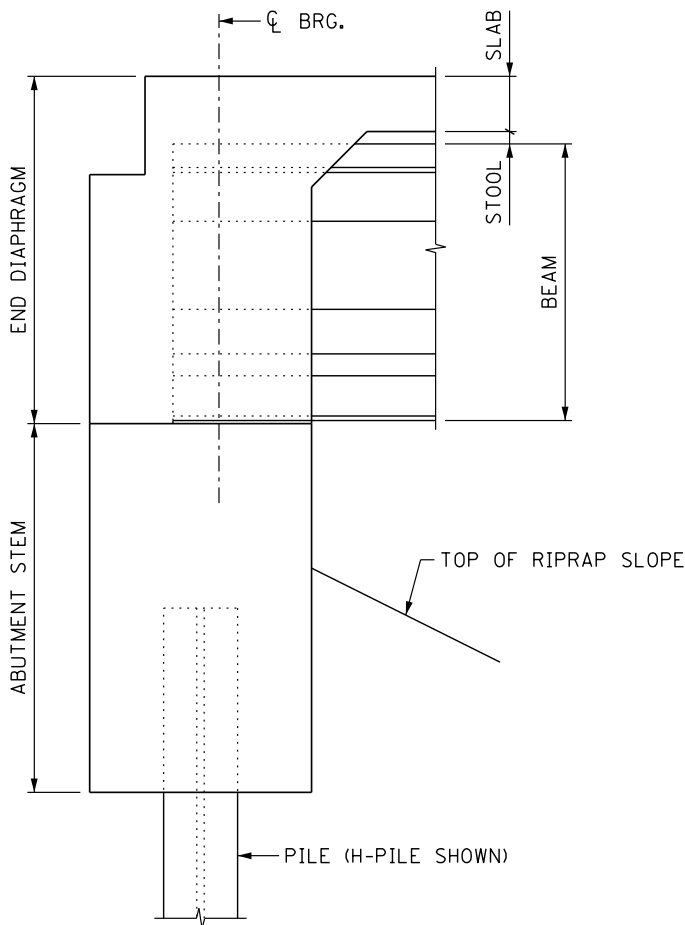
This abutment type results in a bridge that has no expansion joints in the deck, which reduces the maintenance needs for the bridge.

This abutment type also needs no footing, so there is some time savings associated with construction.

The integral abutment type is generally preferred due to its lower cost and ease of construction.

Please be advised that the soil cover (at the bottom of the riprap) can be minimal for the larger riprap classes where the riprap layer is thicker. If soil settlement occurs this could result in the piles being exposed to air, but it may not be evident because the riprap would obscure the bottom of the stem. If H-Piles are used, some counties have used short pipe pile sleeves or they have galvanized the H-Piles to help protect the H-Piles from future corrosion.

There are bridge length/skew limitations when considering this abutment type. Please consult the [MnDOT LRFD Bridge Design Manual \(BDM\), Section 11](#) (PDF) to review the design limitations of the integral abutment type.



## INTEGRAL ABUTMENT

### *Advantages of Integral Abutments*

- Easy to build and don't require footings, which saves time.
- No waterproof expansion joint is required, so this results in lower future maintenance.
- Integral abutments have a robust connection to the deck which can perform well if inundated with flood waters.

### *Disadvantages of Integral Abutments*

- Integral abutments have bridge length/skew limitations. They are not a valid abutment type for bridges longer than 300' or skews greater than 45°. Please consult the [MnDOT LRFD Bridge Design Manual \(BDM\), Section 11](#) (PDF) to review the design limitations of the integral abutment type.

- Integral bridges are not a good choice for tall abutment stems. The stem height is limited per the BDM so the passive earth pressure behind the stem doesn't exceed the design limits of the stem.

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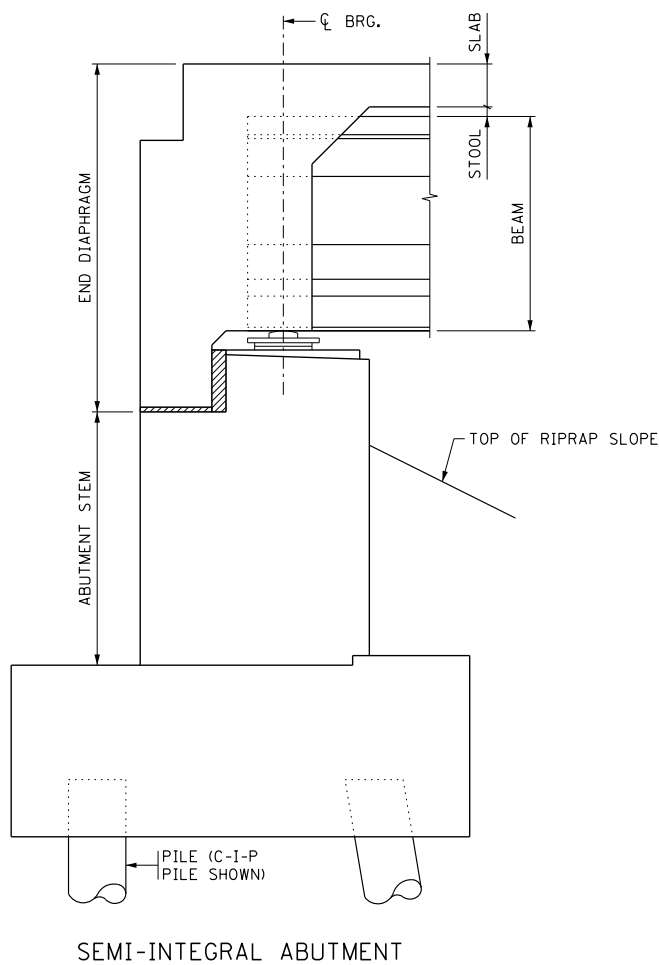
## Semi-Integral Abutments

Semi-Integral abutments consist of a bridge seat that is supported on a pile (or spread) footing. The beams/superstructure rest on bearing assemblies and there is a large concrete end diaphragm that extends below/behind the bridge seat to offer a bridge that doesn't require expansion joints in the deck.

The footing and bridge seat are solidly founded and the bridge superstructure/end diaphragm expands and contracts over the bridge seat. The approach panel is solidly connected to the end diaphragm so the expansion joint is located at the end of the approach panel.

This abutment type has no limits to abutment height, but does have bridge length/skew limits (maximum skew is 30°). Please consult the [MnDOT LRFD Bridge Design Manual \(BDM\), Section 11](#) (PDF) to review the design limitations of the semi-integral abutment type.

It would also be worth noting that bridges with a large width might need to be analyzed for lateral expansion at the wingwall joints.



### *Advantages of Semi-Integral Abutments*

- No waterproof expansion joint is required, so this results in lower future maintenance.
- Taller abutments are allowed, so these are ideal for urban locations where aesthetic treatments are warranted or span lengths need to be reduced.
- Since the bridge wingwalls are isolated from the thermal movements of the bridge, semi-integral abutments are a good choice to connect to adjacent retaining walls.
- Short semi-integral abutments can be built behind a Mechanically Stabilized Earth (MSE) wall system. This can drastically reduce the abutment height and shorten the wingwall length considerably. This will save cost in additional concrete/piles.

### *Disadvantages of Semi-Integral Abutments*

- Semi-Integral abutments have bridge length/skew limitations. They are not a valid abutment type for bridges longer than 300' or skews greater than 30° (for wingwalls parallel to roadway, or 45° for wingwalls NOT parallel to roadway). Please consult the [MnDOT LRFD Bridge Design Manual \(BDM\), Section 11](#) (PDF) to review the design limitations of the semi-integral abutment type.
- Semi-Integral abutments require footings and more piles than integral abutments.

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## Parapet Abutments

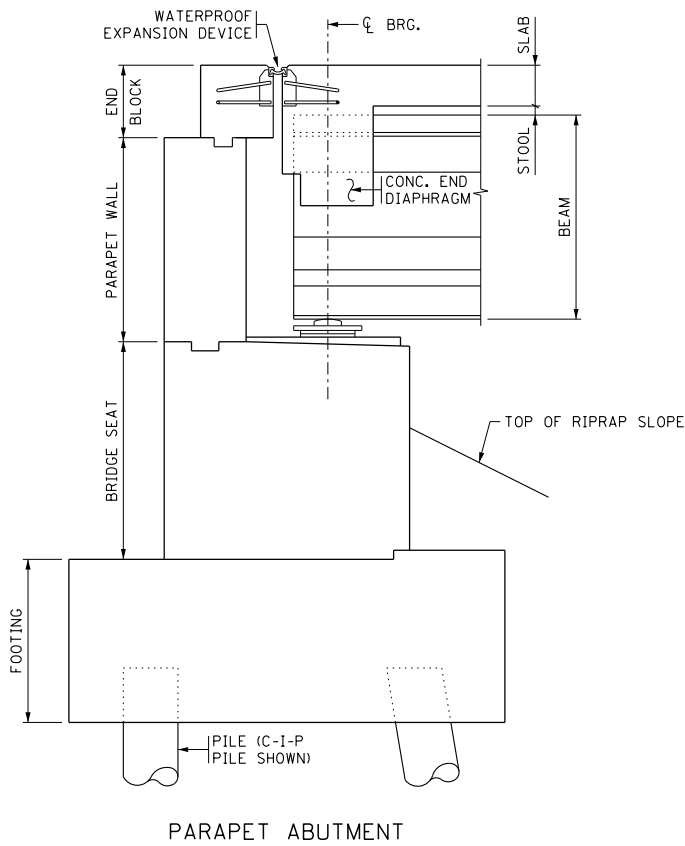
Parapet abutments consist of a footing, a bridge seat, a parapet wall, and wingwalls. The footing can be supported on two or more rows of piles or can rest on either rock or engineered fill material (spread footings). The bridge seat rests on top of the footing and includes pedestals which the superstructure rests upon. The parapet wall retains the earth behind the abutment and also interfaces with the superstructure via a concrete end block.

This abutment type requires the use of a waterproof expansion device as well as expansion bearing assemblies to handle the expansion and contraction of the superstructure.

The waterproof expansion device will require periodic maintenance (cleaning out debris and possible gland replacement) by the local authorities to ensure adequate performance.

This abutment type will allow for bridges of any length, the expansion and contraction is accounted for with the waterproof expansion device. Long bridges may need a modular expansion device, which accommodates large movements. Curved bridges or those with heavy skew may require a larger expansion device to handle twisting or racking of the gland.

This abutment type is also ideal for tall abutments, where the resulting wingwall lengths can be quite long. It is also the proper choice for bridges with a high skew angle.



### *Advantages of Parapet Abutments*

- Parapet abutments are the only choice for large skews ( $>45^\circ$ ).
- Taller abutments are allowed, so these are ideal for urban locations where aesthetic treatments are warranted or span lengths need to be reduced.
- Since the bridge wingwalls are isolated from the thermal movements of the bridge, parapet abutments are a good choice to connect to adjacent retaining walls.
- Short parapet abutments can be built behind an MSE wall system. This can drastically reduce the abutment height and shorten the wingwall length considerably. This will save cost in additional concrete/piles.

### *Disadvantages of Parapet Abutments*

- Parapet abutments require waterproof expansion joints, which will require regular maintenance.
- Parapet abutments require footings and more piles than integral abutments.

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## **Pier Types**

There are several pier types used for local bridges, with the pile bent or encased pile bent piers being the most common. Bridges that are crossing a roadway or railroad traffic will typically be multi-column or hammerhead piers.

Piers that are within 50' of high speed roadways or railroad tracks will require pier protection, per the MnDOT LRFD Bridge Design Manual (see manual links below).

This section will explain each pier type and give advantages/disadvantages to each type.

All pile bent and encased pile bent piers are founded on a single row of piles (H-Piles or C-I-P Piles) and the multi-column and hammerhead pier types could be founded on multiple rows of piles (H-Piles or C-I-P Piles), drilled shafts, or spread footings.

## Pile Bent Piers

Pile bent piers consist of a concrete pier cap supported on exposed piling, which also act as columns. There is no need for a footing as the piles serve dual functions.

This pier type is generally preferred due to its lower cost and ease of construction. There is generally no need for cofferdams or dewatering so they can be built fairly quickly.

These piers are not as aesthetically pleasing when compared to other pier types, so higher profile sites may warrant a different pier type.

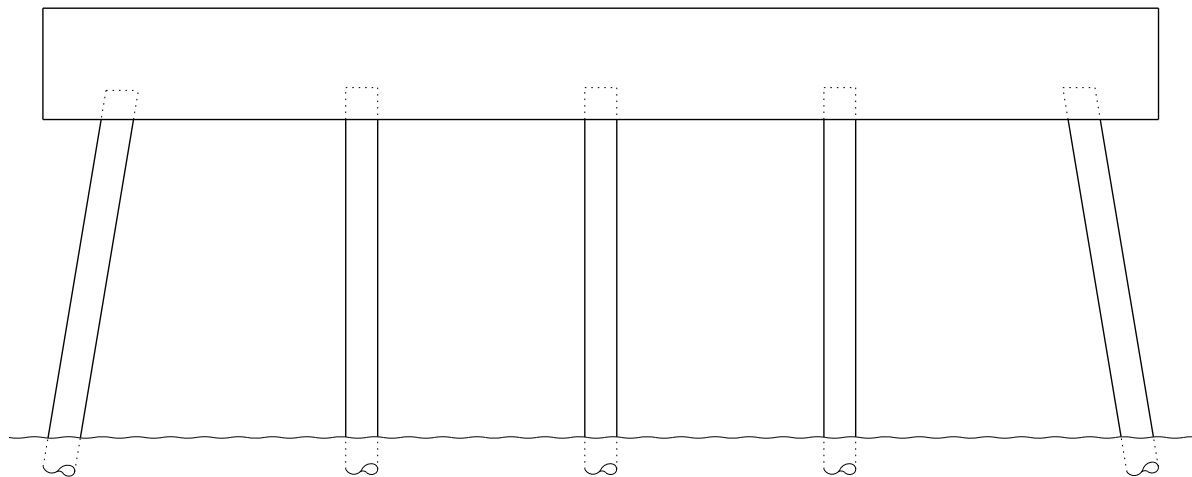
This pier type will need to meet its design limitations in order to be used. There is a maximum distance from streambed to top of pier of 20'-0" and there should be no ice or debris problem at the site.

If ice or debris problems exist at the site, then an encased pile bent pier would be the best option. In lieu of an encasement wall, it may be possible to protect the pier from ice loads by welding an ice nose (a steel angle) to the lead pile. This will require calculations to make sure the lead pile/ice nose will sufficiently withstand the ice forces on that pile, since the piles are not braced together.

Pile types are also restricted. Cast-in-place piles need to be a minimum of 16" in diameter. If H-piles are used they need to be encased in a minimum 16" (or larger if needed) diameter steel pipe shell and filled with concrete. Timber piles are not allowed.

For larger river spans, a pile bent pier may not be able to take all of the loads and a footing-supported pier may be required.

A continuity diaphragm (a concrete encasement cast around the beam ends over the pier cap) would be required if the pile bent pier piles are founded on unstable soils (such as fat clay) or the bridge spans water and there is debris problems or anticipated ice loads.



PILE BENT PIER



### *Advantages of Pile Bent Piers*

- Pile bent piers are low cost and easy to construct.
- There is usually no need for coffer dams or dewatering with pile bent piers.

### *Disadvantages of Pile Bent Piers*

- Pile bent pier heights are limited due to pile stability/flexibility issues. Calculations need to be made to ensure the pile bent meets all of the design requirements. A rule of thumb is 20' from top of pier to the streambed (accounting for scour). Pile diameters can be increased to help with this issue, but would still need to meet design requirements.
- Pile bent piers are not as aesthetically pleasing when compared to other pier types, so higher profile sites may warrant a different pier type. It may be adequate to use an encasement wall with an aesthetic form liner to achieve a desired effect.
- Pile bent piers are susceptible to debris and ice loads and must meet the design requirements for these load cases. Installing an ice nose (a metal angle welded to the lead pile) may be adequate for ice loads, otherwise a different pile type may be warranted.
- Pile bent piers are more susceptible to debris collection.
- Pile bent piers may not be adequate for longer spans, where the loads are greater.

### *Additional information in the MnDOT LRDF Bridge Design Manual (BDM)*

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### **Encased Pile Bent Piers**

Encased pile bent piers are essentially an exposed pile bent pier with an encasement wall encapsulating the exposed piles. This solid wall will provide stability and reduce debris snagging. The wall usually extends from the pier cap to the channel bottom. The wall will only need temperature reinforcement, as it just serves as an encasement to the piles.

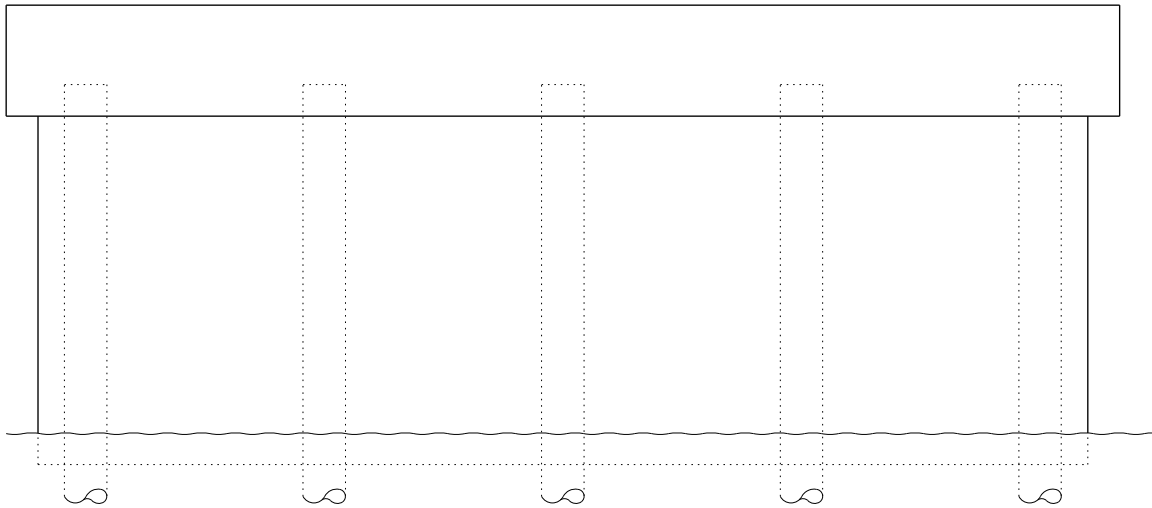
There is no need for a footing as the encased pile wall serves dual functions.

This pier type (when compared to a footing-supported pier) is generally preferred due to its lower cost and ease of construction. There is generally no need for cofferdams (but some dewatering can be required) so they can be built fairly quickly.

The encasement wall could have aesthetic treatments applied to it, resulting in a pleasant appearance and reduced cost when compared to the other pier types.

Since this pier type is essentially a pile bent pier, it will need to meet all of the design criteria for pier height, stability/flexibility/etc.

For larger river spans, an encased pile bent pier may not be able to take all of the loads and a footing-supported pier may be required.



ENCASED PILE BENT PIER

### *Advantages of Encased Pile Bent Piers*

- Encased pile bent piers are generally lower cost and easier to construct than footing-supported pier structures.
- Encasement wall can be built with aesthetic treatments for a pleasing look.
- Encasement wall will help with river debris and ice loads.

### *Disadvantages of Encased Pile Bent Piers*

- Encased pile bent pier heights are limited due to pile stability/flexibility issues. Calculations need to be made to ensure the pile bent meets all of the design requirements. A rule of thumb is 20' from top of pier to the streambed (accounting for scour). Pile diameters can be increased to help with this issue, but would still need to meet design requirements. The encasement wall should not be considered when designing for the pile stability/flexibility.
- Encasement wall forms are not meant to need cofferdams (but some protection may be needed), etc. In some cases it may be prudent to provide a foundation preparation pay item to allow for wall construction.
- Encased pile bent piers may not be adequate for longer spans, where the loads are greater.

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## Multi-Column Piers

Multi column piers consist of a concrete pier cap supported on 2 or more square or round concrete columns. The columns rest upon a footing. The footing can be supported on two or more rows of piles or can rest on either rock or engineered fill material.

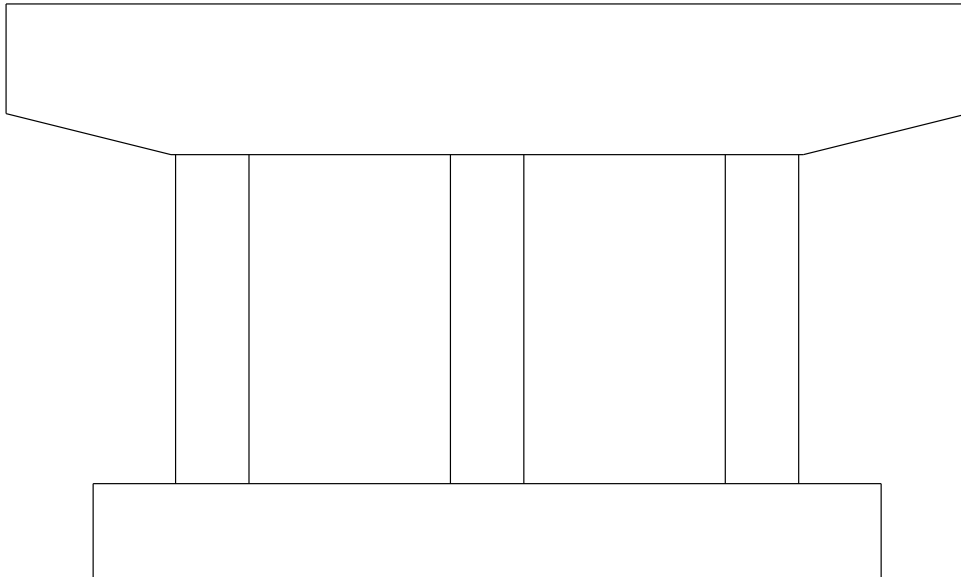
This pier type is typically used for tall piers, as well as long spans where the loads are greater. When built in rivers, there is a need for cofferdams, concrete seals, and dewatering. Hammer head piers (which feature a single large

column) may be a logical choice for river piers because of less chance of debris snagging and can provide additional strength against ice loads.

These piers are considered more aesthetically pleasing when compared to pile bent pier types, so they are also a good choice for high profile sites. They can be formed into any multitude of shapes and can have aesthetic treatments as well.

These piers are more expensive than pile bent piers and require longer construction periods. As a result, they are generally used in larger bridges and in high profile sites.

Piers that are within 50' of high speed roadways or railroad tracks will require pier protection via an approved concrete barrier or strut, per the MnDOT LRFD Bridge Design Manual (see manual links below).



MULTI-COLUMN PIER

#### *Advantages of Multi-Column Piers*

- Multi-column piers are ideal for larger span bridges and bridges over roadways, railroads, etc. (where pier protection may be needed).
- Multi-column piers can be built to meet aesthetic guidelines for projects.
- Multi-column piers may be the best choice when large ice loads or scour issues are present, but may need a strut or full height wall for better protection.

#### *Disadvantages of Multi-Column Piers*

- Footings are required for multi-column piers, which means that cofferdams, concrete seals, and dewatering will be needed for river piers.

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## Hammer Head Piers

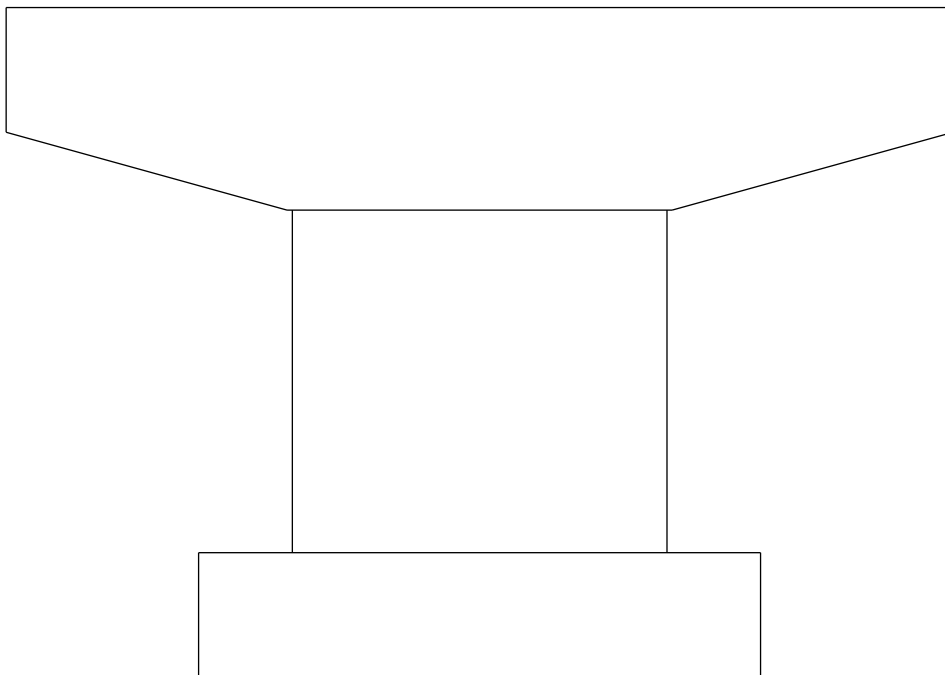
Hammer Head piers consist of a concrete pier cap supported on a single column. The column rests upon a footing. The footing can be supported on two or more rows of piles or can rest on either rock or engineered fill material. Since it's a single column, they can be quite wide depending on the bridge width.

This pier type is typically used for tall piers, river piers where ice and debris problems exist, as well as long spans where the loads are greater. When built in rivers, there may be a need for cofferdams, concrete seals, and dewatering.

These piers are considered more aesthetically pleasing when compared to pile bent pier types, so they are also a good choice for high profile sites. They can be formed into any multitude of shapes and can have aesthetic treatments as well.

These piers are more expensive than pile bent piers and require longer construction periods. As a result, they are generally used in larger bridges and in high profile sites.

These piers may require protection from railroad or high speed roadway traffic via a concrete barrier, or may need to be designed for a heavy impact.



HAMMER HEAD PIER

### *Advantages of Hammer Head Piers*

- Hammer Head piers are ideal for larger span bridges and bridges over roadways, railroads, etc. (where pier protection may be needed). The large single column can often meet the design guideline for pier protection.
- Hammer Head piers can be built to meet aesthetic guidelines for projects.
- Hammer Head piers may be the best choice when large ice loads or scour issues are present.

### *Disadvantages of Hammer Head Piers*

- Footings are required for Hammer Head piers, which means that cofferdams, concrete seals, and dewatering will be needed for river piers.

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