



22-1 SOUNDWALL DESIGN CRITERIA

I. Introduction

In recent years, the vast majority of soundwalls built in California have been concrete masonry. In July of 2003, Reference Specification 51-561(51SWAL) was created to provide alternatives to the State designed masonry block wall. Alternative Noise Barrier Designs is covered in 1102.5 of the Highway Design Manual (Rev. 6).

II. Loads

The following criteria shall be used when designing soundwalls. Wind loads are taken from the AASHTO *Guide Specifications for Structural Design of Sound Barriers*. Seismic loads, except on bridges, were determined using the 1997 Uniform Building Code (Equation 30-5).

Wind Load

Soundwalls on ground;

958 Pa (20 psf) for $H < 4.88$ m (16 ft);

Soundwalls on traffic barriers on foundation;

1293 Pa (27 psf) for $H < 4.98$ m (16'-4" ft);

Soundwalls on retaining walls;

1580 Pa (33 psf) for $H < 4.98$ m (16'-4" ft);

Soundwalls on bridge structures;

1772 Pa (37 psf) for $H < 4.37$ m (14'-4" ft);



Seismic Dead Load

0.57 dead load, except on bridges.

2.0 dead load, on bridges

III. Load Combinations

The following groups represent various combination of loads to which the soundwall structure may be subjected. Each part of the structure and its foundation shall be proportioned for either: Groups 1, 2 or 3; or Groups A, B, C, D or E — as they apply.

Working Stress Design (WSD)	Percentage of Unit Stress
Group 1: D + E + SC	100%
Group 2: D + W + SC + E	100%
Group 3: D + EQD/1.4 + E	100%

Where:

- D = Dead Load
- E = Lateral Earth Pressure
- SC = Live Load Surcharge
- W = Wind Load
- EQD = Seismic Dead Load

Load Factor Design (LFD)

Groups with Load Factors

- Group A: $(\beta \times D) + 1.7 E + 1.7 S$
- Group B: $(\beta \times D) + 1.7 E + 1.3 W$
- Group C: $(\beta \times D) + 1.3 E + 1.0 EQE$
- Group D: $(\beta \times D) + 1.3 E + 1.0 EQD$
- Group E: $(\beta \times D) + 1.1 E + 0.85 (EQE + EQD)$



- Where:
- β = 0.9 or 1.2, whichever controls in Design
 - D = Dead Load
 - E = Lateral Earth Pressure
 - SC = Live Load Surcharge
 - W = Wind Load
 - EQE = Seismic Earth Load
 - EQD = Seismic Dead Load

The Strength Reduction Factors, f

Reinforced Concrete:

For Flexure $\phi = 0.90$

For Shear $\phi = 0.85$

Concrete Masonry Units:

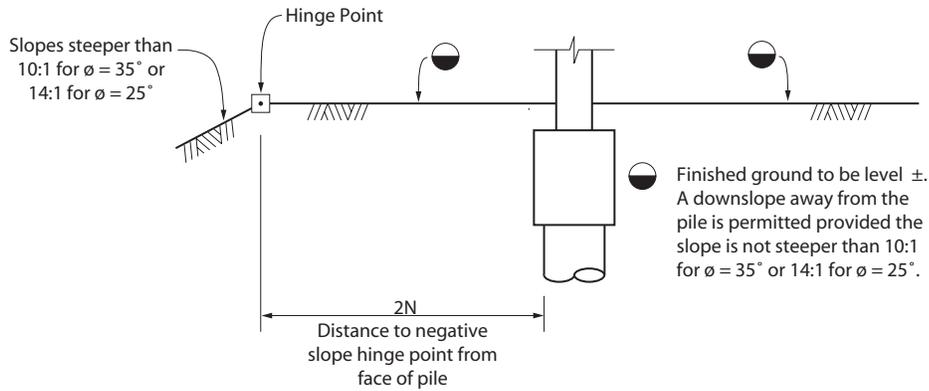
For Flexure $\phi = 0.80$

For Shear $\phi = 0.60$

IV. Foundation Design

The allowable vertical soil bearing capacity, the soil properties to be used in calculating the lateral soil bearing values and other pertinent foundation data will be shown in the foundation report that is provided by the Geotechnical Services Branch of the Transportation Laboratory.

The two ground conditions that are considered in the analysis are: Case 1 – Level ground on both sides of the soundwall and Case 2 – Level ground on traffic side of soundwall and sloping ground (1:2 maximum) on opposite side. A level ground condition is defined as one in which the ground surface is approximately level or, when sloping down and away from the pile, is not steeper than 10:1 for $\phi = 35^\circ$, 12:1 for $\phi = 30^\circ$, or 14:1 for $\phi = 25^\circ$. A level ground condition may also be assumed when the hinge point of any adjacent negative slope is located not closer than 2 times the pile embedment. Figure 5 illustrates the parameter for the level ground condition.



Note: If the location of the slope hinge point is less than 2N, the level ground condition *cannot* be used.

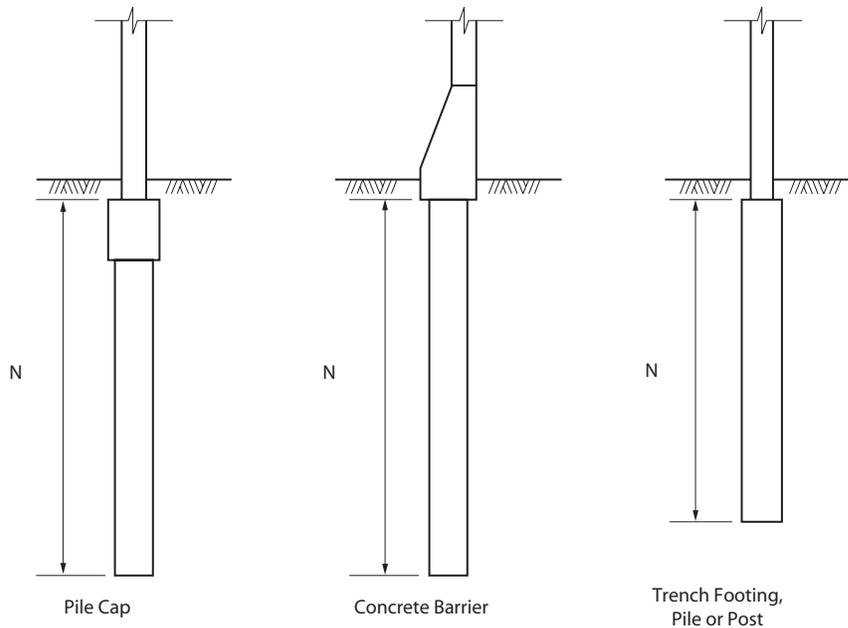


Figure 1 Criteria for Level Ground

There are two failure modes that must be considered in the design of soundwall foundations. The first, 'EXTERNAL STABILITY', is the entire structure either overturns or slides while the structural integrity of the soundwall and the footing remains intact. This scenario shall be considered using service loads (WSD) as shown in Section II: Load Combinations with the appropriate factor of safety. The second, 'INTERNAL STABILITY', is a flexural and/or



shear failure of the footing or piles. This scenario shall be considered using Strength Design (LFD) with factored loads as shown in Section II: Load Combinations. Footings shall be designed for flexure and shear by the strength design method using the maximum of the factored loads or 1.25 times the flexural capacity of the soundwall.

The ground line shall be at the same elevation on both sides of the soundwall for the Spread, Trench and Pile Cap Foundations. The soundwall shall not be used to retain earth. Therefore, no Lateral Earth Pressure, Live Load Surcharge or Seismic Earth Load need be considered. The soundwall on Concrete barrier is allowed to retain soil up to 1.2 m (4 ft.), and all lateral loads must be considered.

A. Spread Footing

Spread Footings shall be designed for 'EXTERNAL STABILITY' using service loads (WSD) with a factor of safety of 1.5 for overturning and 1.2 for sliding. Unless the Soundwall Foundation Recommendations state otherwise, the maximum bearing pressure at the toe of the footing shall not exceed 71.8 kPa (1500 psf). The eccentricity of loading, calculated as the ultimate moment using factored loads divided by the axial load, shall be limited to 3/8 of the footing width in accordance with Bridge Design Specifications 4.11.4.2.5.

B. Trench Footing

Trench footing embedment lengths for 'EXTERNAL STABILITY' shall be determined using the U.S.S. Steel Sheet Piling Procedure (Section 16 of the Bridge Design Aids). The allowable net lateral soil pressures shall be 67% of the ultimate passive pressure based on a log spiral analysis assuming cohesionless soil. A safety factor for overturning, calculated as the resisting moment divided by the overturning moment, shall not be less than 1.5. The maximum moment for 'INTERNAL STABILITY' shall be calculated at the point of zero shear in the footing.

C. Pile Cap Foundation

Piles located on slopes *are* to be protected by a berm. The berm should have 305 mm minimum width and provide 152 mm minimum depth of cover above the top of pile or pile cap.

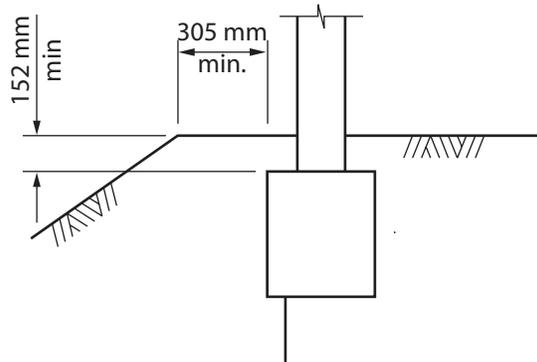


Figure 2

Pile Embedment

Pile embedments are to be determined by structural analysis. Pile embedment lengths for 'EXTERNAL STABILITY' may be determined using the U.S.S. Steel Sheet Piling Procedure (Section 16 of the Bridge Design Aids). The analysis is based on the assumption that the pile is relatively stiff. Therefore, the depth of pile embedment should be limited to 12 times the pile diameter. The allowable net lateral soil pressures shall be 67% of the ultimate passive pressure based on a log spiral analysis assuming cohesionless soil. The 'EFFECTIVE' passive pressure is the allowable net lateral soil pressure multiplied by the 'ISOLATION FACTOR', which is a means to account for the assumption that a laterally loaded pile is resisted by a section of earth that is wider than that of the pile. The 'ISOLATION FACTOR' for level ground is 3.0 and for sloping ground is 2.0. A safety factor calculated as the resisting moment divided by the overturning moment shall not be less than 2.0. The maximum pile moment for 'INTERNAL STABILITY' shall be calculated at the point of zero shear.

There are spreadsheets available for determining soundwall pile embedment lengths. See the soundwall technical specialist for information on these spreadsheets.

Pile Design

Although a study of the interaction diagrams for laterally loaded soundwall piles indicated that they behaved more as flexural members than as compression members, it is strongly recommended that those portions of the UBC, ACI and AASHTO codes dealing with compression members subjected to lateral loads be used for pile design. The three codes



have similar requirements for design in seismic areas where the probability of major damage during an earthquake is high.

Piles must have the capacity to take the applied shear that is generated by the lateral loads. It can be assumed that the spiral reinforcement will serve as the transverse or lateral reinforcement required by the codes. The total shear capacity of the pile can be based on the combination of the resisting values of the concrete and the spiral shear reinforcement. The recommended minimum spiral for shear is MW55 at 150 mm pitch. It is further recommended that the spiral be adequately supported by a minimum of six longitudinal bars and that the minimum bar size be #13. The size of the longitudinal bars should be as required to provide the needed flexural capacity.

The interaction diagrams in *Bridge Design Aids*, page 16-9, may be used for determining the longitudinal pile reinforcement. Note that there are two sets of diagrams. Each set is based on a different ultimate concrete strength. Currently, all soundwall piles are required to have a $f'_c = 22.4$ MPa. The production computer program YIELD may be used for the design of soundwall piles.

D. Soundwall on Concrete Barrier

In general, soundwalls are not used to retain soil. The only exception is when the soundwall is on a concrete barrier. Soundwalls on Concrete Barriers shall be designed similarly to Pile Cap Foundations except the following lateral loads need to be considered.

Earth Pressure

577 kg/m³ equivalent fluid pressure except a pressure of 433 kg/m³ shall be used to obtain maximum loads on heels of wall footings. When highway traffic can come within a distance equal to one-half the height of the retained soil, the pressure shall be increased by adding a live load surcharge equal to not less than 610 mm of earth except that no live load surcharge shall be combined with seismic loads.

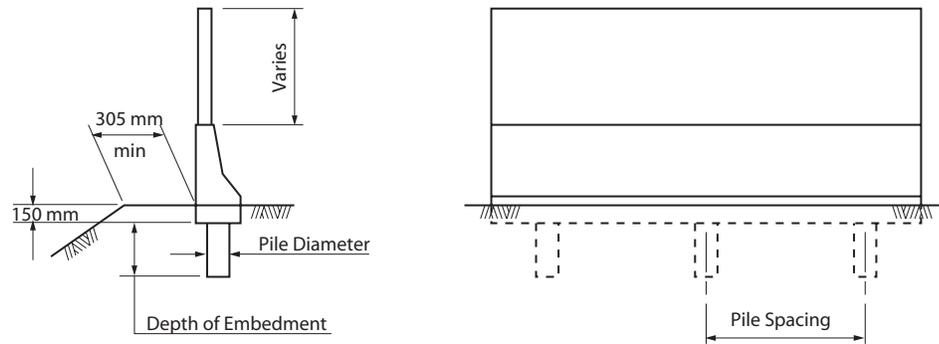
Seismic Earth Load

For those soundwalls that are also used as earth retaining structures, add the seismic load of the soil being retained. The most frequently used method for the calculation of the seismic soil forces is the static approach developed by Mononobe and Okabe. The Mononobe–Okabe analysis is an extension of the sliding wedge theory, which takes into account the horizontal and vertical inertia forces acting on the soil. The analysis is described in detail in the publication *Design of Earth Retaining Structures for Dynamic Loads*, Seed, H. B.

and Whitman, R.V. (1970), ASCE Specialty Conference – Lateral Stresses in the Ground and Earth Retaining Structures.

Traffic Impact Load

It will not be necessary to apply traffic impact loads to soundwalls unless they are combined with concrete safety shaped barriers. The foundation systems for those soundwall and barrier combinations that are located adjacent to roadway side slopes shall not be less than what is required for the traffic impact load alone. The minimum foundation requirements shall meet or exceed the following minimum foundation requirements which were developed from results of crash tests. The test results are contained in Research Report No. M & R 36412.



Pile Diameter	Minimum Depth of Embedment	Maximum Pile Spacing	Minimum Pile Reinforcement	Spiral Pile Reinforcement
304 mm	1220 mm	3000 mm	#19 tot 7	MW25 @ 150 mm
356 mm	1220 mm	3000 mm	#19 tot 6	MW 25 @ 150 mm

Figure 3a Barriers with Pile Supports

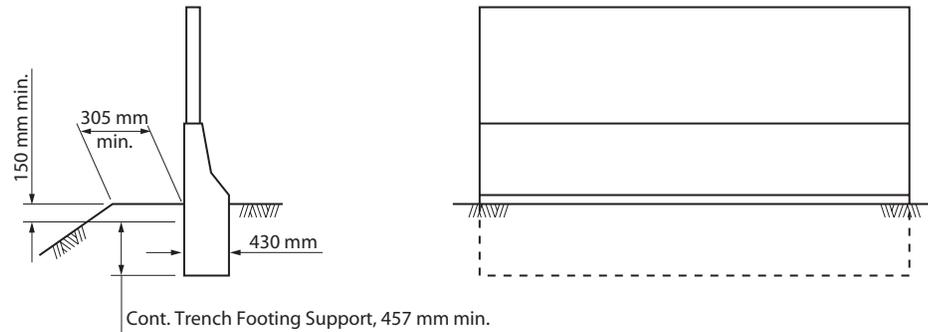


Figure 3b Barriers with Continuous Trench Footing Support

V. Soundwall Design

A. Soundwalls on Ground

Walls placed directly on the footing (ie spread, trench, pile cap) are permissible only when the wall is located outside the vehicle recovery zone as defined in the Highway Design Manual. Since there is room to make repairs, these walls may be designed using the strength design method (LFD).

B. Soundwalls on Concrete Barriers

Whenever soundwalls are placed on top of Concrete Barriers, the soundwall shall be verified by a TL 3 crash test as defined in NCHRP Report 350 or satisfy the Impact Criteria shown in Figure X.

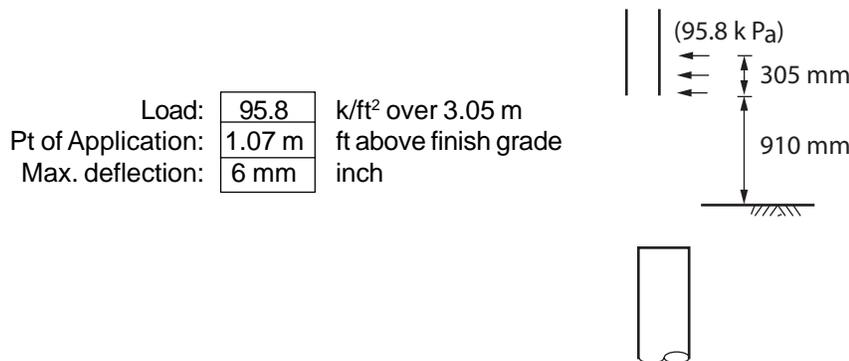


Figure 4. Impact Criteria for Soundwall on Concrete Barrier

C. Soundwalls on Retaining Walls

Soundwalls on Retaining Walls adjacent to pedestrian traffic shall meet the requirements of TL 4 crash test as defined in NCHRP Report 350 or an equivalent test method. The walls and foundation of Standard Retaining Wall Types 1, 1A, 2, 3, 4 and 5 can be considered to withstand the traffic impact load that is transmitted to the wall from the barrier. The walls and foundations will, however, have to be investigated for soundwall loading using the appropriate soundwall group loads.

D. Soundwalls on Bridges

Whenever soundwalls are placed on top of Concrete Barriers on bridges, the soundwall shall be verified by a TL 4 crash test as defined in NCHRP Report 350 or an equivalent test method. Walls must be designed not only to ensure the safety of the vehicle occupants but also prevent falling debris. Each masonry block on bridges must be reinforced and the lower 2440 mm (8 ft.) of blocks should be fully grouted with bond beams at 610 mm (2 ft.) on center (see Figure 2). To control the load that is on the bridges, a maximum mass of the block should be included in the specifications. If the design weights listed in MTD 22-55 are used, the mass of the nominal 203 x 203 x 406 (8 x 8 x 6") masonry unit must not exceed 17.2 kg (38 lbs).

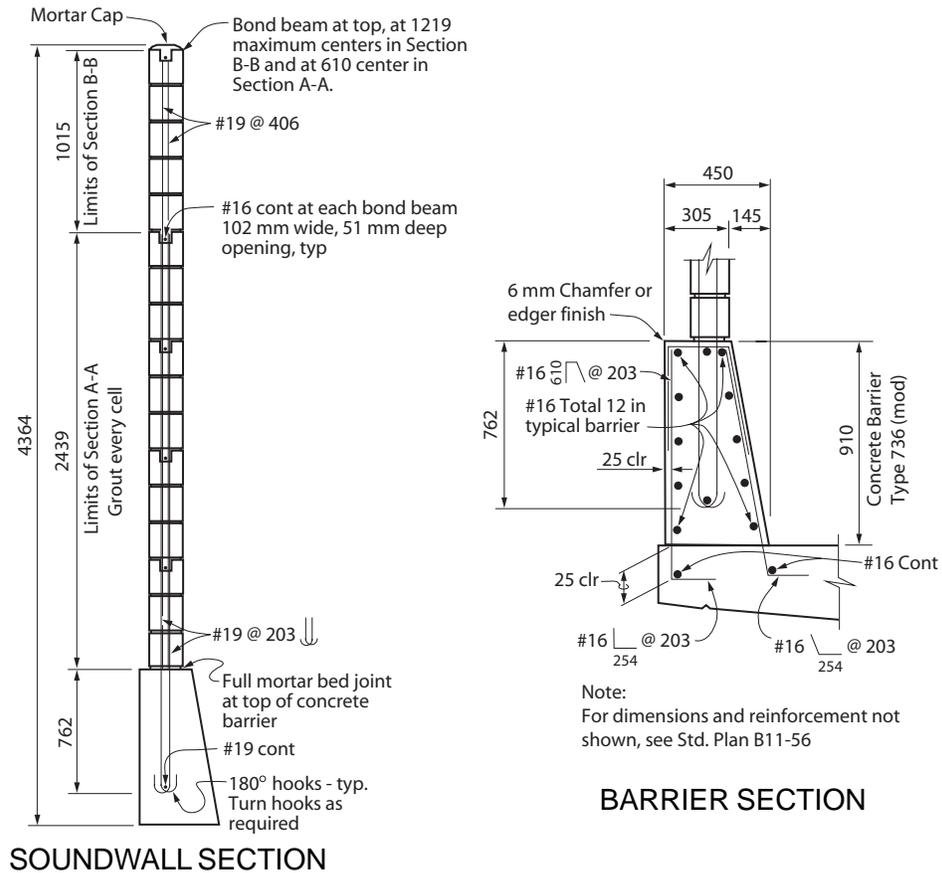


Figure 5 Masonry Soundwall on Bridge

Bridge Loads

When the soundwall and barrier combination is supported on a bridge superstructure, the soundwall, concrete barrier, and overhang shall be designed based on the group loads that apply or on a traffic impact load, whichever controls. The application of traffic impact loading shall be as specified in Article 2.7 – Railings of the *Bridge Design Specifications*.

When a soundwall is supported by a bridge superstructure, the wind or seismic load to be applied to the superstructure and substructure of the bridge shall be as specified in Articles 3.15 – Wind Loads and 3.21 – Earthquakes of the *Bridge Design Specifications*. Note that additional reinforcement may be required in the barrier and overhang to resist the loads carried by the soundwall.

Although BDS 3.23.2.3.1.1 allows the load of the concrete barrier to be distributed equally to all the girders, soundwalls should be considered based on the proximity of the loading. See MTD 22-2 for distribution of moment and shear from the soundwall to the exterior girder.

Expansion joints

Expansion joints are required in walls at the centerline of bents, at the centerline of spans, at hinges and at any other existing expansion joints in the structure. Placing additional joints in the wall may reduce stresses on the wall due to live load deflection of the bridge. A dowel is required at the top of masonry block walls at each joint to maintain proper alignment (see Figure 3). The bridge barrier should be continuous except at expansion joints in the deck.

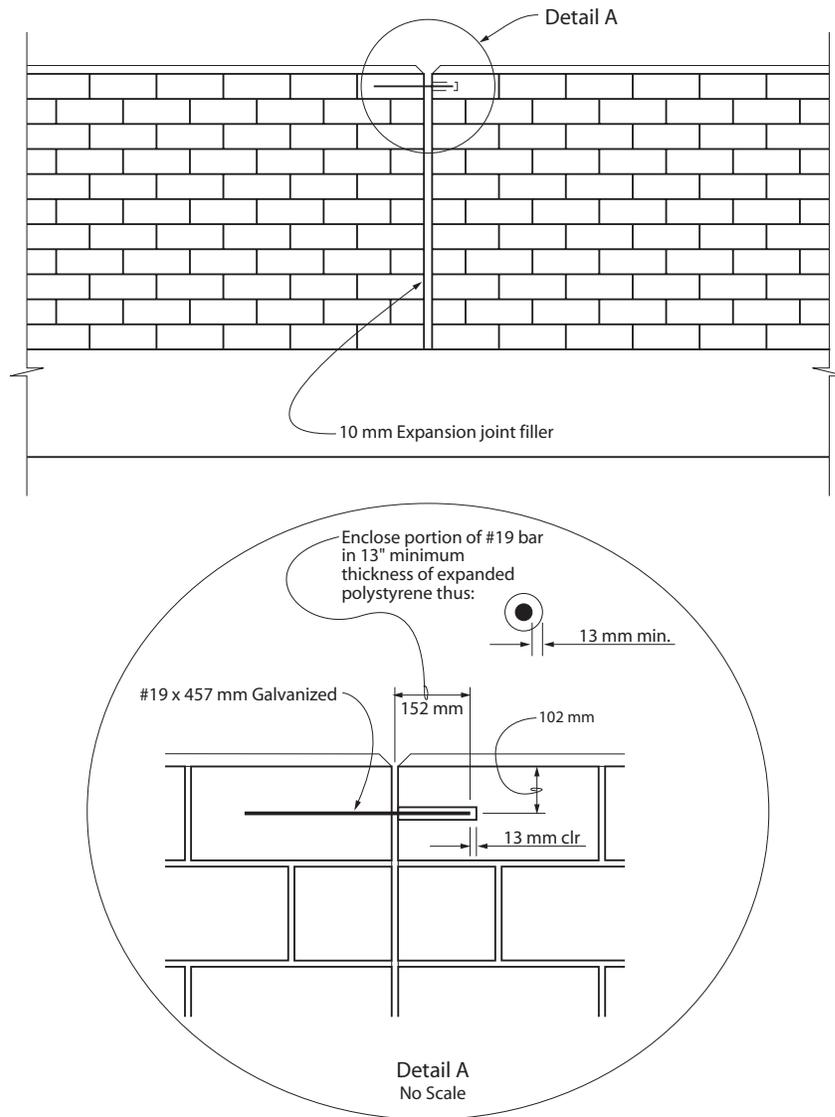


Figure 6 Alignment Key Detail



Other Considerations

Retrofitting barriers with soundwalls may require replacing the entire barrier due to either its inadequate flexural capacity to carry the wall loads, or because of inadequate anchorage of the barrier to the deck. See Memo to Designers 14-6 for barrier anchorage recommendations. Bridge overhangs must be checked for structural adequacy. Check as-built plans or Memo to Designers 9-4 for material capacities of the existing structure. Steel girder bridges may require strengthening. Do not place masonry block walls on existing steel girder bridges when traffic is carried on the structure during masonry construction. Traffic vibration will cause settlement of blocks into the mortar bed.

The addition of soundwalls to existing bridges may cause changes in the structure deflections that could result in drainage problems along the deck surface. Since this may be a particular problem when concrete or masonry soundwalls are placed on structures with flat grades, it is suggested that existing profiles, cross slopes, and deflections be reviewed to assure that adequate drainage is available.

Soundwalls on approach slabs require special consideration. Approach slabs are not designed to accommodate the wall dead load and loads transferred from it. Also, approach slab settlement and deflection may cause structural and alignment problems. See the Approach Slab Committee for recommendations.

VI. Soundwall Materials

A. Concrete Masonry Units

Masonry walls shall be designed as reinforced hollow-unit concrete masonry using either Working Stress Design or Strength Design according to the Uniform Building Code (UBC), 1997 Edition, Chapter 21. Walls are to be reinforced as required by design or to meet the minimum area requirements of UBC. To comply with UBC, the sum of the areas of horizontal and vertical reinforcement shall be at least 0.002 times the gross cross-sectional area of the wall and the minimum area of reinforcement in either direction shall be not less than 0.0007 times the gross cross-sectional area of the wall. The maximum spacing of this reinforcement shall be 1.2 m on center. Bond beams will be required at locations where horizontal reinforcement is placed (see Figure 1).

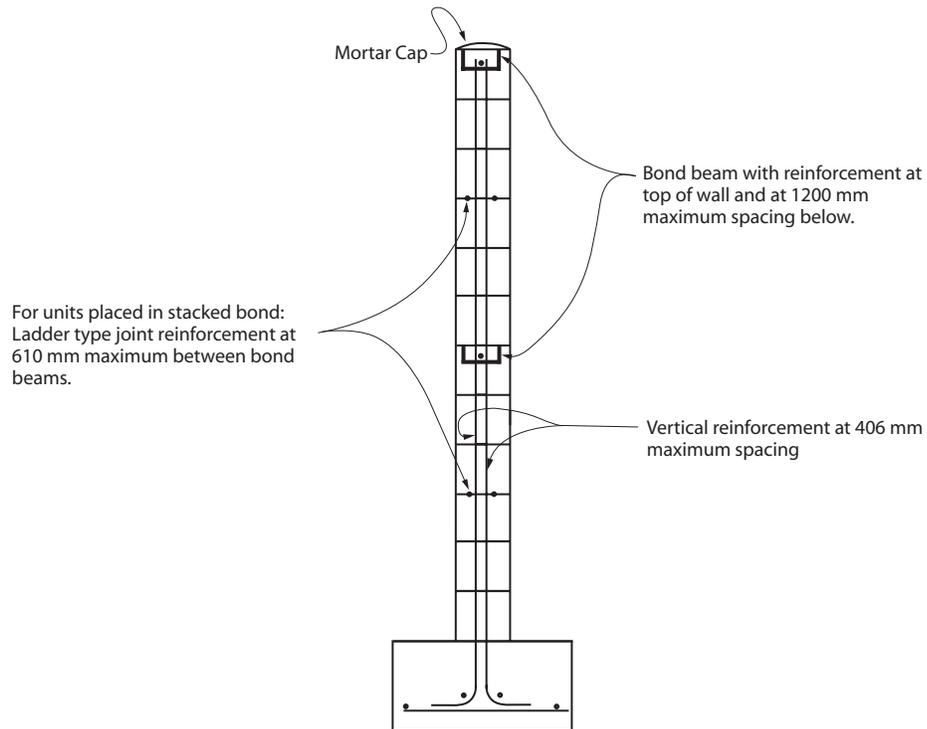


Figure 7 Minimum Reinforcement for Masonry Block Walls

When masonry units are laid in stacked bond, ladder type, galvanized joint reinforcement shall be required. The joint reinforcement shall be not less than two continuous 3.76 mm (9 gage) wires at 1219 mm (4 ft.) maximum. This reinforcement is to be embedded in the mortar bed joints at 610 mm maximum between bond beams.

Masonry soundwalls on bridges shall be high strength with an $f'_m = 17.24$ Mpa (2500 psi) and Special Inspection is required.



B. Other Materials

Specifications

The structural members of the soundwall shall conform to the codes listed below:

- | | |
|----------|--|
| Concrete | <i>Bridge Design Specifications, Section 8 - Reinforced Concrete Design.</i> |
| Timber | <i>Bridge Design Specifications, Section 13 – Wood Structures.</i> |
| Steel | <i>Bridge Design Specifications, Section 10 – Structural Steel.</i> |

Rick Land

Deputy Division Chief,
Engineering Services, Structure Design

DJD:pal