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6.7 Retaining walls

6.7.1 General

Retaining walls may be either part of highway bridge substructures or independent structures. Conventional reinforced concrete retaining walls attached to bridge abutments are identified as wings or wing walls and, for the design of those components, the designer should review the wing wall article [BDM 6.5.4.3]. The Design Bureau has standard details for a combined retaining wall and sidewalk, and in unusual cases the designer may need to refer to those details [DB SRP MI-221].

6.7.1.1 Policy overview

In Iowa rural areas there often is sufficient right-of-way so that differences in ground elevation can be managed with reasonable ground slopes. In urban areas, however, there may be insufficient space for ground slopes and thus a need for retaining structures independent of bridge substructures.

Depending on the difference in ground elevation, the options for retaining walls from small to large heights typically are the following: modular block, segmental, conventional, and mechanically stabilized earth (MSE). For many heights there will be two or more reasonable options, and the designer will need to select among the options based on cost, aesthetics, construction, and site factors.

Three of the options are proprietary: modular block, segmental, and mechanically stabilized earth. For these options, design generally is completed by a consulting Professional Engineer licensed in the State of Iowa. The proprietary systems are limited to approved manufacturers and suppliers identified by the Construction and Materials Bureau in Instructional Memorandums (IMs). Instructional Memorandums also cover detailed material testing and certification requirements. The Iowa DOT Standard Specifications cover materials, construction, method of measurement, and basis of payment.

Although not stated directly in the Iowa DOT Standard Specifications, current design practice for the approved proprietary retaining wall systems generally follows service load design. Design of modular block retaining walls is the responsibility of the engineer. Design of a segmental wall is required to be in accordance with a National Concrete Masonry Association design manual [BDM 6.7.1.5]. The Iowa DOT Standard Specifications currently require that an MSE wall be designed by the AASHTO Standard Specifications. At least one MSE wall supplier can provide load and resistance factor design (LRFD) at this time and, in the future, the Bureau expects to change practice to specify load and resistance factor design.

Conventional gravity and cantilever reinforced concrete retaining walls shall be designed by the AASHTO LRFD Specifications. The complete design needs to include checks of structural and geotechnical conditions checked either by the Soils Design Unit or structural designer. The overall stability should be checked by the Soils Design Unit, and the Unit should provide the designer with bearing and sliding resistances for the strength limit state. Based on those resistances the structural designer shall check bearing, eccentricity, and sliding at the strength limit state. The designer shall consult with the Soils Design Unit regarding wall settlement and lateral displacement at the service limit state.

On urban sites there may be requirements for aesthetic treatment of conventional retaining walls. In those cases, the designer shall provide adequate cover over reinforcing bars considering the depressions caused by form liners and inserts.

Generally, the Bureau recommends that retaining walls be designed for minimal maintenance over a service life of 75 to 100 years. At this time there is no regular inspection program for retaining walls that are not part of bridge substructures.

In the future the Bureau expects to experiment with the geosynthetic reinforced soil integrated bridge system (GRS-IBS), which is a combination of a reinforced soil retaining wall and a spread footing. For that system the best design and construction information available is from the Federal Highway Administration (FHWA) [BDM 6.7.1.5 and 6.7.4.5].

6.7.1.2 Design information

The soils information provided for a retaining wall will depend on the type of retaining wall and whether a retaining wall is part of a bridge substructure or an independent structure. For conventional retaining walls the designer will need nominal bearing and sliding resistances for the strength limit state from the Soils Design Unit.

The designer also will need to ensure that the wall is checked for overall stability, settlement, and lateral displacement at the service limit state. In most cases these checks will require that the designer consult with the Soils Design Unit during the design process.

6.7.1.3 Definitions

Primary Highway System: "Primary roads" or "primary road system" means those roads and streets both inside and outside the boundaries of municipalities which are under department (defined as state department of transportation) jurisdiction [Iowa Code 306.3.6].

6.7.1.4 Abbreviations and notation

ABC, accelerated bridge construction
EH, earth (lateral) pressure
FHWA, Federal Highway Administration
GRS-IBS, geosynthetic reinforced soil integrated bridge system
LRFD, load and resistance factor design
MSE, mechanically stabilized earth
S_{D1}, horizontal response spectral acceleration coefficient at 1.0-sec. period modified by long-period site factor [AASHTO-LRFD 3.10.4.2]

WA, water load

6.7.1.5 References

Adams, M., J. Nicks, T. Stabile, J. Wu, W. Schlatter, and J. Hartmann. *Geosynthetic Reinforced Soil Integrated Bridge System, Interim Implementation Guide, FHWA-HRT-11-026.* Washington: Federal Highway Administration, 2012. (Available on the Internet at: http://www.fhwa.dot.gov/publications/research/infrastructure/structures/11026/11026.pdf)

Adams, M., J. Nicks, T. Stabile, J. Wu, W. Schlatter, and J. Hartmann. *Geosynthetic Reinforced Soil Integrated Bridge System, Synthesis Report, FHWA-HRT-11-027.* Washington: Federal Highway Administration, 2011. (Available on the Internet at: http://www.fhwa.dot.gov/publications/research/infrastructure/structures/11027/11027.pdf)

Elias, V., B.R. Christopher, and R.R. Berg. *Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines, FHWA-NHI-00-043.* Washington: National Highway Institute, Federal Highway Administration, 2001.

Federal Highway Administration (FHWA). *Sample Guide Specifications for Construction of Geosynthetic Reinforced Soil-Integrated Bridge System (GRS-IBS) FHWA-HRT-12-051.* Washington: Federal Highway Administration, 2012. (Available on the Internet at: http://www.fhwa.dot.gov/publications/research/infrastructure/structures/12051/12051.pdf)

National Concrete Masonry Association (NCMA). *Design Manual for Segmental Retaining Walls, Third Edition.* Herndon: National Concrete Masonry Association, 2009.

Construction and Materials Bureau. *Concrete Segmental Blocks, Wet Cast, Instructional Memorandum 445.05.* Ames: Office of Materials, Iowa Department of Transportation, 2006. (Available on the Internet at: http://www.iowadot.gov/erl/current/IM/Navigation/nav.pdf)

Construction and Materials Bureau. *Concrete Segmental & Modular Blocks, Dry Cast, Instructional Memorandum 445.04.* Ames: Office of Materials, Iowa Department of Transportation, 2006. (Available on the Internet at: http://www.iowadot.gov/erl/current/IM/Navigation/nav.pdf)

Construction and Materials Bureau. *Mechanically-Stabilized Earth (MSE) Retaining Wall Panels, Instructional Memorandum 445.03.* Ames: Office of Materials, Iowa Department of Transportation, 2006. (Available on the Internet at: http://www.iowadot.gov/erl/current/IM/Navigation/nav.pdf)

Wilson, K.E., R.E. Kimmerling, G.C. Goble, P.J. Sabatini, S.D. Zang, J.Y. Zhou, W.A. Amrhein, J.W. Bouscher, and L.J. Danaovich. *LRFD for Highway Bridge Substructures and Earth Retaining Structures Reference Manual, FHWA-NHI-05-094.* Arlington: Federal Highway Administration, National Highway Institute, 2005.

6.7.2 Loads

6.7.2.1 Lateral earth pressure

Earth pressures (EH) result from surcharge loading, backfill and retained soil, and compaction. Depending on lateral deflection of the wall, earth pressures can be classified as active, at rest, or passive. For selecting the type of pressure, the Bureau recommends that the designer consult *LRFD for Highway Bridge Substructures and Earth Retaining Structures Reference Manual* [BDM 6.7.1.5].

6.7.2.2 Water

The designer should ensure that the backfill behind a retaining wall is adequately drained. If the backfill cannot be drained adequately the designer shall add full hydrostatic pressure (WA) to the lateral earth pressure [AASHTO-LRFD 11.6.6].

6.7.3 Load application

6.7.3.1 Load modifier

Load factors shall be adjusted by the load modifier, which accounts for ductility, redundancy, and operational importance [AASHTO-LRFD 1.3.2, 3.4.1]. For typical retaining walls the load modifier shall be taken as 1.0.

6.7.3.2 Limit states

By observation, many of the AASHTO LRFD load combinations need not be considered in design of conventional retaining walls. Retaining walls typically are not affected by wind loads, and load factors are such that the Strength I load combination obviously controls over other strength combinations [AASHTO-LRFD Table 3.4.1-1]. Based on the acceleration coefficient S_{D1} [AASHTO-LRFD 3.10.4.2] for Site Class A through E [AASHTO-LRFD 3.10.3.1], all of Iowa shall be classified as Seismic Zone 1 [AASHTO-LRFD 3.10.6], and therefore Extreme Event I does not apply except for highly unusual Site Class F and Mississippi and Missouri River sites. In unusual cases Extreme Event II may apply for vehicular collision force, check floods, or ice load. Of the service load combinations, only Service I applies for retaining walls. Retaining walls are not subject to fatigue loads, and thus fatigue load combinations do not apply.

Applicable limit states and corresponding design checks are summarized in Table 6.7.3.2. (See also Wilson, K.E. et al. *LRFD for Highway Bridge Substructures and Earth Retaining Structures Reference Manual, FHWA-NHI-05-094* [BDM 6.7.1.5].)

Table 6.7.3.2. Limit states, load combinations, and typical design checks

Limit State and Load Combination	Geotechnical Checks	Structural Checks (3)
Strength I	Bearing	Flexure
	Eccentricity	Shear
	Sliding	
Extreme Event I (1)		Flexure
		Shear
Extreme Event II (1)		Flexure
		Shear
Service I	Overall stability	Crack control
	Settlement	Deflection
	Lateral displacement (2)	

Table notes:

(1) The extreme event limit state does not apply for typical retaining walls. See the discussion above.
(2) Lateral displacement is difficult to determine accurately, and the geotechnical check often will need to be based on engineering judgment.
(3) If a retaining wall serves as a support for another structure the wall also needs to be designed for compression and combined compression and flexure.

6.7.4 Guidelines by wall type

6.7.4.1 Conventional

6.7.4.1.1 Analysis and design

Conventional retaining walls shall be designed in accordance with the AASHTO LRFD Specifications [AASHTO-LRFD 11.6]. Retaining walls shall be designed to withstand lateral earth and water pressures, including any live and dead load surcharge, self-weight of the wall, and temperature and shrinkage effects.

In general, structures that can move away from the retained soil mass will mobilize active earth pressures whereas restrained structures should be designed for at-rest earth pressures. In lieu of determining the required movement at the top of a wall to reach the minimum active earth pressure, designers shall conservatively assume at-rest conditions apply. Walls which deflect horizontally into the retained soil should be designed to resist passive earth pressure.

Unless specified otherwise on the plans, concrete for the retaining wall shall be Class C [IDOT SS 2516.03, B]. Class C concrete shall be assumed to have 28-day strength of 4.0 ksi (28 MPa).

Unless specified otherwise on the plans, reinforcement shall be ASTM A 615/A 615M, ASTM A 996/A 996M, or ASTM A 706/A 706M Grade 60 (Grade 420). Wall reinforcement shall be epoxy coated if the retaining wall is part of a bridge substructure [BDM 6.5.4.3.2], within 25 feet (7.620 m) of the edge of a traveled roadway, or otherwise exposed to deicing chemicals.

Under all applicable limit states, the wall design shall be investigated for any combination of forces that may produce the most severe condition of loading.

The designer shall select maximum and minimum load factors to determine maximum bearing, eccentricity, and bearing [AASHTO-LRFD C11.5.5] for geotechnical design at the strength limit state. The designer shall select resistance factors for foundations from the AASHTO LRFD Specifications [AASHTO-LRFD 11.5.6].

If the extreme event limit state applies, the designer shall take geotechnical resistance factors as 1.0 [AASHTO-LRFD 11.5.7].

The designer shall select maximum and minimum load factors to determine maximum shear and moment, and compression if applicable, for structural design at the strength limit state. The designer shall select resistance factors for reinforced concrete from the AASHTO LRFD Specifications [AASHTO-LRFD 5.5.4.2].

If estimated differential settlement along a segment of a conventional retaining wall exceeds 1/500 the designer shall investigate the effects of the settlement on the strength of the wall.

6.7.4.1.2 Detailing

Unless otherwise detailed, cast-in-place retaining wall concrete will be given a simple Class 2 strip-down surface finish [IDOT 2403.03, P, 2, b]. For projects with aesthetic requirements the designer will need to detail and specify the finish.

In retaining walls that are not part of bridge substructures, expansion and contraction joints shall be provided as required by the AASHTO LRFD Specifications [AASHTO-LRFD 11.6.1.6].

The long-term performance of a retaining wall is dependent on proper drainage of water behind the wall. The designer shall check drainage details to ensure adequate capacity, slope, and discharge.

6.7.4.2 Modular block

A modular block retaining wall is a simple gravity wall that does not involve soil reinforcement in the backfill behind the facing blocks [IDOT SS 2430]. The wall generally is of minimal height. A modular block retaining wall is constructed with an approved proprietary system consisting of block units and other materials that meet Iowa DOT testing and certification requirements [IDOT SS 2430, OM IM 445.04].

A modular block retaining wall shall be designed by a Professional Engineer licensed in the State of Iowa. The Iowa DOT does not specify a design method [IDOT SS 2430].

6.7.4.3 Segmental

A segmental retaining wall generally is taller than a modular block retaining wall and usually does require geogrids or reinforcing strips in the backfill soil behind the facing blocks [IDOT SS 2431]. A segmental retaining wall is constructed with an approved proprietary system consisting of block units, geogrid, and other materials that meet Iowa DOT testing and certification requirements [IDOT SS 2431, OM IM 445.04 and 445.05].

A segmental retaining wall shall be designed by a Professional Engineer licensed in the State of Iowa. The Iowa DOT specifies that the design be according to recommendations in *Design Manual for Segmental Retaining Walls* [BDM 6.7.1.5].

The AASHTO LRFD Specifications consider this wall type to be a mechanically stabilized earth wall [AASHTO-LRFD 11.10.1].

6.7.4.4 Mechanically stabilized earth (MSE)

A mechanically stabilized earth (MSE) retaining wall makes use of large precast reinforced concrete panels connected to strips or mesh in the backfill soil that create a reinforced earth zone behind the panel facing [IDOT SS 2432]. Generally, an MSE wall is economical for heights of 15 feet (4.500 m) or more. An MSE wall is constructed with an approved proprietary system consisting of precast concrete units, earth reinforcing, and other materials that meet Iowa DOT testing and certification requirements [IDOT SS 2432, OM IM 445.03].

A mechanically stabilized earth wall shall be designed by a Professional Engineer licensed in the State of Iowa. The Iowa DOT specifies that the design be according to the AASHTO Standard Specifications [IDOT SS 2432].

6.7.4.5 GRS-IBS

The Geosynthetic Reinforced Soil Integrated Bridge System (GRS-IBS) is a combination of a reinforced soil retaining wall and a spread footing that creates a bridge abutment appropriate for a single span bridge. The system blends the roadway into the bridge superstructure to alleviate the bump at the bridge caused by settlement at the approach pavement. By use of the shallow foundation the system can reduce construction cost and time significantly. If the system is to be used for a bridge over a waterway, the designer must conduct a careful hydraulic analysis because the system is inadequate for some scour conditions.

The GRS-IBS has been used on a Buchanan County, IA bridge but not yet on a bridge on the Primary Highway System. Use of the GRS-IBS on the state system requires approval of the Assistant Bridge Engineer or Chief Structural Engineer.

A designer intending to use the system should obtain the following three FHWA publications [6.7.1.5] and search the Internet for additional resources as needed.

- Sample Guide Specifications for Construction of GRS-IBS
- GRS-IBS Synthesis Report
- GRS-IBS Interim Implementation Guide

The GRS-IBS is included in the Bureau draft accelerated bridge construction (ABC) policy.

6.7.4.6 Other

Nongravity, anchored, prefabricated modular, and other special types of retaining walls shall be designed according to the AASHTO LRFD Specifications.