RESEARCH & DEVELOPMENT

State of Practice of Highway Embankment Construction in the U.S.

- A Literature Review of FHWA and USDOTs Requirements for Embankment Material Selection and Embankment Construction

Prepared as part of

NCDOT RP 2015-05

IMPROVEMENT OF MATERIAL CRITERIA FOR HIGHWAY EMBANKMENT CONSTRUCTION

by

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PREFACE

This synthesis report is part of the research project RP 2015-05 funded by the North Carolina Department of Transportation. The material presented was compiled by reviewing Federal, AASHTO, and state standards from 50 U.S. states on embankment material selection and embankment construction. The report preparation was led by Ph.D. research student Mr. Mehrdad Hassani under the supervision of Professors Miguel A. Pando and Rajaram Janardhanam.

Executive Summary

This report presents a synopsis of state of practice of highway embankment construction in the U.S. as part of NCDOT RP 2015-05. The purpose of this synthesis report is to present a summary of the specifications and standards used by the different U.S. Departments of Transportation and the Federal Highway Administration on material selection criteria and on its placement and construction procedures of highway embankments.

The review of state departments of transportation specifications and standards, show that many of the U.S. states have similar specifications and standards regarding the selection of borrow material for construction of highway embankments. A few of states conform to using soil groups as defined by AASHTO Standard M 57. Most of the states allow large rock fragments or boulders to be used as embankment material. However, use of these large sized material is often restricted to the lower portions of the embankment or near the side slopes. Rules regarding construction of bridge approaches, or for fill adjacent to structures, are usually stricter regarding the use of large sized material.

Regarding construction, one of the common specifications is the lift thickness of the approved material. The lift thickness for soil embankments in most U.S. DOTs is specified as a loose lift thickness ranging between 8 to 12 inches. For rock fill embankments, the lift thickness is specified in some states to be as large as 3 feet (36 inches). Most of the U.S. DOTs specify the lift thickness in terms of a loose measurement, that is before compaction. However, in a few cases including Florida, Maryland, Pennsylvania, Rhode Island and West Virginia, it is specified as a lift thickness after compaction.

Another construction related specification is the compaction of the material. Highway embankment compaction level is mostly specified in terms of a minimum relative compaction with respect to a certain compaction test and energy. The majority of U.S. DOTs specify a minimum relative compaction equal to 95 percent typically with respect to the Standard Proctor compaction as per AASHTO T 99. Specifications for moisture content during compaction of material for highway construction was found not to be as common.

The literature review process performed for this report revealed some important differences that are highlighted and discussed in the report. For example, some states are more detailed in their specifications including requirements such as a certain soil plasticity (e.g., maximum allowed plasticity index), or specify the range of placement moisture content which as mentioned above was found not to be a common requirement among USDOT's. Furthermore, many states have the provision that the project Resident Engineer has the discretion to override the Standard USDOT specifications based on the project specific information such as laboratory tests, field testing, and engineering judgement.

An overall summary table for the 50 USDOT specifications reviewed in terms of material selection and material placement and construction is presented in Appendix A of this report.

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List of Abbreviations

- AASHTO: American Association of State Highway and Transportation Officials
- ASTM: American Society for Testing and Materials
- FHWA: Federal Highway Administration
- USDOT: United States Department of Transportation
- $\gamma_{d\max}$: maximum dry unit weight obtained in a standardized laboratory compaction test
- RC: relative compaction which is the ratio of dry unit weight (or dry density if expressed in terms of mass per unit volume) achieved after compaction in the field to $\gamma_{d\max}$
- W_{opt}: optimum moisture content based on specified standardized compaction test
- PI: plasticity index
- LL: liquid limit
- ft.: foot/feet
- in.: inch/inches
- H: height of highway embankment
- $P_{3/4}$: percent of material passing ¾ inch sieve
- P_4: percent of material passing No. 4 sieve
- P_{200}: percent of material passing No. 200 sieve

1. Introduction

This report reviews United States federal and individual states specification on highway embankment material selection and construction requirements. First federal and then states specifications are presented, then the results are compiled and discussed in section five, and finally a summary table is presented in Appendix A to provide a useful way to review the compiled information.

This study found that the embankment material selection criteria may vary considerably from state to state. Common specification requirements which is reviewed in this report include:

- Gradation (through particle size analysis ASTM D422, ASTM D136);
- Atterberg limits including Plasticity index (PI) and liquid limit (LL);
- Maximum organic content;
- And material capable of achieving a certain minimum dry density in the field (although this requirement is associated more with the construction specifications).

Required specifications regarding embankment construction were also found to vary significantly from state to state. The main aspects specified for placement and construction of highway embankments include:

- Compaction control: which is in most of the cases stated as relative compaction (RC). Relative compaction is the ratio of dry unit weight (or dry density if expressed in terms of mass per unit volume) achieved after compaction in the field to the maximum dry unit weight obtained in a standardized laboratory compaction test ($g_{d\max}$). Most U.S. Departments of Transportation specifiy $g_{d\max}$ with respect to the AASHTO T 99 (Standard Proctor) or AASHTO T 180 (Modified Proctor). However, a few states specify the compaction energy associated with a local standard. Out of 50 states, 33 use the Standard Proctor compaction and 8 use the Modified Proctor compaction. In some few cases, compaction control is also stated in terms of the number of passes of the roller or compaction equipment used in the project.
- Moisture control: is usually stated in the form of some whole number of percentage points below or above the laboratory optimum moisture content (W_{opt}) obtained for a specified compaction test. However, a large number of departments do not specify any requirement for the placing moisture content of embankment material. They instead imply that the moisture content should be in a range so that the requirement for dry density could be met.
- Lift thickness: is specified either as loose measurement, that is before layer compaction, or after compaction. Lift thickness of highway soil embankment is significantly different from rock embankment.

2. General observations from the review of State DOT specifications

All departments set some general requirements for embankment construction. These general requirements and points are mentioned in the following paragraphs.

As far as type of material is concerned, most of the state standards ban using muck, plants root, organic soils, perishable or frozen material for embankment construction. Almost all states discuss and put some limitations on using glass particles as embankment material.

Most of the USDOT specifications have special considerations that allow large rock fragments or boulder to be used as embankment material. These materials are usually thicker than the lift thickness for placing soil. While using rock fragments or boulder, these materials are forbidden within some few feet from the top of embankment. This red zone in the top of embankment is in many cases 3-5 feet. In other words, use of these large sized material is often restricted to the lower portions of the embankment or near the side slopes. However, it is noted that this report is solely focusing on the soil embankments.

Best available material should be used for constructing the top portion of embankment, while least quality material shall be pushed to the slopes. Larger rocks shall also be utilized for foundation construction.

Likewise, there are usually some special rules to forbid unsuitable material in adjacent to structures, bridge abutments, driven piles, drilled shafts and underground utilities. Embankments abutting structures shall usually be built with flatter side slopes.

Roadway embankments in the bridge approaches shall usually be compacted to a higher level than other sections of embankment. Bridge approach is mostly defined as the portion 100 feet away from the bridge end.

As height of the embankment decreases in many cases to lower than 5 feet, stricter considerations are directed toward the foundation of embankment. They require embankment foundation to be scarified to a minimum depth and compacted to usually same level as embankment within this minimum depth.

Most of the departments require that rolling starts from outer edges and proceeds toward the center of embankment.

Knowing that all departments have stated limit for lift thickness, some of them also require placing the embankment with a minimum length for each construction section. For instance, Arkansas Highway and Transportation Department specify that embankments shall be constructed

in sections of not less than 200 ft. (60 m) in length, or the full length of the embankment if less than 200 ft. (60 m).

3. Summary of Review of the Federal and AASHTO Specifications

FHWA recommended minimum requirements for compaction of embankments and subgrades as the following table (FHWA 2006). The relative compaction in this table is based on the Standard Proctor (AASHTO T 99). It can be seen that in embankment construction, relative compaction shall exceed 95% for all AASHTO soil classes.

Table 1. Recommended minimum requirements for compaction of embankments (adopted from FHWA, 2006)

AASHTO soil class	Minimum RC (%)		
	Embankments		Subgrades
	H < 50 ft.	H > 50 ft.	
A-1, A-3	≥ 95	≥ 95	100
A-2-4, A-2-5	≥ 95	≥ 95	100
A-2-6, A-2-7	≥ 95	---*	≥ 95**
A-4, A-5, A-6, A-7	≥ 95	---*	≥ 95**

* Special attention to design and construction is required for these materials
** Compaction of layers at within 2% of the optimum moisture content

American Association of State Highway and Transportation Officials (AASHTO) also sets some specification for embankment and subgrade material and construction (AASHTO 2012). It is similar in all fields to the above FHWA table except as what is mentioned in the following.

- AASHTO specification follows FHWA specification mentioned above in all fields.
- In case of availability, preference shall be given to using A-1, A-2-4, A-2-5 and A-3 groups in both embankment and subgrade.
- If A-2-6, A-2-7, A-4, A-5, A-6, or A-7 is used for either embankment or subgrade (not only subgrade as indicated in FHWA), they shall be compacted within 2% of the optimum moisture content.

Kimmerling (2002) in a FHWA funded study on shallow foundations reported the material specifications shown in Table 2 for engineered granular fills.

Table 2. FHWA gradation requirement AASHTO T27 (as reported by Kimmerling, 2002)

U.S. Sieve Size	Required Percent Passing
4 inches	100
#40 (0.0165 inch)	0-70
#200 (0.0029 inch)	0-15

The FHWA Soil an Foundations Reference Manual-Volume I (Samtani and Nowatzki 2006a) provides additional guidelines regarding material selection for the structural backfill as follows. It should be pointed out that structural backfill is the material zone that intermediates embankment general section and bridge abutment. It is also recommended to use a layer of structural backfill as thick as 5 ft (1.5 m) beneath abutments on spread footings.

- Plasticity Index (PI): PI < 10%, PI should not exceed 10 to control long-term deformation
- Largest particle size < ¾ of lift thickness
- Soundness based on AASHTO T104:
    - Durability: to address potential particle breakdown the material shall be free of shale or other granular material that contains particles that are soft and/or of poor durability.

Same FHWA manual from Samtani and Nowatzki (2006a) besides Samtani and Nowatzki (2006b) provide the following guidelines regarding construction considerations of structural backfill and spread footing of bridges.

- Lift thickness: limit to 6 to 8 inches to allow adequate compaction even with small equipment
- Compaction level for spread footings as bridge foundation: 95% of maximum dry density based on Modified Proctor per AASHTO T 180.

4. Summary of Review of State Specifications

This chapter presents a summary by state. For each subsection, main specifications related to material selection, embankment compaction control, lift thickness of placing layers, moisture control is provided, followed by the source of information.

4.1. Alabama

Material: any ***stable*** material which can be compacted to the specified dry density.

Compaction control: RC ≥ 95%, maximum dry density according to AASHTO T 99.

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Source of information: Alabama Department of Transportation (2012), Sections 210 and 306.

4.2. Alaska

Material: No specific material specifications was found in the reviewed source listed below.

Compaction control: RC ≥ 95%, maximum density (ATM 207 equivalent to AASHTO T 99 & T 180).

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Moisture control: W_{opt} ± 2%

Source of information: Alaska Department of Transportation and Public Facilities (2017), Section 203.

4.3. Arizona

Material:

- All embankment material within three feet of the finished subgrade elevation shall have a resilient modulus value equal to or greater than the design resilient modulus value for the pavement structure.
- For material placed at the bridge abutments, PI ≤ 15.

Compaction control:

- RC ≥ 95%, maximum density according to AASHTO T 99 (standard energy).
- For embankments with height of five feet or less, the top six inches of the natural ground shall be compacted to a density of more than 95 percent of the maximum density.

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Source of information: Arizona Department of Transportation (2008), Section 203.

4.4. Arkansas

Material: selected material for bridge approaches.

Compaction control:

- RC ≥ 95%, maximum laboratory density energy dependent on the percent retaining on sieve No. 4 (4.75 mm).
- If less than 31% of the soil material retains on sieve No. 4, then use AASHTO T 99 (Standard Proctor).
- If more than 31% of the soil material retains on sieve No. 4, then use AASHTO T 180 (Modified Proctor).
- For embankment with height less than 3 feet, natural ground should be compacted.

Lift thickness: ≤ 10" (thickness specified as loose measurement)

Source of information: Arkansas Highway and Transportation Department (2014), Section 210.

4.5. California

Material: In embankment areas where piles are to be placed or driven, do not use material containing rocks, broken concrete, or other solid materials larger than 4 inches in greatest dimension.

Compaction control:

- RC ≥ 95% (top 2.5 ft) and 90% (remaining).
- Within 150 feet of each bridge abutment, full width and depth of the embankment should be compacted to 95 percent of relative compaction.
- If 95 percent relative compaction is not required, a relative compaction of at least 90 percent should be obtain for embankment.

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Source of information: California Department of Transportation (2010), Section 19.

4.6. Colorado

Material:

- Maximum dry density of material shall not be less than 90 lbs/ft^3.
- Material shall be predominantly finer than 4.75 mm diameter (sieve No. 4).

Compaction control:

- A-1: RC ≥ 95% (T 180), RC ≥ 100% (T 99).
- A-3: RC ≥ 95% (T 180), RC ≥ 100% (T 99).
- A-2-4: RC ≥ 95% (T 180), RC ≥ 100% (T 99).
- A-2-5: RC ≥ 95% (T 180), RC ≥ 100% (T 99).
- Others: RC ≥ 90% (T 180), RC ≥ 95% (T 99).

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Moisture control: A-2-6, A-2-4, A-4, A-6, A-7: not drier than 2% of the W_{opt} (AASHTO T 99, T 180).

Source of information: Colorado Department of Transportation (2011), Section 203.

4.7. Connecticut

Material: Embankments to an elevation 3 feet (1 meter) above the free water surface at the time of filling, shall be constructed of rock or free-draining material, or a mixture of both.

Compaction control: RC ≥ 95%, maximum dry density in accordance with AASHTO T 180, Method D (Modified Proctor).

Lift thickness: ≤ 12" (thickness specified as loose measurement)

Source of information: Connecticut Department of Transportation (2004), Section 2.02.

4.8. Delaware

Material: specifications for borrow site are as follows:

- Unit Weight: ≥ 90 lb/ft^3;
- Borrow LL ≤ 40.

Compaction control: RC ≥ 95%, maximum dry density (AASHTO T 99 Method C, Modified).

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Moisture control: W_{opt} ± 2% (AASHTO T 99 Method C, Modified)

Source of information: Delaware Department of Transportation (2016), Section 202.

4.9. Florida

Material:

- For A-2-4 material ensure the percentage of fines passing the No. 200 sieve does not exceed 15%.
- For the top 1 ft. of embankment maximum particle sizes should be 3 ½ inches.

Compaction control:

- RC ≥ 100%, maximum density according to AASHTO T 99 Method C.
- Construct embankments in sections of not less than 300 feet in length or for the full length of the embankment.

Lift thickness:

- A-3 and A-2-4 with less than 15% fines: ≤ 12" (thickness specified as compacted measurement).
- A-1, A-2-4 with greater than 15% fines: ≤ 6" (thickness specified as compacted measurement).
- Restrict the compacted thickness of the last embankment lift to 6 inches maximum.

Source of information: Florida Department of Transportation (2014), Section 120.

4.10. Georgia

Material: Pond sand with minimum dry density of 90 lb/ft^3 can be used for embankment construction provided it is encapsulated with 2 ft. of soil on the slopes and 3 ft. of soil on top.

Compaction control: compared to AASHTO T 99 (Standard Proctor).

- Bridge approaches (extend 100 ft. from bridge and): RC ≥ 100%.
- Other: top 1 ft: RC ≥ 100% and below 1 ft: RC ≥ 95%.

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Source of information: Georgia Department of Transportation (2013), Section 208.

4.11. Hawaii

Material:

- For top 2 feet of the embankment, place embankment material with maximum size of 6 inches and sand equivalent (SE) of at least 10.
- Sand Equivalent (SE) of embankment material shall not be less than SE of the existing soil on which embankment is placed.

Compaction control:

- Top 2 ft. of embankment: RC ≥ 95% according to AASHTO T 180 (Modified Proctor).
- Top 6" below top 2 ft. should have RC ≥ 90%.

Lift thickness: 9" (thickness specified as loose measurement)

Moisture control: $W_{opt} \pm 2\%$

Source of information: Hawaii Department of Transportation (2005), Section 203.

4.12. Idaho

Material: other than soil and rock, materials such as wood fibers, light-weight concrete, recycled glass, and geofoam are acceptable.

Compaction control:

- Within the road prism of approximately 2H:1V slope, compact to class A.
- Class A compaction: If less than 10 percent retained on the 3 inch sieve; and less than or equal to 30 percent retained on the ¾ inch sieve, RC ≥ 95% per AASHTO T 99 Method C.
- Areas under embankments to a depth of 8 inches: compact to class A.

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Moisture control: W_{opt} - 4% to W_{opt} + 2% (AASHTO T 99 or T 180 if decided by engineer)

Source of information: Idaho Transportation Department (2017), Section 205.

4.13. Illinois

Material: within top 1 foot, no rock, stones or broken concrete more than 4 in. in largest dimension shall be permitted.

Compaction control: standard laboratory density is according to AASHTO T 99, Method C.

- Embankment height (< 1½ ft.): all lifts to RC ≥ 95%.
- Embankment height (1½ - 3 ft.): first lift to RC ≥ 90%, remaining to RC ≥ 95%.
- Embankment height (>3 ft.): for Lower 1/3: RC ≥ 90%, next 1 ft: RC ≥ 93%, remaining: RC ≥ 95%.

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Moisture control: for top 2 ft. $\leq 1.2*W_{opt}$ according to AASHTO T 99, Method C

Source of information: Illinois Department of Transportation (2016), Section 205.

4.14. Indiana

Material:

- organic content (by dry weight) ≤ 6%.
- minimum dry density: 90 pcf .
- for the top 1½ ft., rock fragments shall be smaller than 3 in. in any dimension.
- When the embankment soils are granular, silty loam, sandy loam, silts, or when the plasticity index of the material is less than 8, the embankment shall be encased with some materials having plasticity indexes more than 8. Encasing material may consist of silty clay loam, clay loam, sandy clay loam, or silty clay and shall be as thick as 12 in. measured perpendicular to the face of the slope. Organic content of the encasing material shall not either exceed 6%.
- Material suitable for vegetation shall be placed on the shoulder slopes with 6 in. minimum depth.
- Top 2 ft. of the embankment shall be composed of suitable material (not rock fragments).

Compaction control:

- Compaction will be controlled using dynamic cone penetrometer.
- As an alternate, all embankments shall be compacted to RC ≥ 95%, and all subgrades shall be compacted to RC ≥ 100% ($g_{d\max}$ as per AASHTO T 99).

Lift thickness: ≤ 6" measured in compacted state and loose lift thickness in no case more than 8".

Moisture control: it varies depending on the soil textural classification and its dry density.

- Clay soil: $W_{opt} \pm 2\%$, also depends on dry density.
- Silty and Sandy soil: W_{opt} - 3% to W_{opt}.
- Granular: 5% - 8%.

Source of information: Indiana Department of Transportation (2018), Section 203.

4.15. Iowa

Material:

- Select cohesive soils must have a plasticity index greater than 10 (PI>10).
- No other specific material specifications was found in the reviewed source listed below.

Compaction control:

- Compaction is controlled by the roller: at least one pass of the sheepsfoot type roller for each inch of the loose thickness of layer (typically 8"). Compaction shall continue until the roller is supported entirely on its feet. (when the tamping feet penetrates no more than 3 inches into an 8-inch lift or 33% of the depth of the layer being placed).
- Compaction controlled by density: RC ≥ 95% as per AASHTO T 99.

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Moisture control: W_{opt} - 3% to W_{opt}

Source of information: Iowa Department of Transportation (2012), Section 2107 & Iowa DOT (2015)

4.16. Kansas

Material:

- Soil, soil/rock and rock can be utilized for embankment construction. Soil is defined as material with no more than 20% retained on the ¾ inch sieve and rock is material with more than 80% passing ¾ inch sieve.
- Using rock material for the base of embankment is desirable.

Compaction control:

- If not specified in the contract documents, Type B compaction is required, which is as follows. According to the engineer visual inspection, no further consolidation should be gained. This is when tamping feet of the sheepsfoot roller walks out of the surface. In low plasticity fine-grained soil material, tamping feet shall support the weight of the roller (without the drum of the roller contacting the lift being compacted).
- If engineer is unable to visually determine whether Type B compaction is obtained, density tests should be performed to show RC ≥ 90%.

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Source of information: Kansas Department of Transportation (2015), Section 205.

4.17. Kentucky

Material: within top 1 ft., do not use rock fragments greater than 4 inches.

Compaction control: RC ≥ 95%, maximum density as per AASHTO T 99.

Lift thickness: ≤ 12" (thickness specified as loose measurement)

Moisture control: W_{opt} ±2%

Source of information: Kentucky Department of Transportation (2012), Section 206.

4.18. Louisiana

Material:

- Embankments shall be constructed with usable soil. Usable soils include soils with a plasticity index as: 11 ≤ PI ≤ 25, maximum organic content of 5%, and silt content of less than 50%. Lime treatment can be used to treat soils with 25 < PI ≤ 35; lime volume shall be at least 6% and yet the requirement for silt content and organic content should be met.
- Embankments may also be constructed with nonplastic material such as sand and stone, with maximum organic content of 4%.
- Bridge approach or header is the portion of embankment within 500 feet of a bridge end. Bridge approach should be usable soil with maximum silt content of 65%. For bridge approaches, no lime treatment to reduce PI of the soil will be permitted.
- If outside layer of embankment has PI less than 10, or pH less than 5.5 or greater than 8.5, a plastic soil blanket with minimum thickness of 12 inches shall me placed.

Compaction control: RC ≥ 95% ($g_{d\max}$ similar to AASHTO T 99).

Lift thickness:

- Plastic Material: ≤ 12" (thickness specified as loose measurement)
- Non-Plastic Material: ≤ 15" (thickness specified as loose measurement)

Moisture control: W_{opt} ± 2%

Source of information: Louisiana Department of Transportation and Development (2016), Section 203.

4.19. Maine

Material: top 2 feet should compose of suitable material.

Compaction control:

- The portion of the embankment inside a 1½ H:1V slope lines shall be compacted to the designated embankment compaction requirements.
- RC ≥ 90% (Maximum density as per AASHTO T 180).

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Source of information: Maine Department of Transportation (2014), Section 203.

4.20. Maryland

Material:

- borrow material with maximum dry density of less than 100 lb/ft^3 is unsatisfactory. For A-2, A-3, or A-2-4 groups, the maximum dry density shall not be less than 105 lb/ft^3.
- Potentially expansive materials, such as steel slag, are prohibited.
- There are some plasticity index criteria for modified borrow, but nothing for common borrow.

Compaction control:

- Top 1': RC ≥ 97%, maximum dry density per T 180.
- Below 1': RC ≥ 92%, maximum dry density per T 180.

Lift thickness: ≤ 8" (thickness specified as compacted measurement)

Moisture control: $W_{opt} \pm 2\%$

Source of information: Maryland Department of Transportation (2008), Section 204.

4.21. Massachusetts

Material:

- embankment construction with material other than rock shall be stopped from December 1 to April 1.
- Embankments with 3 meters of height or more, shall be allowed to settle for 60 days before placing the pavement structure.
- For the top 2 feet, the largest rock fragments is limited to 6 inches in the largest dimension.

Compaction control:

- For fine-grained material RC ≥ 95% as per AASHTO T 99 .
- For coarse-grained material with more than 50% retaining on sieve No. 4 (4.75 mm) engineer satisfaction is enforced.

Lift thickness: ≤ 12" (300 mm, thickness specified as loose measurement)

Source of information: Massachusetts Highway Department (1995), Section 150.

4.22. Michigan

Material:

- A mixture of sound earth with rock, stone, concrete or masonry with the largest dimension no greater than 12 inches can be used, except for the top 3 feet of the embankment, where only sound material is accepted. Frost heave textured material should also be excluded from top 3 feet.
- Frost heave textured material are material with more than 50 percent silt particles by weight, and a plasticity index less than 10.
- Material that has a maximum unit weight of at least 95 pounds per cubic foot are sound material.
- Drainage of granular material should not be blocked by placing impervious material on the outside of embankments.

Compaction control: RC ≥ 95% as per AASHTO T 99

Lift thickness:

- Controlled density method; cohesive material: 9" (thickness specified as loose measurement), granular material: 15" (thickness specified as loose measurement).
- Twelve inch layer method: 12" (thickness specified as loose measurement).

Moisture control:

- Cohesive material: $\leq W_{opt} + 3\%$.
- Granular material: below saturation.
- Cohesive material in the top 3 ft. should not exceed optimum.

Source of information: Michigan Department of Transportation (2012), Section 205.03.

4.23. Minnesota

Material: No specific material specifications was found in the reviewed source listed below.

Compaction control: (type of AASHTO compaction test not specified)

- Upper 3 ft. of embankment: RC ≥ 100%.
- Within 3 ft. of structure: RC ≥ 100%.
- Remaining: RC ≥ 95%.

Lift thickness: When uniformly compacted lifts are not achieved, engineer should restrict loose lift thickness to 12".

Moisture control:

- Where 100% maximum density is required, relative moisture content should be in the following range: 65% - 102%.
- Where 95% maximum density is required, relative moisture content should be in the following range: 65% - 115%.

Source of information: Minnesota Department of Transportation (2014), Section 2015.

4.24. Mississippi

Material:

- No rock fragments in top 3 feet.
- Boulders shall be placed near the outer slopes in lower portions of the embankment.

Compaction control:

- Top 3 feet of embankment: RC ≥ 98% (compaction test not specified).
- Below top 3 feet: RC ≥ 95%.

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Source of information: Mississippi Department of Transportation (2017), Section 203.

4.25. Missouri

Material:

- No rocks over 2 inches in size in the upper 4 inches.
- Rocks and boulders greater than 24 inches shall be dispersed to reach uniform compaction.
- Rock fragments larger than lift thickness shall be used in the side slopes.

Compaction control:

- Upper 18 inches of embankment: RC ≥ 95%, elsewhere: RC ≥ 90%. AASHTO T 99 may be used as standard compaction.
- Material having more than 20 percent retained on a 3/4-inch sieve will generally be considered too rocky for satisfactory density testing. Compactive effort on rocky material shall consist of making four complete passes on each layer with a tamping-type roller or two complete passes on each layer with a vibratory roller.
- If compaction of the embankment is a requirement of the contract but has not been specified in it, the compactive effort on each layer shall consist of distributing all equipment movements over the entire embankment area and of at least three complete passes with a tamping-type roller.
- For embankments less than 4 feet height, a depth of 6 inches of the foundation shall be compacted in the same manner as embankment.

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Moisture control:

- Class A material having liquid limit of 40 or more and within top 5 feet: ≥ W_{opt}.
- Leossial soils in embankments less than 30 ft. heigh: ≤ W_{opt} + 3%.
- Leossial soils in embankments higher than 30 ft.: ≤ W_{opt}.

Source of information: Missouri Department of Transportation (2017), Section 203.

4.26. Montana

Material: Top 2 ft. shall be free from rock fragments.

Compaction control:

- RC ≥ 95%, for A-1 material according to AASHTO T 180.
- For embankments 4 feet high or less, top 8 inches of embankment foundation shall be scarified and compacted to RC ≥ 95%.

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Moisture control: W_{opt} ± 2%

Source of information: Montana Department of Transportation (2014), Section 203.

4.27. Nebraska

Material:

- stone and rock fragments larger than 3 inches may be used below top 2 ft. of the embankment surface.
- Maximum allowable size of rock is dependent to the class of embankment, but it is roughly 8 inches. Larger excavated rocks are also allowable, but not for the top 2 feet of the embankment.
- If embankment is to be built with granular material, cohesive material (35% or more passing through No. 200 sieve) capable of supporting vegetation shall be used for the upper 6 inches of slopes and earth shoulders.
- Removed bituminous surfacing and base courses may be placed in the outer slopes of the embankment, but 1 foot (300 mm) below the surface of those slopes and shoulders.

Compaction control and lift thickness: Embankment density and lift thickness is controlled according to the class of embankment. In all cases, the hauling shall be distributed over the entire layer to assist in compacting the material.

- **Class I:** will not be rolled unless specified. Even and dense compaction shall be achieved by varying hauling equipment route over the entire area of each layer. Lift thickness is 12 inches (thickness specified as loose measurement) unless for embankment next to structures that is 6 inches (thickness specified as loose measurement). For embankments next to structures each layer should be compacted by one pass of crawler tractor weighing at least 10 tons or two passes of ordinary compaction equipment.
- **Class II:** Lift thickness is 8 inches in loose state. Each layer shall be rolled at least twice with compacting equipment.
- **Class III:** Lift thickness is 8 inches in loose state. Embankments shall be compacted to the density and moisture content specified in the plans.
- Upper 6 inches of the embankment foundation shall be scarified and compacted to the same requirements for embankment compaction.

Source of information: Nebraska Department of Roads (2007), Section 205.

4.28. Nevada

Material:

- When there are choices of material, place the best material in upper 1 foot of the embankment.
- The upper 6 inches of the embankment shall not include rock fragments.
- Largest rock size is 3 feet. If rock fragments used, they shall form embankment foundation or side slopes.

Compaction control:

- RC ≥ 90%, maximum density according to Nev. T108 (AASHTO T 180).
- For select borrow: RC ≥ 95%.

Lift thickness: ≤ 8” (thickness specified as loose measurement)

Source of information: Nevada Department of Transportation (2014), Section 203.

4.29. New Hampshire

Material:

- Embankment material shall conform with AASHTO M 57.
- Rock fragments as embankment material shall not exceed 4 feet in its largest dimension.

Compaction control:

- For all earth material: RC ≥ 95%, maximum density according to Standard Proctor (AASHTO T 99).
- Bridge approaches and near to structures: RC ≥ 98%.
- For embankments less than 3 ft. high, top 6” of the embankment foundation shall be compacted to the same density as the embankment.

Lift thickness: ≤ 12” (thickness specified as loose measurement)

Source of information: New Hampshire Department of Transportation (2016), Section 203.

4.30. New Jersey

Material:

- The top 30 inches of embankment shall not contain any aggregate larger than 2” in any dimension.

Compaction control:

- For granular material density control test is used: RC ≥ 95% and maximum density according to AASHTO T 99.
- Compaction equipment and operation may also be confirmed by constructing a control strip. Relative compaction tested at the control strip shall be at least 95%, while maximum dry density is determined via AASHTO T 99.
- Embankment more than 15 feet high shall not be constructed without stabilizing the slope.

Lift thickness: ≤ 8” (thickness specified as loose measurement)

Source of information: New Jersey Department of Transportation (2007), Section 203.

4.31. New Mexico

Material:

- In the top 6” of embankment rock fragments shall not be used.
- The top 2 feet of the finished subgrade shall contain material with the design R-value (response value to applied pressure under specific conditions).

Compaction control:

- RC ≥ 95%, maximum density according to AASHTO T 180.
- Embankments that contain mostly rock or coarse-grained material (65% or greater retained on the No. 4 sieve) does not require moisture and density control, except the top 6” of the embankment.
- Original ground surface shall be scarified and compacted to RC ≥ 95% for at least a depth of 6”.

Lift thickness: ≤ 8” (thickness specified as loose measurement)

Moisture control:

- For soils with a plasticity index of 15 or greater compaction moisture content shall be: W_{opt} to W_{opt} + 4%.
- For rock or coarse-grained material: W_{opt} – 5% to W_{opt}.

Source of information: New Mexico Department of Transportation (2014), Section 203.

4.32. New York

Material: No specific material specifications was found in the reviewed source listed below.

Compaction control:

- 2 upper ft. of the subgrade area: RC ≥ 95%, maximum laboratory density as per Standard Proctor.
- Remaining: RC ≥ 90%.

Lift thickness: Depends upon total load per wheel of the compaction equipment-attained via charts.

Source of information: New York Department of Transportation (2015), Section 203.

4.33. North Carolina

Material:

- For the top 1 foot of subgrade A-2-5 and A-5 soils with a PI of less than 8 shall not be used.
- Rock fragments or broken pavement lifts with the largest dimension as 3 feet shall not be placed within top 2 feet of the embankment.
- Rock fragments or broken pavement greater than 2" in diameter shall not be used within top 12" of the embankment.
- Shoulder and slope borrow: Material shall be capable of supporting vegetation, material with $6 \leq PI \leq 25$ and $5.5 \leq PH \leq 6.8$.
- For borrow material, plasticity index requirements are applied. North Carolina is divided into three geological regions. Plasticity Index requirement differs with the construction location. These requirements are listed in the following table.

Table 3. NCDOT criteria for selecting borrow material

Piedmont and Western Mountainous Area	
$PI \leq 25$	Acceptable
$26 \leq PI \leq 35$	Acceptable, but not to be used in top 2 ft. of embankment or backfill
$PI \geq 35$	Not Acceptable
Coastal Area	
$PI \leq 15$	Acceptable
$16 \leq PI \leq 20$	Acceptable, but not to be used in top 2 ft. of embankment or backfill
$PI \geq 20$	Not Acceptable

Compaction control: RC ≥ 95%, maximum density according to AASHTO T 99.

Lift thickness: ≤ 10” (thickness specified as loose measurement)

Source of information: North Carolina Department of Transportation (2012), Section 235.

4.34. North Dakota

Material:

- Topsoil shall be removed to a depth of 6".
- No rock fragments larger than 4" shall be placed in the top 1 foot.
- No rock fragments shall be used in the top 2 feet.

Compaction and moisture control:

- Unless the contract specifies otherwise, compaction requirement is as follows: RC $\geq$ 90%, maximum density according to AASHTO T 180, moisture content as W_{opt} to W_{opt} + 5%.
- In case Standard Proctor (AASHTO T 99) is specified in the contract: RC $\geq$ 95%, and moisture content as W_{opt} - 4% to W_{opt} + 5%.

Lift thickness: $\leq$ 12" (thickness specified as loose measurement)

Source of information: North Dakota Department of Transportation (2014), Section 203.

4.35. Ohio

Material:

- Natural soils with maximum dry density of at least 90 lbs/ft^3.
- Soil liquid limit should be less than 65.
- Group classifications A-5, or A-7-5 should be abandoned. Granular material A-2-5 is also unqualified.
- Some gradation limits apply to granular material.
- Silt or ODOT group classification A-4b can not be used within 3 ft. below the surface of the subgrade.

Compaction control: maximum laboratory density according to AASHTO T 99.

- For $g_{d\max}$ = 90-104.9 lb/ft^3, Minimum RC = 102.
- For $g_{d\max}$ = 105-119.9 lb/ft^3, Minimum RC = 100.
- For $g_{d\max} \geq$ 120 lb/ft^3, Minimum RC = 98.
- Top 8" of the foundation should be compacted to 95% relative compaction (AASHTO T 99).

Lift thickness: $\leq$ 8" (thickness specified as loose measurement)

Source of information: Ohio Department of Transportation (2016), Section 203.

4.36. Oklahoma

Material:

- Borrow material shall be free from dispersive clay. If dispersive clay is present in the borrow material, slopes shall be clay plating with a layer of soil having $8 \leq PI \leq 18$.
- Embankment foundation shall be cleared from topsoil. Cleared ground shall be scarified to a depth of 8", then compacted to RC ≥ 95% maximum density according to AASHTO T 99.
- Rock fragments shall be placed furthest from the roadbed centerline. Rock fragments larger than 3" are forbidden in the top 1 foot of the fill.
- Material for backfilling must be in accordance with AASHTO M 145.

Compaction control: RC ≥ 95%, maximum density according to AASHTO T 99**.**

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Moisture control: within ±2% of W_{opt}

Source of information: Oklahoma Department of Transportation (2009), Section 202.

4.37. Oregon

Material: Stone and rock fragments larger than 3" in size are not allowed in the upper 1 foot of embankment.

Compaction control:

- 1 foot depth of existing ground of the embankment shall be compacted to the same density as embankment.
- For each embankment layer, a minimum of three coverages is needed.
- RC ≥ 95%, maximum density according to AASHTO T 99 (not mentioned directly).
- At least one deflection test for each 3 feet of embankment needs to be performed. The layer tested shall not exhibit any deflection.
- If material contain rock fragments and are not density testable, a minimum of four full coverages using a smooth drum vibratory roller is needed.

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Moisture control: W_{opt} - 4% to W_{opt} + 2%

Source of information: Oregon Department of Transportation (2018), Section 00330.

4.38. Pennsylvania

Material:

- Embankment material include soil (fine-grained), granular material type 1, granular material type 2, rock, shale and random material (granular material combined with shale, concrete, brick, stone, or masonry units).
- Soil material (fine-grained portion) shall meet the following requirements. It shall consist of earth having 20% or more of the material passing the No. 200 sieve and having a minimum dry density of 95 pounds per cubic foot, maximum liquid limit of 65, and for soils with $41 < LL < 65$, $PI \geq LL-30$.

Compaction control:

- Top 3 feet of embankment: $RC \geq 100\%$, maximum density in accordance with AASHTO T 99.
- Remaining: $RC \geq 97\%$.

Lift thickness: ≤ 6” in compacted state, and for granular material type 2 limited to 8” after compaction.

Moisture control: W_{opt} - 3% to W_{opt} for non-granular material, ±2% of optimum moisture content for granular material.

Source of information: Pennsylvania Department of Transportation (2016), Section 206.

4.39. Rhode Island

Material:

- Common borrow for the embankment construction shall not contain more than 17% passing sieve No. 200.
- Rock fragments shall not be used for the upper 2 feet.

Compaction control:

- Top 3 feet: $RC \geq 95\%$, maximum density according to AASHTO T 180.
- Below upper 3 feet: $RC \geq 90\%$.
- For embankments less than 4 feet high, ground surface shall be scarified to a minimum depth of 6” and compacted to same requirements as embankment.

Lift thickness: ≤ 12” (thickness specified as compacted measurement)

Source of information: Rhode Island Department of Transportation (2013), Section 202.

4.40. South Carolina

Material:

- A-7 soil shall not be used for embankment construction.
- Recycled glass aggregate must be limited to 25% (by weight).
- No glass aggregate in the top 18" of the embankment.
- In the top 5 feet of embankment dry density of borrow material shall be at least 100 lb/ft^3.
- Soils with optimum moisture content greater than 25% shall not be used.
- In the top 5 feet of embankment, loss on ignition of borrow material shall be less than 1.0%.
- Acceptable material also varies by county according to AASHTO M 145 classification.
- The top 2 feet shall be free from rock fragments.

Compaction control:

- RC $\geq$ 95%, maximum density according to AASHTO T 99.
- In addition to compaction tests, proof rolling shall be performed for the top 5 feet of embankment. It contains a minimum of 5 passes using rollers only with air-filled pneumatic tires.

Lift thickness: $\leq$ 8" (thickness specified as loose measurement)

Source of information: South Carolina Department of Transportation (2007), Sections 203 and 205.

4.41. South Dakota

Material:

- The top 6 inches of embankments shall be free of rock fragments and stone larger than 4 inch in all direction.
- Top 1 foot shall be free from 3 feet large rock fragments.

Compaction control:

- RC $\geq$ 95%, maximum density according to AASHTO T 99.
- When A-3 soil (fine sand) or A-2-4 (0) soil is encountered or when embankment contains over 40% by weight of durable material passing an 8-inch square opening and retained on a 3/4 inch sieve, density requirements will be waived. The embankment shall be compacted with approved rollers to the satisfaction of engineer.

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Moisture control:

- If $0\% \leq W_{opt} \leq 15\%$: $W_{opt} \pm 4\%$
- If $15\% \leq W_{opt}$: W_{opt} - 4% to W_{opt} + 6%

Source of information: South Dakota Department of Transportation (2015), Section 120.

4.42. Tennessee

Material: Plastic soil shall not be used in combination with rocks.

Compaction control:

- For constructing embankment within 3 feet of the subgrade, ground surface shall be scarified to a minimum depth of 6" and compacted to same requirements as embankment.
- Top 6" of embankment: RC ≥ 100%, maximum density according to AASHTO T 99.
- Below top 6": RC ≥ 95%.

Lift thickness: ≤ 10" (thickness specified as loose measurement)

Moisture control:

- In all cases pumping shall not occur under loads applied by the construction equipment.
- In case 100% of maximum density is required: $W_{opt} \pm 3\%$.

Source of information: Tennessee Department of Transportation (2015), Section 205.

4.43. Texas

Material: For a material to be considered as granular material: LL ≤ 45, PI ≤ 15. Other Materials such as rock, loam, clay, or other approved materials are also acceptable.

Compaction control:

- Laboratory compaction curve is determined at standard energy according to AASHTO T 99.
- Required field relative compaction is according to the following table.

Table 4. Texas DOT requirements for embankment compaction control and moisture control

PI of soil material	RC	Moisture content
$PI \leq 15$	$98\% \leq RC$	
$15 \leq PI \leq 35$	$98\% \leq RC \leq 102\%$	$\geq W_{opt}$
$PI \geq 35$	$95\% \leq RC \leq 100\%$	$\geq W_{opt}$

Moisture control: according to above table to reach the desired dry density.

Lift thickness: 8” (thickness specified as loose measurement)

Source of information: Texas Department of Transportation (2014), Item 132.

4.44. Utah

Material:

- Embankment borrow material shall fall within A-1-a through A-4 AASHTO classification. The granular borrow may be A-1-a, non-plastic, well-graded and 3” maximum.
- Embankments at bridge approaches shall be constructed with granular borrow.
- For constructing embankment within 6 feet of the subgrade, ground surface shall be scarified to a minimum depth of 8” and compacted to 90% relative compaction.
- Rock fragments or pavement materials over 1 foot shall not be used. Rock fragments are not allowed within upper 1 foot.

Compaction control:

- Average RC ≥ 96%, maximum laboratory density according to AASHTO T 180 for A-1 soils and for all other soils according to AASHTO T 99.
- Compacting equipment that causes shear failure shall not be utilized.
- At bridge approaches (within 150 feet of bridge end), post-construction settlement of new embankments shall be mitigated. Mitigation program which is done by surcharge shall complete (cause) 98% of the projected total primary settlement.

Lift thickness:

- Granular borrow: ≤ 6” (thickness specified as loose measurement)
- Other: ≤ 12” loose measurement

Source of information: Utah Department of Transportation (2012), Section 02056.

4.45. Vermont

Material:

- Cohesive soils of A4, A5, A6, or A7 that have excess moisture, may be mixed by granular soils of A1, A2 or A3 to attain acceptable compaction.
- Rock fragments and boulders are not allowed in the top 1 foot. Generally, they shall be placed to form the base of embankment.

Compaction control:

- Top 2 feet: RC ≥ 95%, maximum density according to AASHTO T 99.
- Below top 2 feet: RC ≥ 90%.
- Placement of material other than rock shall stop when the air temperature below 0 °C (32 °F), prohibits achievement of the required compaction.
- Rutting, rolling, shoving, or other displacement in excess of 150 mm (6 inches) under the action of construction equipment may be considered evidence of stability issues.

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Moisture control: less than W_{opt} + 2%

Source of information: Vermont Agency of Transportation (2011), Section 203.

4.46. Virginia

Material: Borrow material shall conform to AASHTO M 57 standard specifications.

Compaction control: RC ≥ 95%, maximum density as per AASHTO T 99.

Moisture control:

- For soil material: W_{opt} ±20%.
- Material having a moisture content above optimum by more than 30% shall not be placed on a previously placed layer of the embankment for drying purposes, unless it is shown that the bottom layer will not become over-moist by downward migration of moisture in the material.
- For shoulder material: W_{opt} ±2%.

Lift thickness:

- For soil material, lift thickness may be limited to 8 inches in loose state.
- Unsuitable material used in widening embankments and flattening embankment slopes shall be placed in uniform layers not more than 18 inches in thickness before compaction.

Source of information: Virginia Department of Transportation (2016), Section 303.

4.47. Washington

Material:

- Any embankment containing 25 percent or more, by volume, gravel or stone 4 inches or more in diameter is referred to as rock embankment. Rock embankment shall not contain material larger than 4" in diameter in the upper 6" layer.
- Common borrow material shall not contain more than 3 percent organic material by weight.
- Common borrow material shall meet plasticity index requirements as following table.

Table 5. Washington State DOT PI requirements for common borrow

Percent passing sieve No. 200	PI
0-12	N/A
12.1-35	PI ≤ 6
above 35	PI = 0

Compaction control:

- Top 2': RC ≥ 95% .
- Below top 2': RC ≥ 90%.
- Maximum dry density and laboratory compaction energy depends on the material gradation. For material with less than 30% retaining on the No. 4 sieve, AASHTO T 99 with Standard Proctor energy is used. For material with more than 30% retaining on the No. 4 sieve, compaction test method would be WSDOT T606 with compaction energy approximately equal to 90 to 95 percent of Modified Proctor.
- Natural ground under the embankment shall be scarified at least to a depth of 6" and compacted to the required density as for the embankment.

Lift thickness:

- Top 2': 4" (thickness specified as loose measurement)
- Below top 2': 8" (thickness specified as loose measurement)

Source of information: Washington State Department of Transportation (2016), Section 2-03.

4.48. West Virginia

Material:

- Organic content of the embankment material shall not exceed 7.5% by weight.
- Subgrade shall be 6" (150 mm) compacted thickness for all embankment and excavation sections and shall be constructed with suitable material not having particles larger than 3".

Compaction control:

- RC ≥ 95%, maximum dry density determination depends on portion of material by weight which passes ¾ inch (19 mm) sieve. If this portion is less than 40%, laboratory compaction energy follows AASHTO T 99. But if it is more than 40%, maximum dry density is determined by a process involving roller passes. The roller shall apply a minimum force of 10 tons. The test section shall be compacted by 12 roller passes, then density is checked after 2 more passes. If the difference is not more than 1 lb/ft^3, the material is considered to have achieved its maximum density.
- The top 8 inches (200 mm) of the embankment foundation shall be scarified and compacted to the density requirements specified.

Lift thickness: ≤ 6" measured after compaction.

Moisture control: For material having less than 40% by weight of particles retained on the ¾ inch (19 mm) sieve: W_{opt} - 4% to W_{opt} + 3%.

Source of information: West Virginia Division of Highways (2010), Section 207.

4.49. Wisconsin

Material: For the top 8 inches, earth embankment material shall be free from large rock and stone fragments.

Compaction control:

- Discontinue constructing embankments in the fall or early winter.
- Upper 6 feet of the embankment, or embankment within 200 feet of bridge end: RC ≥ 95%, maximum dry density according to AASHTO T 99.
- Below 6': RC ≥ 90%.

Lift thickness: ≤ 8" (thickness specified as loose measurement)

Source of information: Wisconsin Department of Transportation (2017), Section 207.

4.50. Wyoming

Material: No specific material specifications was found in the reviewed source listed below.

Compaction control:

- RC ≥ 95%, maximum dry density according to AASHTO T 99 (not mentioned clearly).
- Natural ground surface under the embankment shall be scarified to a a depth of 6” and compacted to RC ≥ 90%.

Lift thickness: ≤ 8” (thickness specified as loose measurement)

Moisture control: W_{opt} - 4% to W_{opt} + 2%

Source of information: Wyoming Department of Transportation (2010), Section 203.

5. Summary and Conclusions

5.1. Summary

An extensive survey and review of Federal, AASHTO and state departments of transportation agencies was performed to review state of practice regarding material selection and construction of highway embankments.

The following subsections graphically summarize the main specifications for material selection and for construction control.

5.1.1. Requirements on Material Gradation

After intensive review of the state standards it is noted that only a few of them have minor requirements set for material gradation. These include six states of Colorado, Ohio, Rhode Island, South Carolina, Utah and Pennsylvania. In all cases, these requirements are very general; for instance, South Carolina specifies that A-7 group soil shall not be used. Pennsylvania also sets some requirements only for the fine-grained portion of the embankment material. Figure 1 shows states imposing requirements on gradation. It is noted that two U.S. separate states, that is Alaska and Hawaii are also shown on the map.

All states mention a maximum allowable particle size suitable for the upper layers of embankment. They usually forbid using particles larger than 4 to 6 inches in the upper 1 or 2 feet, and also disallow use of large rock fragments and stones in the top few feet of the highway embankment.

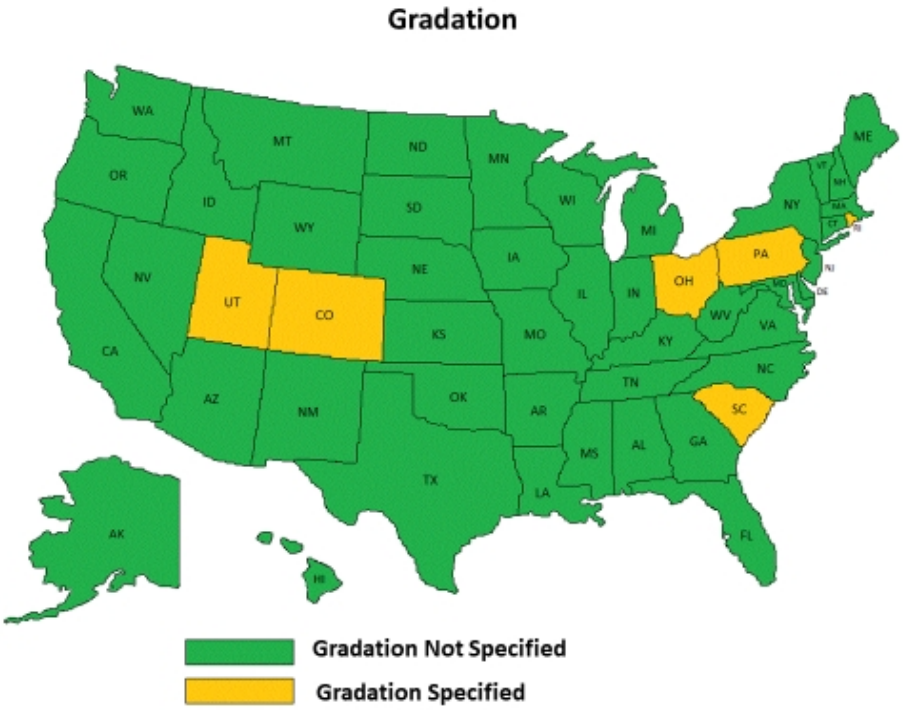

Figure 1. States imposing requirements on gradation as material selection criterion

5.1.2. Requirements on Material Atterberg Limits

Seven states including Delaware, Louisiana, North Carolina, Ohio, Pennsylvania, Texas and Washington have specifications on the Atterberg limits required for the material used in embankments. Figure 2 shows states imposing requirements for Atterberg limits.

Instead of setting a maximum plasticity index, Delaware has specified a maximum liquid limit of 40%. Louisiana sets a minimum PI of 11 and a maximum of 25 for what they classify as usable soil for embankment construction. North Carolina's current specifications require that the plasticity index stay below 15 for coastal area, and below 25 for piedmont and western area. Pennsylvania specifies that embankment material can consist of both fine-grained portion and granular portion, then it states some conditions regarding gradation, and Atterberg limits of the fine-grained portion which are listed in Table 6. In Texas, for a material to be considered as granular the following shall hold: LL $\leq$ 45, PI $\leq$ 15. Texas also correlates acceptable relative compaction to the PI of the soil being compacted. In Washington, as borrow material becomes finer, the PI shall be limited to a lower value. This state is probably one of the strictest states with PI = 0 for material having more than 35.1% passing sieve No. 200. Table 6 also summarizes information for U.S. states which use Atterberg limits as embankment material selection criteria.

Of course, in some specific portions of the embankment, like bridge approaches, or for the select borrow which is usually of higher quality than common borrow, plasticity index requirement

may be stricter (in this case lower). However, requirements pertaining to the bridge approaches or to the select borrow are not covered completely in this report.

One instance of atypical specifications which are set for sections other than embankment body is as following; Iowa DOT (2015) specifies that select cohesive soils must have a plasticity index greater than 10 (PI>10), which of course denies the dominant portion of requirements with a trend to limit PI to a maximum value.

Table 6. Summary of states specifying Atterberg limits as material selection criteria

State	Specification
Delaware	LL of borrow ≤ 40
Iowa	PI > 10, for select cohesive soils
Louisiana	11 ≤ PI ≤ 25
North Carolina	PI ≤ 15 for coastal area; PI ≤ 25 for piedmont and western area
Ohio	LL < 65
Pennsylvania	for soil (fine-grained portion): LL < 65; if 41 < LL < 65: PI ≥ LL-30
Texas	LL ≤ 45, PI ≤ 15 for granular material
Washington	if 12.1 ≤ P_{200} ≤ 35, PI ≤ 6 if 35.1 < P_{200}, PI = 0

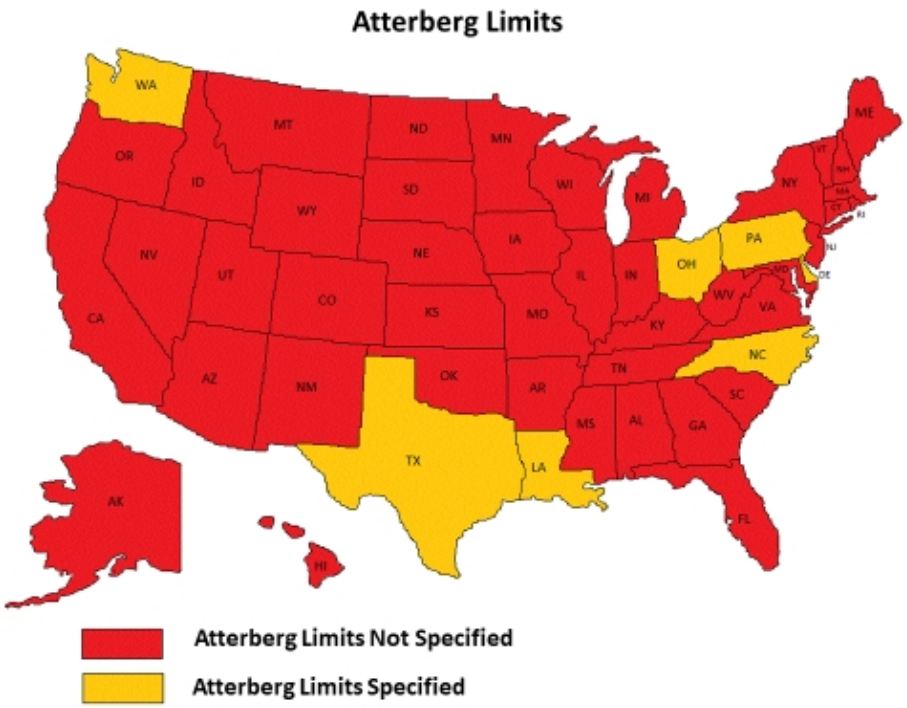

Figure 2. States imposing requirements on Atterberg limits as borrow material selection criteria

5.1.3. Requirements on Minimum Field Dry Unit Weight and Relative Compaction

Nine states (Colorado, Delaware, Georgia, Indiana, Maryland, Michigan, Ohio, Pennsylvania and South Carolina) have specifications limiting the minimum dry unit weight of material placed in highway embankment. Of these states, Colorado, Delaware, Georgia, Indiana and Ohio limit the dry unit weight to a minimum value of 90 lbs/ft^3. Michigan and Pennsylvania limit the unit weight to a minimum of 95 lbs/ft^3. Maryland and South Carolina limit the minimum unit weight to 100 lbs/ft^3.

The majority of states require achieving a minimum relative compaction specified with respect to a laboratory standard compaction test, such as Standard Proctor (AASHTO T 99) or Modified Proctor (AASHTO T 180). Of course, a vast number of states use local standards, which represent AASHTO standards with a level of minor modification.

Of all the 50 states reviewed, 33 states somehow state that maximum laboratory dry density ($g_{d\max}$) shall be obtained in accordance with AASHTO T 99, which uses Standard Proctor energy. 23 of these states necessitate reaching exactly the minimum relative compaction of 95%, while others range from minimum RC of 90% to 102%. AASHTO and FHWA also require compacting embankments to RC $\geq$ 95% while $g_{d\max}$ obtained at standard energy level. This fact may justify the high number of states sticking to AASHTO T 99. Number of states accepting AASHTO T 180, Modified Proctor energy, is equal to eight. Half of them require minimum RC of exactly 95% while others range within 90% to 95%.

Five of the states combine standard and modified energy in quality control process, correlating level of compacting energy to factors like material gradation or selected minimum RC in the plans. Two states of Kansas and Nebraska test the quality of embankment compaction according to the roller status. Compaction is considered accomplished by them for example when tamping feet of the roller walks out of the surface, or when a specific number of passes is obtained. No information regarding compaction energy could be found for the two states of Minnesota and Mississippi. They have only stated relative compaction level. Table 7 summarizes compaction energy level distribution among states and Figure 3 shows compaction energy level specifications by each state across the U.S.

Table 7. Summary of compaction energy required by states

Energy Level	Number of States
Standard Proctor	33
Modified Proctor	8
Standard/Modified Proctor	5
roller controlled	2
not mentioned	2

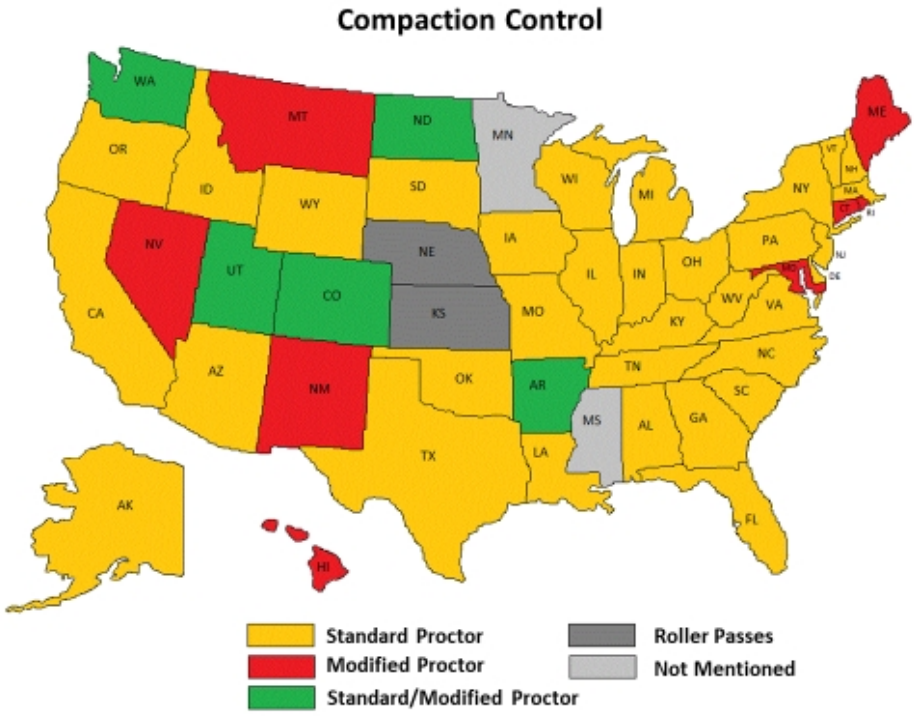

Figure 3. Compaction energy specifications by state

5.1.4. Requirements on Moisture Control

Twenty seven (27) states have specified some kind of criteria as the moisture content control. These requirements are in most of cases as an acceptable range for placing moisture content. The requirements differ based on the material gradation, Atterberg limits of material, moisture content of material itself, and level or energy of compaction.

Ten (10) states have specified acceptable moisture content in the range of ±2% of optimum moisture content. This high number seems to be related to the same specification set by Federal and AASHTO standards.

Twenty three (23) states have not specified any to designate moisture content of the embankment layers. Of course, all of them imply that material moisture content shall be in a range that minimum field density requirement is achievable.

5.1.5. Requirements on Lift Thickness

A lift thickness of 8” in loose state is required by 31 states, while two of the agencies require same 8” lift thickness but measured after compaction. Majority of the states consider lift thickness in loose state as only five states of Florida (6” or 12” depending on gradation), Maryland (8”), Pennsylvania (6”/8” for granular material), Rhode Island (12”), West Virginia (6”) set lift thickness requirement measured after compaction. Only Indiana uses a compound lift placement measurement as 6” after compaction and 8” in loose state.

It is noted that maximum accepted lift thickness is 12”, while the minimum is 4” loose measurement in Washington that is for the top 2 feet of embankment. Depending on material gradation, compaction class or position of layer, some states have different placing layer thicknesses.

All states have mentioned lift thickness as an easy to use, smooth and whole number, whether loose or compacted, except New York where lift thickness shall be obtained via charts with the load per wheel of compacting equipment as input. Lift thickness specifications requirement is summarized and illustrated in Figure 4. This figure shows 7 states having lift thicknesses equal to 12”; out of which only Rhode Island referring to compacted state and the rest indicating loose state. For states colored as “other” please refer to the extended explanations or the appendix table.

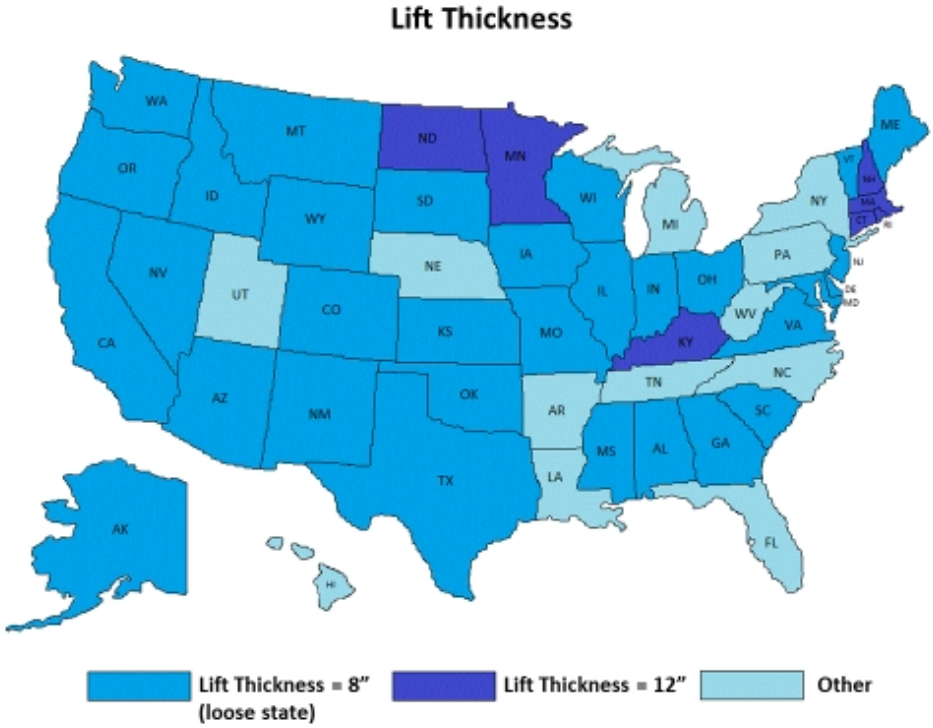

Figure 4. Variation of lift thickness specifications by state

5.2. Conclusions

This study found that embankment material selection criteria may vary considerably from state to state. Among U.S. fifty states, only a few impose requirements on material gradation or material plasticity criteria that is Atterberg limits including the plasticity index and liquid limit. Most state specifications include provisions to ensure suitable mineral soils with minimum organic content.

In contrast, the FHWA specifies for engineered fills that will support bridge foundations a requirement of a PI not greater than 10 to minimize long-term deformations.

Regarding construction related specifications, most states specify a maximum lift thickness in terms of loose thickness. Additionally, it is common to use a minimum relative compaction to specify a minimum compacted dry unit weight. The most commonly used compaction efforts are the AASHTO T 99 (Standard Proctor) or AASHTO T 180 (Modified Proctor); however; a few states specify the compaction energy associated with a local standard. Out of 50 states, 33 use the Standard Proctor compaction and 8 use the Modified Proctor compaction. In some few cases, compaction control is also stated in terms of the number of passes of the roller or compaction equipment used in the specific project.

The specification of the placement moisture content of the compacted soil was found not to be as prevalent, for about half of the state departments do not specify any requirement for the placing moisture content of embankment material. However, they instead imply that the moisture content should be in a range so that the requirement for a minimum field dry density could be met. For the states that do specify moisture control, it is usually stated in the form of some whole number of percentage points below or above the laboratory optimum moisture content (W_{opt}) obtained for the same specified compaction test to define the RC. Ten (10) states have specified acceptable moisture content in the range of ±2% of optimum moisture content.

Based on the survey of literature the following knowledge gaps and needs have been identified:

- Material selection needs to include issues such as durability and soundness of the material.
- The use of PI is limited to a few states, but the possibility of undesirable long-term deformations should be investigated when material with PI greater than 10 is used.
- Conventional field compaction acceptance criteria based on RC does not provide any information relating to embankment slope stability and/or embankment allowable settlement.
- Lack of moisture control requirements could result in some cases of unwanted engineering performance such as large embankment deformations or slope stability issues.

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APPENDIX A – Summary Table for Specifications

In this section, a summary of the federal and states specifications is presented for easy and quick use purposes. It is noted that state specifications are not limited to the listed items in the table, but most of the specifications associated with rock fragments dimension, gradation, plasticity index, minimum $\gamma_{d\max}$, minimum required RC, laboratory compaction energy to get $\gamma_{d\max}$, lift thickness and placing moisture content are listed. As described in the list of abbreviations, $P_{3/4}$, P_4 and P_{200} indexes present in some fields of the table represent percent of material passing ¾ inch sieve, No. 4 sieve and No. 200 sieve respectively.

It is noted that in the "Compaction Energy" column of the table, standard and modified refer to the Standard Proctor and Modified Proctor respectively. They are shortened only to save space.

Table A1. Summary of the U.S. Federal and States specifications for embankment material selection and embankment placement

Standard or State	Source	Material Specification	Compaction Energy	Compaction Control	Lift Thickness*	Moisture Control
FHWA	[12]	special attention for A-2-6, A-2-7, A-4, A-5, A-6, A-7	standard	RC ≥ 95%	n.f.	W_{opt} ±2% (for subgrades with fine-grained soils)
AASHTO	[1]	- A-1, A-2-4, A-2-5 and A-3 groups are preferable - special attention for A-2-6, A-2-7, A-4, A-5, A-6, A-7	standard	RC ≥ 95%	n.f.	W_{opt} ±2% (for embankments and subgrades with fine-grained soils)
Alabama	[4]	n.f. *	standard	RC ≥ 95%	8” loose	n.f.
Alaska	[5]	n.f.	ATM 207 (Not mentioned clearly)	RC ≥ 95%	8” loose	W_{opt} ±2%
Arizona	[6]	- material within 3’ of subgrade shall meet resilient modulus - PI ≤ 15, at the bridge abutments	standard	RC ≥ 95%	8” loose	n.f.
Arkansas	[7]	selected material for bridge approaches	standard (less than 31% on sieve No. 4) modified (more than 31% on sieve No. 4)	RC ≥ 95%	10” loose	n.f.
California	[8]	n.f.	Not mentioned	top 2.5’: RC ≥ 95% below 2.5’: RC ≥ 90%	8” loose	n.f.
Colorado	[9]	- $\gamma_{d\,max} \geq 90$ lbs/ft^3 - Predominantly finer than sieve No. 4 (4.75 mm)	standard/modified (RC depends on compaction level selected)	granular: RC ≥ 95% (modified) or RC ≥ 100% (standard) fine-grained: RC ≥ 90% (modified) or RC ≥ 95% (standard)	8” loose	A-2-6, A-2-4, A-4, A-6, A-7 groups: not drier than W_{opt} - 2%

* Notes: n.f.: not found: no specific information was found in the reviewed source - Lift thickness can be initial loose or final compacted

Table A1. Summary of the U.S. Federal and States specifications for embankment material selection and embankment placement (continued)

State	Source	Material Specification	Compaction Energy	Compaction Control	Lift Thickness	Moisture Control
Connecticut	[10]	n.f.	modified	RC ≥ 95%	12” loose	n.f.
Delaware	[11]	- $\gamma_{d\max}$ of borrow: ≥ 90 lb/ft^3 - LL of borrow ≤ 40	standard	RC ≥ 95%	8” loose	W_{opt} ± 2%
Florida	[13]	- P_{200} ≤ 15% (For A-2-4 group) - in top 1’, no fragments larger than 3 ½”	standard	- RC ≥ 100% - embankment Construct in sections longer than 300’	6” or 12” compacted (depending on gradation)	n.f.
Georgia	[14]	- pond sand: $\gamma_{d\max}$ ≥ 90 lb/ft^3 - pond sand shall be encapsulated	standard	top 1’: RC ≥ 100% below 1’: RC ≥ 95%	8” loose	n.f.
Hawaii	[15]	- in top 2’ no fragments larger than 6” and minimum sand equivalent of 10	modified	top 2’: RC ≥ 95% 6” below top 2’: RC ≥ 90%	9” loose	W_{opt} ± 2%
Idaho	[16]	n.f.	standard	Class A compaction: RC ≥ 95%	8” loose	W_{opt} - 4% to W_{opt} + 2%
Illinois	[17]	in top 1’, no fragments larger than 4”	standard	RC: ≥ 90% to 95% depending on embk. height and lift location	8” loose	for top 2’ ≤ 1.2*W_{opt}
Indiana	[18]	- $\gamma_{d\max}$ ≥ 90 lb/ft^3 - organic content ≤ 6% - in top 1½’ no fragments larger than 3” - if PI of embk. material is less than 8, encase embk. - 6” deep material suitable for vegetation on shoulder slopes	standard	dynamic cone penetrometer control alternately: RC ≥ 95%	6” compacted 8” loose	Clay soil: W_{opt} ± 2% Silty and Sandy: W_{opt} - 3% to W_{opt} Granular: 5% - 8%
Iowa	[19],[20]	- PI of select cohesive soils > 10 - n.f. in the main standard book	standard	density controlled: RC ≥ 95% roller controlled: at least 1 pass/inch of the loose thickness of layer	8” loose	W_{opt} - 3% to W_{opt}

Table A1. Summary of the U.S. Federal and States specifications for embankment material selection and embankment placement (continued)

State	Source	Material Specification	Compaction Energy	Compaction Control	Lift Thickness	Moisture Control
Kansas	[21]	n.f.	n.f.	Type B compaction: tamping feet of the roller walks out of the surface	8” loose	n.f.
Kentucky	[22]	in top 1’ no fragments larger than 4”	standard	RC ≥ 95%	12” loose	W_{opt} ± 2%
Louisiana	[24]	- usable soil: 11 ≤ PI ≤ 25, organic content ≤ 5%, silt content ≤ 50% - granular material with organic content ≤ 4%, - if PI < 10, place minimum 12” plastic soil blanket	standard	RC ≥ 95%	12” loose (plastic) 15” loose (non-plastic)	W_{opt} ± 2%
Maine	[25]	suitable material for top 2’	modified	RC ≥ 90%	8” loose	n.f.
Maryland	[26]	- $\gamma_{d\max}$ of borrow ≥ 100 lb/ft^3 - A-2, A-3, or A-2-4 groups: $\gamma_{d\max}$ ≥ 105 lb/ft^3 - expansive material, such as steel slag, are prohibited	modified	top 1’: RC ≥ 97% below 1’: RC ≥ 92%	8” compacted	W_{opt} ± 2%
Massachusetts	[27]	- in top 2’, no fragments larger than 6” - no soil embk. construction from December 1 to April 1 - embk. higher than 3 m shall be allowed to settle for 60 days	standard	fine grained soil: RC ≥ 95% coarse-grained: engineer satisfaction	12” loose	n.f.
Michigan	[28]	- top 3’ (sound material): $\gamma_{d\max}$ ≥ 95 lb/ft^3 - top 3’ (no frost heave): silt content ≤ 50% or PI ≥ 10 - drainage of granular material should not be blocked	standard	RC ≥ 95%	9” loose (cohesive) 15” loose (granular) 12” loose (12” method)	cohesive material: ≤ W_{opt} + 3% granular material: below saturation

Table A1. Summary of the U.S. Federal and States specifications for embankment material selection and embankment placement (continued)

State	Source	Material Specification	Compaction Energy	Compaction Control	Lift Thickness	Moisture Control
Minnesota	[29]	n.f.	not mentioned	top 3': RC ≥ 100% below 3': RC ≥ 95%	12" loose	for RC ≥ 100%: 65% - 102% of W_{opt} for RC ≥ 95%: 65% - 115% of W_{opt}
Mississippi	[30]	- no rock fragments in top 3' - boulders shall be placed near outer slopes in lower portions	not mentioned	top 3': RC ≥ 98% below 3': RC ≥ 95%	8" loose	n.f.
Missouri	[31]	no rocks over 2" in top 4"	standard	- top 18": RC ≥ 95% - below 18": RC ≥ 90% - rocky material ($P_{3/4}$ < 80%): tamping-type roller, 4 passes/layer - rocky material: vibratory roller, 2 passes/layer - if not specified: minimum 3 passes with tamping-type roller	8" loose	if LL ≥ 40, for the top 5': ≥ W_{opt} Leossial soils in embk. lower than 30': ≤ W_{opt} + 3% Leossial soils in embk. higher than 30': ≤ W_{opt}
Montana	[32]	no rock fragments in top 2'	for A-1 group: modified	RC ≥ 95%	8" loose	W_{opt} ± 2%
Nebraska	[33]	- no fragments larger than 3" in top 2' - in granular embk., cohesive material (P_{200} ≥ 35%) capable of supporting vegetation shall be used for the upper 6" of slopes and earth shoulders	n.f.	Class I: hauling equipment Class II: 2 passes/layer Class III: density and moisture content specified in the plans	Class I: 12" loose Class II & III: 8" loose	n.f.
Nevada	[34]	no rock fragments in top 6"	modified	RC ≥ 90%	8" loose	n.f.
New Hampshire	[35]	material shall conform to AASHTO M 57	standard	RC ≥ 95%	12" loose	n.f.
New Jersey	[36]	no fragments over 2" in top 30"	standard	RC ≥ 95% embk. higher than 15': slopes shall be stabilized	8" loose	n.f.

Table A1. Summary of the U.S. Federal and States specifications for embankment material selection and embankment placement (continued)

State	Source	Material Specification	Compaction Energy	Compaction Control	Lift Thickness	Moisture Control
New Mexico	[37]	no rock fragments in top 6”	modified	- RC ≥ 95% - coarse-grained embk. ($P_4 \leq$ 35%) does not require moisture and density control, except the top 6”	8” loose	for PI ≥ 15: W_{opt} to W_{opt} + 4% for rock or coarse-grained material: W_{opt} - 5% to W_{opt}
New York	[38]	n.f.	standard	top 2’ within subgrade: RC ≥ 95% below 2’: RC ≥ 90%	depending on load per wheel of equipment	n.f.
North Carolina	[39]	- within 1’ of subgrade, A-2-5 and A-5 groups with PI ≤ 8 is rejected - no fragments over 2” in top 1’ - piedmont and western area, PI ≤ 25 - piedmont and western area, 26 ≤ PI ≤ 35, not for top 2’ - coastal area, PI ≤ 15 - coastal area, 16 ≤ PI ≤ 20, not for top 2’ - Shoulder and slope borrow: capable of supporting vegetation; 6 ≤ PI ≤ 25 and 5.5 ≤ PH ≤ 6.8	standard	RC ≥ 95%	10” loose	n.f.
North Dakota	[40]	no fragments over 4” in top 1’	standard/modified	RC ≥ 90% (modified) RC ≥ 95% (standard)	12” loose	Modified Proctor: W_{opt} to W_{opt} + 5% Standard Proctor: W_{opt} - 4% to W_{opt} + 5%
Ohio	[41]	- $\gamma_{d\max}$ ≥ 90 lb/ft^3, LL < 65 - A-2-5, A-5 and A-7-5 are banned - silt (or A-4b) is forbidden within 3’ of subgrade	standard	RC ≥ 98%-102% depending on $\gamma_{d\max}$	8” loose	n.f.
Oklahoma	[42]	- no fragments over 3” in top 1’ - no dispersive clay as borrow material	standard	RC ≥ 95%	8” loose	W_{opt} ± 2%

Table A1. Summary the of U.S. Federal and States specifications for embankment material selection and embankment placement (continued)

State	Source	Material Specification	Compaction Energy	Compaction Control	Lift Thickness	Moisture Control
Oregon	[43]	no fragments over 3" in top 1'	standard	- RC ≥ 95% - minimum of 3 coverages/layer - minimum 1 deflection test for each 3' of embankment depth	8" loose	W_{opt} - 4% to W_{opt} + 2%
Pennsylvania	[44]	- for fine-grained portion: $\gamma_{d\max} \geq 95$ lb/ft^3, LL < 65, $P_{200} \geq$ 20%, for soils with 41 < LL < 65: PI ≥ LL-30	standard	top 3': RC ≥ 100% below 3': RC ≥ 97%	6" compacted 8" compacted (for granular material type 2)	non-granular: W_{opt} - 3% to W_{opt} granular: W_{opt} ± 2%
Rhode Island	[45]	- common borrow: $P_{200} \leq 17\%$ - no rock fragments in top 2'	modified	top 3': RC ≥ 95% below 3': RC ≥ 90%	12" compacted	n.f.
South Carolina	[48]	- A-7 soil shall not be used - recycled glass aggregate limited to 25% - no glass aggregate in the top 18" - for top 5': $\gamma_{d\max} \geq 100$ lb/ft^3, and loss on ignition ≤ 1% - soil with $W_{opt} > 25$ shall not be used - no rock fragments in top 2'	standard	- RC ≥ 95% - for top 5', proof rolling shall be performed in addition to compaction tests. It contains a minimum of 5 passes using rollers with air-filled pneumatic tires	8" loose	n.f.
South Dakota	[49]	no fragments over 4" in top 6"	standard	- RC ≥ 95% - for A-3, A-2-4 (0) or large durable material density requirement is waived and substituted by satisfaction of engineer	8" loose	If 0% ≤ W_{opt} ≤ 15%: W_{opt} ± 4% If 15% ≤ W_{opt}: W_{opt} - 4% to W_{opt} + 6%
Tennessee	[50]	plastic soil shall not be used in combination with rocks	standard	top 6": RC ≥ 100% below 6": RC ≥ 95%	10" loose	for RC ≥ 100%, W_{opt} ± 3%
Texas	[51]	for granular material: LL ≤ 45, PI ≤ 15	standard	for PI ≤ 15, 98% ≤ RC for 15 ≤ PI ≤ 35, 98% ≤ RC ≤ 102% for PI ≥ 35, 95% ≤ RC ≤ 100%	8" loose	if PI ≥ 15, W ≥ W_{opt}

Table A1. Summary of the U.S. Federal and States specifications for embankment material selection and embankment placement (continued)

State	Source	Material Specification	Compaction Energy	Compaction Control	Lift Thickness	Moisture Control
Utah	[52]	- embk. borrow material shall fall within A-1-a to A-4 groups. - no rock fragments in top 1’	for A-1 group: modified for other soils: standard	RC ≥ 96%	granular: 6” loose other: 12” loose	n.f.
Vermont	[53]	no rock fragments in top 1’	standard	top 2’: RC ≥ 95% below 2’: RC ≥ 90%	8” loose	≤ W_{opt} + 2%
Virginia	[54]	borrow shall conform to AASHTO M 57	standard	RC ≥ 95%	for soil: 8” loose	for soil: W_{opt} ± 20% for shoulder: W_{opt} ± 2%
Washington	[55]	- no fragments over 4” in top 6” - borrow spec: organic content: ≤ 3% if 12.1 ≤ P_{200} ≤ 35, PI ≤ 6 if 35.1 < P_{200}, PI = 0	fine-grained: standard coarse-grained: 90%-95% of modified	top 2’: RC ≥ 95% below 2’: RC ≥ 90%	top 2’: 4” loose below 2’: 8” loose	n.f.
West Virginia	[56]	organic content: ≤ 7.5%	if $P_{3/4}$ < 40%: standard if $P_{3/4}$ > 40%: roller controlled	RC ≥ 95%	6” compacted	if less than 40% retained on the ¾ inch sieve: W_{opt} - 4% to W_{opt} + 3%
Wisconsin	[57]	no rock fragments in top 8”	standard	top 6’: RC ≥ 95% below 6’: RC ≥ 90%	8” loose	n.f.
Wyoming	[58]	n.f.	standard	RC ≥ 95%	8” loose	W_{opt} - 4% to W_{opt} + 2%