SECTION 330 Embankments

330.1 General

The success of an embankment constructed to support a pavement structure depends upon proper preparation of the foundation, use of suitable materials, and proper placing and compacting of materials. To provide stability the material placed in an embankment is required to be uniformly compacted to proper density.

Uniform, proper density is best obtained in an embankment by placing the fill material in complete layers and compacting each layer to the required density. The maximum thickness of a layer of soil that can be readily and acceptably compacted will depend upon the character of the soil and the type and weight of the equipment in use, but generally should not exceed 8 inches. See standard spec 207.3.2, standard spec 207.3.3, and standard spec 207.3.4 for placing layers, placing in marsh, and placing rock.

Only materials determined to be acceptable for providing stability are to be placed in the portion of embankment that lies between one-to-one slopes extending outward and downward from the finished shoulders. Unsuitable materials or materials that will adversely affect the stability of the roadbed may be placed, in limited quantities, in the fill outside the assumed one-to-one slopes.

Most native soils, including silty soils and clays, are suitable for embankments when dried to optimum moisture content. Drying may take an extended period of time, especially if rain or cold affect progress of the work. It will then be a matter for the engineer to determine whether to allow the contractor to waste the native soil and backfill with a more suitable soil, or to require the contractor to proceed with drying operations.

If a problem with the embankment material is suspected, the engineer may request that the contractor run a loaded truck over the grade. Whether or not the engineer asks to see loaded trucks run the grade, it does not relieve the contractor of responsibility for the soundness of the grade. If the presence of excessive moisture content is shown by rutting, pumping, cracking, clipping, or collapse, placement and compaction of an embankment should not proceed. Operations should be halted and the material either allowed to dry or be manipulated and aerated using appropriate equipment such as graders, discs, or harrows. All ice and snow must be removed from the ground surface before placing embankment. Do not place embankment on frozen subgrade.

Where rock fills are constructed, to avoid or minimize future settlement, the rock should not be dumped in its final position but should be deposited slightly aside and bulldozed or otherwise shoved into position in such a manner that the various sizes of rock are uniformly distributed and all voids are completely filled with fine material.

Where embankments are required to be built in half-widths to accommodate traffic or for other reasons, it is advisable that the two be bonded together by cutting benches in the first part as the second part is placed.

When starting soil compaction work, it is good practice to perform several field compaction tests to determine proper compaction equipment, number of passes, and roller speed needed to attain density or stability. Usually, tests are made only after several passes (4-8) have been made using the contractor's equipment.

At the end of each day's grading operations, the subgrade surface should be sealed to aid in drainage of any surficial water and minimize water infiltration into the compacted subgrade, according to standard spec 207.3.9.

330.2 Compaction Methods

330.2.1 General

Standard spec 207.3.6.1 provides, except for hydraulic and rock fills and for backfilling of wet marshes, that all embankments must be compacted as provided for standard compaction, unless special compaction is required by the plans or contract. The terms special compaction and standard compaction have nothing to do with the desired soil density. Rather, they are terms for the methods used to check or observe that the desired soil density is being achieved.

Advantages and disadvantages of each compactive method are outlined below:

TABLE 330-1 Standard v. Special Compaction

Standard Compaction	
Advantages	Disadvantages
Less testing equipment.	Experienced personnel needed.
Allows broader enforcement.	Judgmental for highly variable soils.
Adequate for many soils, particularly granular.	Poorer coverage and lift thickness control.
Simplified record keeping.	Misleading in dry cohesive soils.
	Ambiguous specification.
	Less confidence in design.
	Misleading in clod-type soils.

Special Compaction	
Advantages	Disadvantages
Specific data at specific site.	Difficult to select standard lab density.
Enforceable in specific language.	Impossible or largely judgmental in highly variable soils.
Allows more control on problem soils as fat clay, silts, organics, etc.	Largely unneeded on granular soils, etc.
Easily documented.	Requires more equipment to be effective.
Better confidence in design for high fills,	Process often too slow to effectively control lifts: i.e., additional lifts go on before testing is complete.
Plastic soils in subgrade or similar critical uses.	
See subsection 207.3.6.1.	

The advantages and disadvantages noted above must be considered and applied to the combination of local soil conditions encountered, design parameters, and performance requirements. As these vary in numerous combinations, no exact parameters can be applied. However, the guidelines above can be used to set up recommendations made by the region to the engineer.

For plastic soils with liquid limits greater than or equal to 45, special compaction should be recommended. For soils with liquid limit less than or equal to 25, standard compaction, if done according to specification, should give acceptable performance. On some very bony soils, density tests of any type are virtually impossible. On these, no density requirements are expected, and are rarely needed.

Fill height should also be a criterion. Fills with heights exceeding 35 feet should have a controlled compaction specification and fills in excess of 50 feet should mandate both density and moisture controls. Silts in higher fills should have moisture controls and always be compacted at 2% to 5% below optimum moisture. Fills with heights exceeding 50 feet, if built of silts or clay, should have analyses based on tests to give design parameters. Also, low height fills of material having a liquid limit greater than 45 should have special compaction.

With a considerable amount of current construction being on short fills that are inherently difficult to compact, the region soils engineer should give special attention to these situations.

It is intended that a check density test be made on all embankments regardless of the acceptance method. Refer to CMM 832 for testing frequencies.

Also, the consequences of future settlements should be weighed. A higher fill will settle more than a shallow fill. For example, often a 25-foot fill will cause foundation settlement much more than 2-1/2 times that of a 10-foot fill. Also, the soil engineer should relate anticipated future settlement in the foundation to the fill design, for if there is to be a future settlement of say one foot in the foundation soil, then 3 inches of settlement in the fill due to lack of compaction may not be of primary concern.

For optimum field results, it should be emphasized that standard compaction without adequate overall control can be difficult. Similarly, grade inspections using special compaction should never depend on tests alone to control compaction. Use of correct equipment, method of placement, lift thickness, and compactive coverage under direct observation and inspection are essential.

See standard spec 207.3.6.1, standard spec 207.3.6.2, and standard spec 207.3.6.3 regarding compaction.

330.2.2 Standard Compaction

Standard spec 207.3.6.2 relating to standard compaction provides that each embankment layer must be compacted to the degree no further appreciable consolidation is evidenced under the action of the compaction equipment, before any material for a succeeding layer is placed on it. The embankment must be compacted across its full width from slope-to-slope. The standard specifications require the contractors hauling and leveling equipment to be routed over the complete area being compacted during placement, until adequate compaction is achieved. If this does not adequately compact the materials, the engineer may require the additional use of specialized compaction equipment. The engineer should ensure that the specialized compaction equipment being used is suitable for the soils encountered.

The engineer will base the determination on field evidence that demonstrates the compaction afforded by the contractor's hauling and leveling equipment is acceptable and the specialized compaction equipment is not needed. Field evidence should be recorded if verifying density using only hauling and leveling equipment. Include a record of soil type, types of equipment in use, specific pattern of uniform routing and distribution of hauling equipment over the grade, frequency and results of personal observation, measurement of rut depths or lack thereof, and back-up density tests. See standard spec 207.3.6.2.

Marginal or erratic compliance by the contractor with specification requirements concerning full and uniform compaction of each lift across the full width of the embankment must be immediate cause for requiring specialized compaction equipment or adjustment in the contractor placing operations.

The determination of when the degree of compaction required for standard compaction has been attained is one of judgment. Density tests are not performed as a control of compaction, and test results are not available for handy documentation.

The standard specifications provide that when standard compaction is employed, layers must generally not exceed 8 inches in thickness before compaction. This thickness may need to be reduced for some clay or clay-bearing soils.

Soils of different types require different degrees of effort to obtain compaction to required density, and their moisture content will influence the degree of density attained through the effort expended. Generally, soils will compact most readily when their moisture content is between 90% and 110% of their optimum moisture content.

Moisture content is more of a means to an end to achieve density than a desired property within itself. For example, a heavy clay compacted considerably dry of optimum will be compacted only with tremendous compaction energy, say 4 to 5 times normal compactive effort. A 2% increase in moisture content would allow the clay to be compacted with normal effort. Silts compacted at or above optimum moisture usually cannot be brought up to the desirable density and therefore should be compacted at 2-5% below optimum.

Some properties of soils are affected to a degree by compaction moisture content. A clay compacted fairly wet will have slightly less consolidation and slightly greater strength than it would exhibit if compacted rather dry. A check should always be made where moisture is of concern, either by drying a wet soil or wetting a dry material.

The observation and inspection of embankments compacted under standard compaction procedures is essential. The grade inspector should ensure each layer meets the thickness and placing requirements and is uniformly compacted across the full width of the embankment to the required degree.

To provide a record of compaction achievement and a basis of documentation, the grade inspector must make at least one entry per day in the inspector's diary for each embankment, excluding minor fills, being constructed. The entry should indicate the location, soil type, amount and type of hauling, leveling and specialized compacting equipment, relative moisture content of the material (very wet, wet, moist, dry, etc.), layer thickness and pertinent information on rutting or displacement, drying or aeration, addition of water, routing pattern of hauling equipment, coverage with compaction equipment, and any special difficulties encountered. Additional entries may be required when substantial changes in soils, moisture, or other conditions occur during the day. When equipment, soils, moisture, or other conditions remain the same from day-to-day, appropriate simplified diary entries may be made indicating this condition instead of a complete detailed statement reported daily.

Random density tests for informational purposes, to indicate the approximate level of standard compaction being achieved statewide, must be made at the frequency and in accordance with the requirements of CMM 832. On projects involving variable soil conditions or erratic contractor operations, the frequency should be increased.

330.2.3 Special Compaction

Where special compaction of embankment is required, the contractor may use suitable compacting equipment of the contractor's choice and is responsible for the proper moisture content of the soil for consolidating to the specified density under the efforts of the equipment. It is the responsibility of the inspection forces to determine whether or not the embankment materials have been acceptably consolidated. Density tests for determining the attained density in the compacted material should be taken as frequently as necessary for adequate control under particular job circumstances and minimum frequency of the tests should be as required under CMM 832.

Compaction control of an embankment by density tests should be only for that portion of the embankment that is within the limits designated by assumed one-to-one slopes extending outward and downward from the finished shoulders. Portions of embankment lying outside the assumed one-to-one slopes will receive standard compaction effort.

330.3 Compaction Equipment

Under standard spec 207.3.6.2 the contractor is required to route dozers, trucks, scrapers, end loaders, and other leveling and hauling equipment laterally across the grade. Operations concentrated along fixed wheel paths will not provide adequate compaction. If the contractor's operations are spread out across the grade but still not providing adequate compaction, the contractor should adjust their operations and equipment to improve the level of compaction. If adjustments fail to produce the required level of compaction, the engineer should intercede to ensure that proper compaction is achieved.

The engineer may direct additional operational changes and, under standard spec 207.3.6.2, may also require that differing and additional compaction equipment be used. The engineer will expect that the additional equipment be designed specifically for compacting the soil types encountered but may also approve other equipment the contractor might suggest.

The specification allows the contractor to control their means and methods as long as the engineer determines that adequate compaction is achieved. The contractor might select equipment on the basis of soil type, the contractor's experience, availability of equipment types, required rate of production, or for other reasons.

The contract requires that compaction be done at or near the optimum moisture content for a given soil type. The contractor and engineer can use table 330-2 to get a general idea of the effectiveness of various pieces of construction equipment under those conditions. If there are issues obtaining adequate compaction, the contractor should coordinate with the engineer to determine the mix of engineer-approved equipment and construction operations appropriate for the work.

TABLE 330-2 Compaction Effectiveness

Soil Type	Equipment Type						
	Pneumatic Tired Vehicles				Smooth Drum Vibratory Roller	Padfoot Vibratory Roller	Padfoot or Sheepsfoot Static Roller
	Rubber-Tired Dozers	Off-Road Trucks	End Loaders	Scrapers			
Sand	Very Good	Very Good	Very Good	Very Good	Very Good	Fair	N/A
Sand & Gravel	Very Good	Very Good	Very Good	Very Good	Very Good	Fair	N/A
Silty Sand & Gravel	Very Good	Very Good	Very Good	Very Good	Good	Fair	Poor
Clayey Sand & Gravel	Good	Good	Good	Good	Fair	Good	Good
Silt	Good	Good	Good	Good	Fair	Very Good	Very Good
Clay	Good	Good	Good	Good	Poor	Excellent	Excellent

Construction equipment provides a combination of static or dynamic pressure, kneading, and vibration actions to compact/densify the subgrade soils. The most effective compaction action for the various types of soils depends on several factors including the soil type, moisture, and depth of required densification. Table 330-3 describes the general mechanical action provided by various types of equipment. Review of tables 330-2 and 330-3 will assist the engineer in ensuring the contractor employs the most effective equipment that provides the appropriate mechanical action for project and soil conditions.

TABLE 330-3 Mechanical Action Under Construction Equipment

Equipment	Mechanical Action
Vibratory Roller	The contractor may use vibratory rollers to compact granular soils. Vibration overcomes the friction between particles and reduces voids. A relatively light vibratory roller can equal or exceed the compactive effect of an extremely heavy unit. Generally, the slower the forward speed of a vibratory roller the more effective the operation. Track dozers have some vibratory effect, but their weight is distributed over such a large area that unit pressures are very low. Vibrations have little effect on cohesive soils.
Padfoot Roller	The pads on this roller transfer mechanical action to compact the soil. Each imprint receives a high pounds per square inch (psi) pressure at the bottom of each imprint. The soil is too wet to compact if the inspector sees material sticking between pads. Compaction will only happen if the soil is somewhere near optimum moisture content. If the moisture content is too high, the bottom of the imprint left by the padfoot roller will be soft. The roller compacts soil from the bottom up. The roller will ride higher and higher on the roadbed on successive passes over the subgrade. Under optimum conditions, the roller will "walk out" of the roadbed.
Sheepsfoot Roller	The long spikes on the drum of a sheepsfoot roller puts a lot of force on a small area. It breaks down the cohesion in silts and clays. This roller compacts soil from the bottom up. The feet penetrate to a bottom layer on the first pass. On successive passes, if the soil has the right moisture content, the roller will ride higher and higher until it "walks out". It is not effective on coarse grained non-cohesive soils.
Pneumatic Tired Vehicles	Rubber tired rollers provide both kneading and pressure. To a lesser extent, rubber tired earthmoving equipment has a similar action. It is effective on both cohesive and granular soils.
Smooth Drum Static Roller	A static smooth wheel roller is good for sealing the working surface after the days operation. This sealed surface assists in rain runoff and reduces water penetration. This roller does not provide adequate lift compaction.

330.4 Embankment Slopes

Standard spec 207.3.8 requires the embankment slopes be built to the lines and section shown on the plan or as directed by the engineer.

The engineer or inspector should check during grading operations that the fills are not being overbuilt without permission or direction by WisDOT. Overbuilding unnecessarily uses up the relatively inexpensive material excavated on the project and could require costlier borrow excavation to be imported from outside the project.

The contractor must build embankments to the planned slopes and section until we are confident that overbuilding can be done to absorb excess excavation, waste excavation, or surplus excavation without resulting in the need to purchase more borrow than required by the plan. Before proceeding with overbuilding, the contractor must obtain the approval of the engineer.

If overbuilt fills are discovered during the grading phase of the project and no direction or approval has been given by WisDOT, the engineer will order the contractor to stop the overbuilding and to correct the situation.

Overbuilt fills discovered after completion of the grading may require a reduction in the quantity of the classes of excavation used to construct the embankment.