PUTTING RESEARCH TO WORK BRIEF

Lift Thickness Limits and Embankment Construction

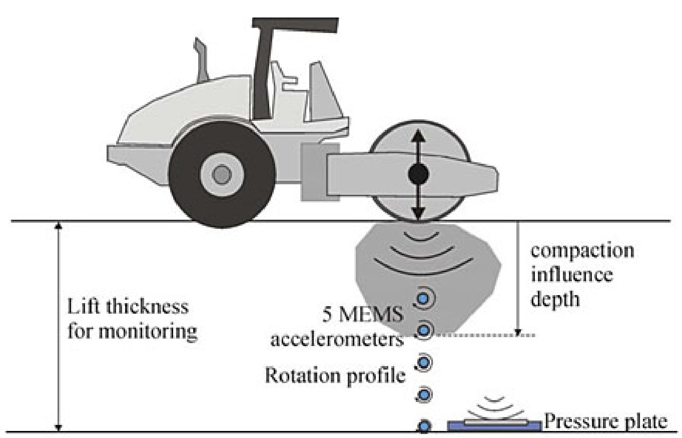
The Wisconsin Department of Transportation (WisDOT) spends approximately ten percent of its annual improvement project budget on embankment construction. An embankment consists of a series of compacted lifts, or layers, of suitable material placed on top of one another until the level of the subgrade surface is reached. A critical aspect of embankment construction is stability. This stability is essential for pavement construction and contributes to the long term performance of the structure by transferring traffic loads to the foundation soil. To produce effective embankment lifts, WisDOT developed specifications to limit loose lift thickness during construction. The current specification limits lift thickness to 0.20 meters (8 inches) for most soil conditions. This limit was established for a variety of reasons, most notably that practical field experience with contractor methods and equipment showed this to be an adequate embankment compaction level that did not require excessive testing or inspection by WisDOT staff.

Background

The determination of appropriate lift thickness used in embankments has important economic and engineering implications in the design, construction and performance of transportation systems. A small lift thickness results in excessive construction time and costs, whereas a large lift thickness may result in poor compaction homogeneity, ultimately compromising the stability and performance of the embankment. Although the 0.20-meter (8-inch) thickness was initially established through practical field experience, compaction technology has since advanced. Questions have also been raised after a few WisDOT projects exceeded the 0.20-meter (8-inch) limit. These two developments require WisDOT to reevaluate its specifications to determine if the 0.20-meter (8-inch) lift thickness is still the optimal limit for embankment construction.

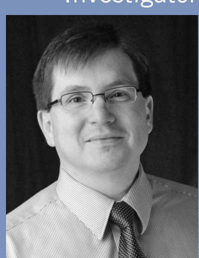
Research objectives

1. Develop a field monitoring system to evaluate compaction energy and the subsequent degree of compaction at various depths below the surface.
2. Conduct numerical analyses to relate the degree of soil compaction at various depths to compactor type, operating weight, and contact width (footprint).
3. Determine the influence of soil parameters (e.g. soil texture, water content, plasticity) on the dissipation of compactive energy.
4. Create recommendations to optimize lift thickness for the compaction equipment and soil types most commonly encountered during WisDOT construction projects.



Instrumented soil layer by MEMS accelerometers

Investigator



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Methodology

Field testing was conducted using six different types of soil compactors and earthmoving equipment, including smooth-drum vibratory rollers, pad foot rollers and scrapers. Evaluation of the compactors and earthmoving equipment was conducted on different soil types (e.g. poorly graded sand, silty sand), which possessed different water contents, while increasing loose lift thickness from 0.20 meters (8 inches) to 0.60 meters (24 inches). Evaluation of the compaction effectiveness was conducted using soil stiffness gauge (SSG), pressure plate, dynamic cone penetrometer, sand cone, nuclear density gauge, and P-wave propagation analysis. The field studies were complemented with a numerical simulation designed to evaluate the compaction-soil interaction.

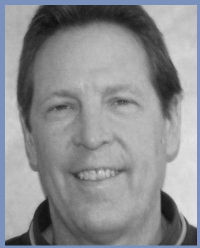
Results

- For coarse-grained soils, loose lift thickness up to 0.40 meters (16 inches) performed well in all tested parameters, including soil particle rotation, dynamic cone penetration and nuclear density gauge. However, the interpretation of the SSG modulus at the near surface, and P-wave-based modulus at the bottom of thick lift layers, provided evidence of under-compaction regions at the bottom of lifts in coarse- and fine-grained soils. These data justify setting maximum limits of 0.40 meters (16 inches) on loose lift thickness, even though for most coarse-grained soils the use of large equipment appears to be effective in achieving required compaction levels.
- For fine-grained soils, the data are not as definitive. However, nuclear density gauge results from two different sampling depths do not appear to show a detrimental effect for the tested loose lift thickness at different water contents and with different compaction equipment. These findings were confirmed by the results from the dynamic cone penetration (DCP) testing. DCP showed that for all conditions, the 0.30-meter (12-inch) lift thickness displayed the maximum shear strength along the compaction profiles in all but one of the tested cases.
- Tire-based roller and earthmoving equipment provided higher contact pressures. These high pressures propagate deeply into the soil mass, resulting in successful compaction of thicker layers. However, as shown by the pressure plates in the field experiments, this type of roller may produce zones that are under-compacted if the roller misses the path above the plate. Because the area coverage of these rollers is limited, WisDOT officials and contractors need to be mindful of offsetting passes to ensure that the entirety of the lift has received an appropriate level of compaction.
- Shear-induced rotation measurements indicate soil particle movement, which is dependent on the type of soil and compaction equipment used. This observation suggests that the current, conservative lift thickness specification for coarse-grained soils may be increase by well-controlled compaction equipment and the water content of the soil.
- Results of numerical modeling show that:
    - » The compaction process is a function of the compactor's weight, soil type, and contact width of the wheel load.
    - » Using a soil model that measures volumetric hardening and deviatoric hardening, it is possible to use volumetric strain and failure zones in numerical simulations to indicate depths of compaction effectiveness.
    - » The evaluation of the relative compaction using volumetric strain analyses indicates that compaction effectiveness (RC>95%) is observed at 0.30-meter (12-inch) depth, regardless of soil or compactor types. However, tire-based rollers may leave areas that are under-compacted due to their highly localized and high pressure footprints.

Recommendations

Overall results and interpretations of the field monitoring, field testing and numerical modeling of wheel loading compaction suggest that 0.30-meter (12-inch) loose lifts for coarse- and fine-grained soils could be implemented in accordance with WisDOT's Quality Management Program. However, before any revisions are made to WisDOT specifications, additional data collection for different soil types and compaction equipment is necessary. As a result, until more data have been analyzed, WisDOT should continue to adhere to its current lift thickness limit of 0.20-meter (8-inch) for coarse- and fine-grained soils undergoing standard compaction.

Project Manager



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This brief summarizes Project 0092-08-11,
"Effective Depth of Soil Compaction in Relation to Applied Compactive Energy"
Wisconsin Highway Research Program