The Greatest Problem and Solution in Infrastructure

All civil engineers know that the governing standard for the practice of professional civil engineering & construction (E&C) is to ensure that engineering design requirements are achieved in construction with direct data verification, in full accordance with the code of professional engineering practice. This is why design is done before construction, all construction is inspected, and all materials are tested and certified during construction. For example, samples of all new concrete pours are tested and broken to measure strength and ensure design strength requirements are achieved. This is also why construction that fails to meet engineering requirements is reconstructed. For example, all new concrete pours not meeting strength requirements are destroyed and reconstructed during construction. All elements of construction require direct verification of engineering design achievement during construction. The requirements for earthen fill construction are no different than any other element of civil construction. An important distinction though, is that earthen fills are a founding element of most infrastructure.

The Earthen Fill Component of Construction

The greatest risk in infrastructure is ground risk. The earthen fill elements of infrastructure are the most critical components of ground risk today, and the primary source of the greatest problem in infrastructure. See "**The Most Critical Component of Ground Risk Today**."

The Importance of Compaction Control in Fill Construction

Fills are built by the compaction of soils. Soil compaction is the most prevalent form of ground modification used in all infrastructure developments. However, compaction control is largely misunderstood in the industry, and thus control efforts are inadvertently dysfunctional. These typical control problems lead to **the constant production vs. engineering struggles that plague the industry, during construction and after**.

The purpose of compaction is to improve the engineering properties of soil material as a stable supporting element of foundations, structures and pavements. Compaction is also conducted to construct low-permeability barrier fills. Soil compaction must achieve the engineering requirements specific to each design fill. Compacted fills should always be an improvement of engineering properties over the in-situ or "bank" soil conditions of naturally placed soils. Today however, that is too often not the case.

All geotechnical engineers specify a compaction standard and process control methods for construction. The process controls always intend to achieve the compaction standard in construction. The compaction standard is typically a moisture-density range connected to the optimum moisture content and maximum dry-density in the compaction of a given soil.

Most geotechnical engineers know well the importance of wet-of-optimum compaction. This is why wet-of-optimum compaction is routinely specified in practice. Most geotechnical engineers understand at least some of the many reasons why wet-of-optimum compaction is so important and why dry-of-optimum compaction is dangerous. Regardless, all geotechnical engineers intend for the specified compaction standards to be achieved, but generally do not realize those standards are typically not achieved in construction.

The primary cause of strength loss, differential settlements and shrink-swell problems developing over time with moisture change, is insufficient fills that are assumed to be acceptable. This condition is the primary cause of the $19 billion in annual US property damage -- and escalating at $0.35 billion annually. This damage persists because the compaction standards (and mainly wet-of-optimum compaction) are generally not achieved in construction as required, engineers assume the standards are achieved, and the engineering properties of compacted fills are unknown and typically deficient. Geotechnical engineers know to require wet-of-optimum compaction, but many do not realize that the assumptions and associated trial & error exercised in the various process control methods used do not achieve that requirement throughout fills and often result in dry-of-optimum compaction instead.

Percent of maximum density control requirements are also essentially never achieved in construction, also contributing to the infrastructure problems.

Full, asymptotic compaction is also usually not achieved, and this contributes to the problem as well. Many engineers know the importance of full and uniform compaction in construction. (This is why standard reference lab compaction tests simulate full, uniform compaction … *of a specific compactor*.) Typical process control assumptions and most trial & error habits force limited compaction effort, which causes partial compaction and varied compaction energy across all lifts. Partial compaction lessens properties and causes varied compaction. Varied compaction results in varied properties across lifts. Both limited and varied compaction contributes to the problem.

When soils are not sufficiently compacted in construction, the fill soils can later be expected to compact more due to the combination of new infrastructure loading and moisture variation over time. During construction, the difference in the compaction loads between the largest and smallest compactors, can result in as much as a 2” difference in lift compression. When subsequent loads from the infrastructure built atop the fill exceed the loads induced by the compactor during fill construction, the fill can be expected to compress further. Shrink-swell problems will also occur with moisture variation where compaction states are insufficient. We must compact all fills sufficiently in construction.

The Problem Affecting Process Controls in Fill Construction

Many process control methods and efforts vary and are widely used across the industry, all for the same compaction specifications. All process control methods are intended to achieve the compaction standards required in construction. All process control problems are inadvertently caused by engineers applying the specified compaction standards to compaction curves that are always different than the compaction curves in construction. This forces contractors to try to get compactor operators to “target” something different than what the compactor or roller produces – which is a mechanical impossibility. This always results in assumptions, trial & error exercises with lab and field data, and inadvertent errors. This, in turn, results in inadvertent engineering compromise and deficient construction, which is always proven by routine field data. These conditions prevent the controls needed for both engineering and construction.

Compaction Control of Fills

Compaction is a mechanical densification of soil by external forces. The function of compaction is the expulsion of air from soil. More specifically, compaction is densification of unsaturated soil by reducing the volume of air voids, while the volume of solids and water remain essentially the same. The air content represents moisture content increase potential. Therefore, effective compaction increases density with a consequent reduction of moisture content increase potential.

The primary engineering purposes of compaction (of cohesive soils) are listed below.

- Reduce moisture content increase potential (how much water can get in the compacted soil)
- Increase shear strength
- Stabilize strength during wetting and saturation
- Reduce permeability (how easily water can infiltrate the compacted soil)
- Control swelling and shrinking (from wetting and drying of the compacted soil)
- Reduce liquefaction potential

Compaction controls are designed to achieve these engineering purposes. These objectives must be achieved in construction to the minimum design requirements of each fill, in order for each fill to have the strength & stability needed to prevent excessive strength loss, differential settlements and shrink-swell movements for the long-term. However, these objectives are typically not achieved in construction today as engineers generally assume.

Minimizing air content in compaction fully achieves of all of these engineering purposes -- and maximizes those achievements with the right compaction controls. Densification by the expulsion of air is the function of compaction. The compaction controls dictate the effectiveness of that function. Compaction controls can be effective or counter-effective.

Wet-of-optimum compaction equals minimum air content. In order to achieve wet-of-optimum compaction in construction, optimum moisture content must be known in construction (field compaction). Without ESOL's tools, optimum moisture is never known in construction.

"Without ESOL's tools, optimum moisture is never known in construction"

- Soil densification increases fill strength. Compaction wet-of-optimum moisture content stabilizes fill strength, stabilizes fill volume, and minimizes fill permeability. Compaction dry-of-optimum moisture content destabilizes fill strength, destabilizes fill volume, and increases and maximizes permeability.

- Wet-of-optimum compaction results in a true, stable strength that reduces only slightly when the fill is saturated. Dry-of-optimum compaction results in a deceptive, unstable strength that drops dramatically when the fill is saturated. These significant drops occur immediately dry-of-optimum, and become increasingly worse with further dry-side compaction.

- Wet-of-optimum compaction minimizes water accessibility and how much water volume can get in or through the fill (and evaporate out). Dry-of-optimum compaction rapidly increases both water access and water volume that can get in the fill (and evaporate out). These impacts are significant immediately dry-of-optimum, and gradually get worse with further dry-side compaction.

- Wet-of-optimum compaction minimizes shrink-swell of fills from minimized wetting and drying potential. Dry-of-optimum compaction rapidly increases shrink-swell of fills from maximal wetting and drying. These impacts are significant immediately dry of optimum compaction, and gradually get worse with further dry-side compaction.

- Where wet-of-optimum compaction is achieved in construction (with the right compaction controls), strength loss will be minimal, differential settlements of fills will not occur, and shrink-swell movements will be controlled and minimized. These conditions protect and preserve infrastructure developments.

- Where wet-of-optimum compaction is not achieved in construction, strength loss, differential settlements, and shrink-swell problems will develop to some extent with moisture variation over time. These problems cause major infrastructure damage. The slightest movements - measured in millimeters – can damage rigid infrastructure built over the fills. These degrees of movements can occur from fills as thin as just a lift or two. In all cases, service life is greatly reduced and maintenance costs are increased significantly.

Solution of the Greatest Problem in Infrastructure

ESOL provides the controls needed to remove the assumptions, trial & error exercises and inadvertent compromise from any and all process control methods currently in use. ESOL provides real-time E&C control with direct data verification for all project parties -- before, during and after construction. These controls make all process control methods functional, corrects inadvertent errors, achieves engineering standards of practice, maximizes production in construction, and provide best possible compaction control and performance with direct data recordation.