



# Structural Performance Dossier

LL30 · LL25 · LOAD-BEARING CAPACITY · REV. B

ENGINEERING DOSSIER — REV. B

# Structural Performance

*Laboratory-to-field correlation of the load-bearing capacity of the LL-TEQ™ pavement system (LL30 / LL25). In-service strength exceeds the unconfined laboratory value.*

**1,310–3,705 PSI** **Corrected UCS range**  
16 specimens, 2 accredited labs, 7 years (2016–2023).

**PCASE 2.09** **Field-certified under real aircraft loads**  
As a final wearing surface (UFC 3-260).

**Mark D. Hardy, P.E.** **Engineer of Record**  
Hardy Engineering · PE 36538.

## | Subject

This dossier establishes the factual and reasoned link between accredited third-party laboratory test data and the in-service structural performance of the LL-TEQ™ pavement system (LL30: structural integration; LL25: surface seal). It is the load counterpart to the Freeze-Thaw Performance dossier.

## | Central finding

The compressive strength of the LL30 layer in service exceeds the value reported by the unconfined laboratory cylinder, because in service the layer is laterally confined by the surrounding treated material and cannot expand laterally. The unconfined laboratory value is therefore a floor, not a service average. Five independent families of evidence (compressive strength, rutting resistance, accelerated load at elevated temperature, permeability, and real aircraft loadings) converge on the same conclusion of high structural performance.

## | Scope and boundary

This dossier documents structural performance. It does not produce the resilient modulus ( $M_r$ ) value required as the design input of the Québec CHAUSSÉE 2 method, which remains to be produced by the LC 22-400 test (§3). That boundary is stated openly.



### **Engineer of Record scoping note**

The signing Engineer of Record has monitored the LL-TEQ™ system in actual service since 2015. The LL-TEQ system is a road technology that provides both the wearing surface and the structural function as a single unified layer, implemented through cold in-place recycling or in-place stabilization of native soil, on a treatment depth of  $\approx 150$  mm (6 inches), reaching  $\approx 200$  mm (8 inches) for the most demanding service

regime. The underlying raw test data are held in the STR / FLD / SUP source record; this dossier does not replicate that data, it establishes the structural interpretation that the source reports do not, on their own, provide.

*Companion to the LL-TEQ™ Freeze-Thaw Performance dossier: the structural (load) pillar, counterpart to the climate pillar. A faithful French translation is available for reading purposes; the English version signed and sealed by the Engineer of Record is the official document.*

# The laboratory value is a floor, not the service performance

01

A single mechanism, from which everything else follows

## | Physical cause (A)

In service, the treated LL30 layer is integrated continuously across the full width and depth of the pavement. It is laterally confined by the surrounding treated material, which shares the same cohesion mechanism. No lateral expansion is mechanically possible.

## | Evidence (B)

The compressive strength (UCS) values of the record are obtained on cylindrical cores of  $\approx 100$  mm (4-inch) diameter (with one  $\approx 150$  mm / 6-inch core for the recycled crushed-concrete specimen, STR-9), tested per ASTM C31/C39/C42, without lateral confinement. Under increasing load, the stabilized material exhibits cohesive ductile behaviour, with lateral expansion observed before peak load. The unconfined cylinder therefore reports a strength under conditions that allow lateral expansion — precisely the conditions that do not exist in service.

## | Conclusion

The in-service compressive strength of the LL30 layer exceeds the unconfined laboratory value. A direct comparison of LL-TEQ™ unconfined UCS with that of a brittle binder (Portland cement concrete) does not, on its own, reflect the in-service difference: a brittle binder's service performance is bounded by its unconfined value (fragile rupture, no prior lateral expansion), whereas LL-TEQ operates in service under continuous lateral confinement not reproduced by the cylinder.

*In plain terms. A pile of loose sand spreads sideways and collapses under your weight. The same sand inside a rigid bucket holds far more, because the walls stop it from spreading. The sand has not changed; the confinement changes what it carries. The laboratory cylinder is the loose sand; the road is the sand in the bucket.*

This mechanism is independent of the substrate category (sand-clay, sandy silty clay with gravel, crushed recycled aggregate, etc.), consistent with the LL/OPSDIRT Application Guide preconditions. The field load-bearing record (§2.5) confirms it empirically.

## Compressive strength (UCS) → structural capacity

2.1

Convergent evidence — cause A + proof B

**A.** The copolymer binder coats and bonds the particles into a continuous cohesive matrix that carries load throughout the treated volume.

**B.** Corrected UCS of **1,310 to 3,705 PSI** (9.0 to 25.5 MPa), across 16 specimens, 2 independent laboratories (S.A.M. Consultants; Universal Construction Testing), 7 years (2016–2023), and 4 substrate categories:

| SUBSTRATE                    | CORRECTED UCS       | REF. (YEAR)  |
|------------------------------|---------------------|--------------|
| Crushed recycled aggregate   | <b>3,705 PSI</b>    | STR-9 (2019) |
| Sandy silty clay with gravel | 3,159 PSI           | SUP-2 (2017) |
| Sand-clay                    | 1,625 PSI           | STR-4 (2016) |
| Yuma soil                    | 1,310 and 1,900 PSI | STR-1 (2016) |

On that same Yuma soil, the untreated material holds only 50 PSI — a gain approaching a factor of 26 to 38, measured on cores of the same material in the same report. Documented cure gain: 2,861 PSI (7 d) → 3,218 PSI (28 d) (STR-8, 2023).

*Honest reserve: strength depends on substrate and dosage; the dosage response is not monotonic (North/South borrow material peaks near 3 %, falls back at 4 %, SUP-6/-7, 2022). Project dosage is calibrated to the substrate by incremental on-site testing.*

# Rutting: Hamburg Wheel-Track AASHTO T-324 → shear

## 2.2 resistance

Convergent evidence — cause A + proof B

**A.** No thermosensitive bituminous matrix: nothing that softens in heat or hardens with age.

**B.** **1.78 mm maximum rut at 20,000 passes**, 25 °C under water immersion (LL30, Behnke Materials Engineering, AMRL-accredited, 2018) — i.e. 14 % of the maximum allowable (12.5 mm at 50 °C) for the most heavily-trafficked bituminous concrete (high-volume interstate, PG 58-28 binder). Companion LL31 test: 1.33 mm at 25 °C, 1.29 mm at 35 °C; the slight improvement at higher temperature documents the absence of thermal softening. Stripping inflection point not reached during the test.

## Accelerated load MMLS → coverage of a second thermal

### 2.3 regime

Convergent evidence — cause A + proof B

- A. Thermal stability of the bonded matrix across an extended temperature range.
- B. **100,000 cycles at 46–60 °C with no measurable deflection or rutting** (MMLS, Kamen Engineering, 2012). Combined with the Hamburg test at 25 °C (§2.2), this covers two distinct thermal regimes (cold and hot) through two independent protocols.

## Permeability → structural water-tightness

### 2.4

Convergent evidence — cause A + proof B

**A.** Closed, non-connected porosity: no continuous capillary network for water to travel through.

**B.** Hydraulic conductivity (ASTM D5084, S.A.M. Consultants, 2017), measured on three companion specimens of the same soil:

| SPECIMEN                             | HYDRAULIC CONDUCTIVITY            |
|--------------------------------------|-----------------------------------|
| Untreated                            | $\approx 6.0 \times 10^{-8}$ cm/s |
| LL30 through the full mass           | $\approx 5.9 \times 10^{-9}$ cm/s |
| LL30 with an added LL30 surface coat | $\approx 3.1 \times 10^{-9}$ cm/s |

Treatment lowers conductivity by about one order of magnitude. The low-permeability LL30 matrix limits water infiltration into the structure.

## Field load-bearing → real aircraft loadings

2.5

Empirical confirmation of the thesis

**A.** The real in-service structural capacity of the laterally confined layer (§1) manifests under high concentrated loads.

**B.** Allowable pass ratings computed by PCASE 2.09 from measured CBR, certified by U.S. military engineers, as a final wearing surface (UFC 3-260-01 / 3-260-02):

| SITE                   | AIRCRAFT & LOAD               | RESULT                                      | SOURCE                     |
|------------------------|-------------------------------|---|----------------------------|
| Mocoron, Honduras      | C-17 Globemaster @ 450,000 lb | 2,470 passes                                | USAF AFSOC (SUP-4)         |
| Mocoron, Honduras      | C-130 / C-130J @ 155,000 lb   | 23,847 passes                               | USAF AFSOC (SUP-4)         |
| ALZ Sandhill, 29 Palms | KC-130J @ 175,000 lb          | <b>10,000+ passes;<br/>surface CBR ≥ 60</b> | USMC MAWTS-1, 2019 (FLD-6) |

Aeronautical loads (concentrated on few landing-gear assemblies under high tire pressures) present per-tire contact pressures greater than standard road traffic. These are field-measured pass ratings, not laboratory projections. **What carries the heavier load carries the lighter.**

*Note: the cumulative real traffic at 29 Palms is the subject of an Engineer of Record update pending documentary confirmation; only the 2019 certified figures are stated here.*

**B.** On GTR class B3 silty gravel (NF P 94-093, EN 13286), LL30-treated:

| DOSAGE              | IPI |
|---------------------|-----|
| 3 %                 | 200 |
| 2 %                 | 270 |
| 1 %                 | 335 |
| Untreated reference | 68  |

About 3 to 5 times the untreated reference (Grollemund LaboRoutes, 2019).

## 03 boundary

Two distinct pathways — one remains open

The performance above is demonstrated. Its translation into Québec design inputs follows two distinct pathways, not to be confused, and one of them remains open.

### | Structural coefficient $a_2$ (AASHTO 1993)

Derived from UCS, it situates the layer as a structural base. The value carried in the record (0.21 to 0.30) is taken by analogy to published ranges for cement-stabilized bases (ARDOT; FHWA/GA) — a design hypothesis to be validated, not a measurement specific to LL30.

### | Resilient modulus $M_r$ (CHAUSSÉE 2)

This is the mandatory design input of the Québec method, and no  $M_r$  is measured in the record. It must be produced by the LC 22-400 test (recommended route), or estimated by the CBR →  $M_r$  correlation (CHAUSSÉE 2, Figure 7, with its limits: support soil, ~43 kPa, seasonal adjustment).

## **Boundary**

This dossier proves high structural performance; it does not produce the regulatory Mr value. The signature that follows attests the reasoning and the performance conclusion, not an Mr that has not been measured. This limit is assumed: it is what makes the dossier credible. Given the performance already supported by the field record and the convergence of tests, the design engineer may anticipate, with high confidence, that a measured Mr will meet or exceed requirements; a correlation provides a range; the LC 22-400 test will quantify the margin.

The preceding evidence documents a central conclusion: across independent laboratory protocols and certified field loadings, the LL-TEQ™ layer delivers high structural capacity, and its unconfined laboratory value understates that capacity by construction of the test geometry.

- 1 Load-carrying response.** The layer is cohesive throughout its full depth, with no interface or internal slip plane, and carries load as a continuous block rather than as stacked courses that can debond. Compressive strength, rutting resistance and permeability are mutually consistent expressions of the same bonded, low-porosity matrix.
- 2 Confinement and service geometry.** The lateral-confinement argument (§1) is strongest in plan (continuous width), and more nuanced in thickness (a thin 150 mm layer with a free surface). The dossier therefore states that in-service strength exceeds the unconfined floor, without quantifying by how much; that quantification is precisely the role of the LC 22-400 measurement (§3).
- 3 Empirical corroboration.** The field record corroborates the reasoning: LL-TEQ layers have carried thousands of certified passes of heavy aircraft as a final wearing surface, under per-tire pressures exceeding road traffic. No unconfined-cylinder reading explains that field behaviour; the confinement argument does.



# Declaration of the Engineer of Record

Signed and sealed — Mark D. Hardy, P.E.

I, the undersigned, **Mark D. Hardy, P.E.**, in my capacity as Engineer of Record on behalf of Hardy Engineering, certify having prepared or supervised the preparation of the present dossier on the structural performance of the LL-TEQ™ pavement system, at the request of Nicolas Giguère.

I attest that the correlation framework set out herein, in particular the lateral-confinement argument (§1), and the conclusion of high structural performance (§§2, 4) are founded on the third-party accredited laboratory test data and the documented field performance referenced in the source record (STR / FLD / SUP).

This attestation does not extend to the resilient modulus (Mr) value required as the design input of CHAUSSÉE 2, which has not been measured and remains to be produced by the LC 22-400 test (§3); the interpretation and integration of these data into any specific project remain the responsibility of the design engineer under the applicable jurisdiction.

The present declaration pertains to the structural performance documented as of the date of signature.

|                                      |                                     |
|--------------------------------------|-------------------------------------|
| <b>Name</b>                          | Mark D. Hardy, P.E.                 |
| <b>Firm</b>                          | Hardy Engineering, Santa Monica, CA |
| <b>Licence</b>                       | PE 36538                            |
| <b>Signature, Engineer of Record</b> | <i>[signed]</i>                     |
| <b>Date</b>                          | May 12, 2026                        |
| <b>Professional seal</b>             | <i>[seal applied]</i>               |

*This English version is intended to be the official document signed and sealed by the Engineer of Record. A faithful French translation is available for reading purposes; in the event of any discrepancy, the signed English version prevails.*

## References and cross-links



Source record and dossier-system cross-links

### Source record (third-party data)

| TEST                                     | LABORATORY / AUTHORITY              | YEAR      | REF.          |
|--|-------------------------------------|-----------|---------------|
| UCS, sand-clay, ASTM C39/C42             | S.A.M. Consultants                  | 2016      | STR-4         |
| UCS, sandy silty clay w/ gravel          | S.A.M. Consultants                  | 2017      | SUP-2         |
| Hydraulic conductivity, ASTM D5084       | S.A.M. Consultants                  | 2017      | STR-7         |
| Core testing, crushed recycled aggregate | S.A.M. Consultants                  | 2019      | STR-9         |
| 28-day curing curve                      | S.A.M. Consultants                  | 2023      | STR-8         |
| UCS, Yuma soil                           | Universal Construction Testing      | 2016      | STR-1         |
| Hamburg Wheel-Track AASHTO T-324         | Behnke Materials Engineering (AMRL) | 2018      | STR-5 / STR-6 |
| MMLS accelerated load                    | Kamen Engineering                   | 2012      | STR-3         |
| IPI, NF P 94-093 / EN 13286              | Grollemund LaboRoutes               | 2019      | STR-2         |
| Pass rating DCP/CBR, Mocerom             | USAF AFSOC, PCASE 2.09              | 2015-2019 | SUP-4         |
| Certification, ALZ Sandhill              | USMC MAWTS-1                        | 2019      | FLD-6         |

## **| Cross-links within the dossier system**

Source evidence relied upon: STR-1 to STR-9, SUP-2, SUP-4, FLD-6. This dossier reasons these sources; it does not replace them.

Companion pillar: Freeze-Thaw Performance dossier, Site 7 (Bridgeport) documents a C-17 in real service on an 8-inch LL-TEQ™ layer under 172 freeze-thaw cycles per year — the crossing point of the structural and climate pillars.

*Standard numbers and revisions of the cited standards (MTQ, AASHTO, ASTM, BNQ) are to be verified against current catalogues before submission. Application Guide preconditions apply to all deployments: CBR ≥ 40, no organic material, Dmax ≤ 80 mm, unfrozen soil, granulometric correction for high-plasticity soils.*



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