

# Civil Engineering Challenges and Sustainable Infrastructure Strategies for Hyperscale Data Centers

Dhruval Jigar Shah<sup>1</sup>

Department Manager, ECS Southeast LLC, NC, USA<sup>1</sup>

**Abstract** — The rapid growth of hyperscale data centers has created new demands on civil engineering systems that support mission-critical digital infrastructure. This paper evaluates civil engineering challenges associated with large data-center campuses through a real-life case study of the QTS data center development in York County, South Carolina. Publicly available project information is combined with established civil engineering and construction-management principles to examine mass grading, geotechnical engineering, foundation interfaces, stormwater management, underground utilities, pavement systems, construction materials testing, quality assurance, and sustainability. The study proposes a risk-based framework in which civil infrastructure is treated as a reliability system rather than as a collection of independent site activities. The case study demonstrates that phased development, dense utility networks, temporary drainage conditions, heavy construction traffic, and rapid technology change require strong coordination and location-based quality documentation. Project-specific confidential information is not assumed; technical controls beyond verified public facts are presented as engineering recommendations. The resulting framework is applicable to hyperscale and mission-critical construction projects where long-term reliability depends on the quality of site and civil infrastructure.

**Keywords**— Data Center, Civil Engineering, QTS, Construction Management, Geotechnical Engineering, Stormwater, Quality Assurance, Sustainability

## I. INTRODUCTION

Data centers are becoming essential infrastructure for cloud computing, artificial intelligence, financial services, communications, and other digital systems. Although these facilities are commonly discussed in terms of electrical power, servers, and cooling equipment, their reliability begins with civil engineering. Stable building pads, predictable foundation support, positive drainage, durable pavements, protected utility corridors, and verified construction materials are necessary before mission-critical equipment can operate reliably.

Large hyperscale campuses create a distinctive construction-management challenge because the civil systems are highly interconnected. A localized problem such as poorly compacted trench backfill can later become pavement settlement; inadequate temporary drainage can create erosion or soft subgrades; and unresolved utility conflicts can delay structural, electrical, or mechanical work. The purpose of this study is to evaluate these civil risks and propose a practical quality-assurance framework using the QTS York County, South Carolina data center campus as a contemporary real-world case study.

QTS publicly describes the York County development as a nine-building campus planned in three phases. York County states that QTS purchased industrial-zoned land in 2023 and

that the buildings are in various stages of development. This scale and phased delivery make the project an appropriate case for studying civil infrastructure coordination. The analysis in this paper uses only public project information. Actual QTS geotechnical reports, construction drawings, material strengths, testing records, costs, and schedules are not available to this study and are not invented.

## II. LITERATURE REVIEW

### Civil infrastructure in mission-critical construction

Civil engineering for mission-critical facilities integrates geotechnical, water-resources, transportation, materials, and construction-engineering disciplines. The building pad and foundation system must control total and differential settlement; stormwater systems must protect buildings and equipment from uncontrolled runoff; utility corridors must accommodate dense networks while maintaining separation and accessibility; and pavements must survive both heavy construction loading and long-term operational traffic. These systems are conventional individually, but their interaction under accelerated schedules creates elevated interface risk.

### Quality assurance and construction materials testing

Quality assurance is most effective when inspection intensity reflects the consequence of failure. Structural fill, foundation subgrades, concrete foundations and equipment pads, utility

trench backfill, drainage structures, and pavement layers are common civil elements requiring verification. ASTM and ACI standards provide widely used procedures for soil compaction and concrete testing. However, compliance with a minimum testing frequency alone does not guarantee reliable performance if test locations are poorly documented or if failures are not linked to corrective actions and retesting.

#### **Sustainable data-center infrastructure**

Sustainability in data-center development extends beyond electrical efficiency. Civil decisions affect water consumption, earthwork balance, erosion and sediment control, pavement durability, construction waste, material use, and the amount of rework required. QTS reports using closed-loop cooling technology in newer greenfield facilities and has published portfolio-level water and energy performance metrics. These corporate metrics are useful context but should not be interpreted as measured operational performance of a campus that is still under development.

### **III. QTS YORK COUNTY CASE STUDY**

#### **Project Context**

QTS identifies its York County, South Carolina development as a nine-building data-center campus constructed across three phases. The company describes the first phase as four buildings across approximately 109 acres, with five additional buildings planned in later phases. York County reports that the property was industrially zoned when acquired and that data centers were permitted by right. The county also reports that the approved site plans provide vested development rights for the nine buildings.

#### **Evolving technology and infrastructure:**

York County reports that QTS requested additional building height in 2025 as data-center technology and cooling systems evolved. The county subsequently amended its zoning requirements after review and also approved an agreement for road improvements. These public actions illustrate an important civil-engineering issue: data-center technology can change faster than traditional land-development cycles, requiring site grading, roads, drainage, fire access, utility corridors, and building interfaces to accommodate design evolution.

#### **Water and Stormwater:**

QTS states that the York County campus will use an air-cooled closed-loop cooling system that does not consume water for cooling after the system is initially charged, and that groundwater will not be used for the development. QTS also

describes permanent stormwater basins intended to hold, filter, and slowly release runoff. From a civil-engineering perspective, these systems affect water-service planning, site drainage, basin geometry, erosion-control sequencing, commissioning, and long-term maintenance.

### **IV. METHODOLOGY SUMMARY**

This study uses a qualitative applied case-study method. First, verified public information from QTS and York County is used to define the project context. Second, the project is divided into six civil workstreams: site development and grading; geotechnical engineering and foundations; stormwater and erosion control; underground utilities; pavements and construction access; and construction-material quality assurance. Third, the potential consequence and interface risk of each workstream are evaluated. Finally, recurring controls are synthesized into a five-stage management framework consisting of baseline characterization, design-interface coordination, risk-weighted construction verification, readiness-gate turnover, and lessons-learned feedback.

Table 1: Evidence classification used in the study

| Evidence Type                | Definition                      | Use                    | Example                        |
|------------------------------|---------------------------------|------------------------|--------------------------------|
| Public project fact          | Published by QTS or York County | Defines case context   | Nine buildings in three phases |
| Company-reported performance | Published by QTS                | Used with attribution  | Closed-loop cooling            |
| Engineering interpretation   | Civil/construction analysis     | Explains implications  | Temporary drainage risk        |
| Proposed control             | Recommendation from this study  | Framework contribution | Readiness gates                |

### **V. RESULTS AND DISCUSSIONS**

#### **1. Site development and mass grading**

Large data-center buildings require broad, controlled pads integrated with equipment yards, roads, substations, security features, drainage systems, and future-phase connections. The principal risk is not simply achieving final grades but maintaining stable and drainable conditions throughout construction. Structural fill should be placed in controlled lifts at appropriate moisture content and verified by field density testing. Cut-to-fill transitions and localized soft areas require

particular attention because differential performance can affect foundations, slabs, pavements, and buried utilities.

## 2. Geotechnical engineering and foundation interfaces

A campus-wide geotechnical program should characterize soil stratigraphy, existing fill, groundwater, rock depth, moisture sensitivity, compressibility, and bearing behavior. For mission-critical facilities, uniform performance is often more important than maximizing nominal bearing capacity. Field observations, proofrolling where specified, density testing, and foundation-subgrade verification should be connected to a rapid escalation process so unexpected conditions are resolved before they are covered by concrete or subsequent work.

## 3. Stormwater management and erosion control

Permanent stormwater facilities are only one part of the drainage problem. During phased construction, large disturbed areas may exist before final stabilization and before all permanent systems are functional. Temporary diversions, sediment controls, stabilized construction entrances, inlet protection, dewatering, slope stabilization, and basin maintenance must evolve with the earthwork sequence. The highest risk may occur during temporary conditions rather than after final buildout.

## 4. Underground utilities and spatial coordination

Data-center campuses contain dense underground networks that can include storm drainage, sanitary sewer, domestic and fire water, electrical duct banks, grounding systems, telecommunications, and other process-related piping. The most difficult locations are often building entries, road crossings, equipment yards, and future-phase interfaces. Three-dimensional coordination, survey control, and as-built capture before backfill can reduce rework and improve lifecycle maintenance. Trench backfill should receive the same attention as general fill because poor compaction can later cause settlement beneath pavement and hardscape.

## 5. Pavement and construction traffic

Heavy construction traffic can consume a significant portion of pavement life before a facility is commissioned. Concrete trucks, cranes, delivery vehicles, and abnormal loads can damage final surfaces if they are installed too early. A staged pavement strategy can use temporary haul routes, protect subgrade and aggregate base, repair utility trenches, and delay final wearing surfaces until major heavy construction is substantially complete. York County's reported road-improvement agreement associated with the QTS development reinforces the importance of transportation infrastructure at campus scale.

## 6. Construction materials testing and QA/QC

The proposed quality system is risk based. Areas with high failure consequence or high interface density receive greater verification effort. Each field test should be traceable to location, elevation, material, contractor, date, specification requirement, result, and corrective action. Digital location-based records can reveal recurring problems that are difficult to identify from isolated laboratory reports.

Table 2: Risk-based civil quality control framework

| Work Activity       | Potential Failure                 | Consequence           | Primary Verification         | Control Action              |
|---------------------|-----------------------------------|-----------------------|------------------------------|-----------------------------|
| Engineered fill     | Low density / unsuitable moisture | Settlement            | Density and moisture testing | Correct and retest          |
| Foundation subgrade | Unrecognized variability          | Differential movement | Geotechnical observation     | Disposition before concrete |
| Concrete            | Fresh/strength nonconformance     | Repair or delay       | Fresh tests and specimens    | Engineering evaluation      |
| Utility backfill    | Poor compaction                   | Trench settlement     | Lift and density testing     | Rework before pavement      |
| Stormwater          | Incorrect grade/outlet            | Ponding or erosion    | Survey and inspection        | Correct before turnover     |
| Pavement            | Weak support / low density        | Premature distress    | Base and asphalt QC          | Repair before acceptance    |

## 7. Five-stage civil infrastructure management framework

- Baseline characterization: Establish survey control, geotechnical conditions, drainage constraints, existing utilities, access limits, permitting requirements, and future-phase interfaces.
- Design-interface coordination: Resolve high-consequence crossings and conflicts among civil, structural, electrical, mechanical, fire-access, security, and vendor systems before installation.
- Risk-weighted construction verification: Allocate inspection and testing according to failure consequence, uncertainty, and interface density. Record quality data by location.

- Readiness-gate turnover: Require objective evidence before pad release, foundation release, underground closure, pavement release, and final civil turnover.
- Lessons-learned feedback: Analyze failed tests, nonconformances, RFIs, drainage issues, and utility conflicts from each phase and incorporate improvements into later phases.

#### **Sustainability Implications:**

QTS reports a 2025 portfolio Water Usage Effectiveness (WUE) of 0.44 and average portfolio Power Usage Effectiveness (PUE) of 1.38. The company also reports broader use of closed-loop cooling in new greenfield facilities. These values are portfolio-level company-reported metrics and are not presented here as measured York County campus performance. For civil engineers, sustainability also includes earthwork optimization, durable materials, erosion prevention, stormwater quality, reduced rework, construction-water management, and maintainable infrastructure.

The case study shows that quality and sustainability are closely linked. Preventing failed fill, damaged pavement, incorrectly installed utilities, or defective concrete reduces material consumption, equipment use, schedule disruption, and waste. Lifecycle performance should therefore be considered alongside operational water and energy metrics when evaluating the sustainability of data-center infrastructure.

#### **Practical Recommendations:**

- Establish a campus-wide geotechnical baseline and update it as excavation exposes actual conditions.
- Use phase-specific grading and temporary drainage plans rather than relying only on final-buildout conditions.
- Create a location-based civil quality register linking inspections, test results, failures, corrective actions, and retests.
- Coordinate underground utilities in three dimensions and capture survey information before backfill.
- Use formal readiness gates before covering underground work or transferring areas to subsequent trades.
- Delay final pavement surfaces until major heavy construction and utility disturbance are substantially complete where practical.
- Trend nonconformances and RFIs across buildings so lessons learned from early phases improve later phases.
- Keep portfolio sustainability metrics separate from site-specific measured construction and operational performance.

#### **Limitations**

This study is based on public information and does not include confidential QTS drawings, geotechnical boring logs, foundation schedules, concrete mix designs, testing reports, cost data, schedules, or operational measurements for the York County campus. Therefore, the paper does not attempt to calculate actual settlement, pavement life, stormwater discharge, concrete strength, or project-specific failure rates. Future research could test the proposed framework using anonymized field data from multiple mission-critical projects and quantify relationships among nonconformance frequency, rework cost, schedule impact, and long-term performance.

## **VI. CONCLUSIONS**

Hyperscale data centers are technology-intensive facilities, but their reliability depends on conventional civil infrastructure performing at an unusually high level. The QTS York County case provides a useful real-world setting for examining the interaction of phased site development, earthwork, geotechnical conditions, stormwater, dense underground utilities, heavy construction traffic, materials testing, and sustainability. The central finding is that civil quality should be managed cumulatively and spatially rather than through isolated test reports.

The proposed five-stage framework treats civil infrastructure as a reliability system. Baseline characterization establishes known conditions; design-interface coordination reduces conflicts; risk-weighted verification focuses resources on high-consequence work; readiness gates prevent unresolved defects from transferring to later trades; and lessons-learned feedback allows repeated buildings and phases to improve over time. This approach can support better constructability, durability, environmental performance, and lifecycle reliability on hyperscale and other mission-critical construction projects.

## **REFERENCES**

1. QTS Data Centers. York County, South Carolina Data Center Campus. QTS Data Centers, 2026.
2. QTS Data Centers. 2025 Sustainability Report. QTS Data Centers, 2026.
3. York County, South Carolina. Data Centers: QTS and Facilities in York County. York County Government, 2026.
4. American Concrete Institute. ACI 318-19: Building Code Requirements for Structural Concrete and Commentary. ACI, 2019.

5. ASTM International. ASTM D698: Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort. ASTM International.
6. ASTM International. ASTM D6938: Standard Test Methods for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods. ASTM International.
7. ASTM International. ASTM C31/C31M: Standard Practice for Making and Curing Concrete Test Specimens in the Field. ASTM International.
8. ASTM International. ASTM C39/C39M: Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. ASTM International.
9. U.S. Environmental Protection Agency. National Pollutant Discharge Elimination System: Stormwater Discharges from Construction Activities. U.S. EPA.