2026 ASEE ANNUAL CONFERENCE
June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
Paper ID #53542

# The Role of Math Readiness in Undergraduate Civil Engineering Education

**Dr. Lekshmi Sasidharan, University of Arkansas**

Dr Lekshmi Sasidharan is a teaching assistant professor in the Civil Engineering department at University of Arkansas. Dr Sasidharan is very much interested in working on ideas to improve the student retention and student success.

**Samundra Paudel, University of Arkansas**
**Eric Fernstrom, University of Arkansas**

## The Role of Math Readiness in Undergraduate Civil Engineering Education

Mathematical readiness plays a foundational role in the academic and professional success of undergraduate civil engineering students. Analytical thinking, problem solving, quantitative analysis, proficiency in mathematics (particularly in algebra, trigonometry, calculus, and differential equations) are essential for civil engineers. This study explores the significance of the early math preparedness of civil engineering undergraduate students in an R1 university and its impact on students' ability to engage with core engineering concepts such as mechanics, structural analysis, surveying systems, fluid mechanics, geotechnical design, and transportation systems. The study also focuses on identifying the math courses that are highly correlated with the students' performance in the civil engineering core courses. This knowledge can help strengthen the student's math preparation in the pre-college and early undergraduate levels to ensure their long-term success in civil engineering education.

Keywords: Math Readiness; Civil Engineering; Calculus; Mechanics; Retention; Attrition

## Introduction

Accreditation bodies such as Accreditation Board for Engineering and Technology (ABET) and professional societies such as American Society of Civil Engineers (ASCE) articulate clear expectations for the mathematical preparation of future civil engineers. One of the Student Outcomes in Criterion 3 of ABET's Engineering Accreditation Commission (EAC) requires that engineering graduates be able to "identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics" [1]. This shows the importance of mathematics as a core competency at the point of graduation. In parallel, the Engineering Technology Accreditation Commission (ETAC) specifies that Baccalaureate programs include "the application of integral and differential calculus, or other mathematics above the level of algebra and trigonometry, appropriate to the student outcomes and the discipline," thus formalizing minimum mathematics expectations for civil engineering technology curricula [2].

Within the civil engineering profession, the ASCE Civil Engineering Body of Knowledge (CEBOK3) [3] delineates mathematics as a foundational learning outcome, framing the quantitative abilities required to enter responsible charge. It identifies the primary areas of mathematics relevant to civil engineering as algebra, calculus, linear algebra, geometry and topology, differential equations, computation and numerical analysis, probability, set theory, statistics, and trigonometry. CEBOK3 situates mathematics as prerequisite to engineering mechanics, design, and technical breadth/depth outcomes central to civil engineering practice

[3]. In short, accreditation and professional guidance converge on the idea that mathematics is not ancillary; it is fundamental to professional formation in civil engineering.

However, many students enter civil engineering programs not fully “math-ready”, creating sequencing delays that ripple through materials science, engineering mechanics, experimental methods and data analysis, and critical thinking and problem solving and several of the technical outcomes (e.g., risk and uncertainty and engineering economics), extending time-to-degree and heightening attrition risks [3]. Program criteria and faculty commentaries repeatedly note the tight coupling among mathematics, mechanics, and analysis, and report the need for careful advising to maintain progression. These structural realities make early mathematics performance, especially the first college-level math course (often Calculus I), a practical bottleneck for persistence in engineering [4], [5], [6].

Motivated by these concerns and the need to align with CEBOK3, this study examines how grades in early mathematics courses relate to student success in civil engineering programs, and identifies which math courses are most strongly associated with performance in civil engineering core courses.

## Literature Review

A growing body of research suggests that performance in Calculus I plays an important role in shaping students’ persistence in STEM majors [7], [8]. Findings from the Mathematical Association of America’s national study (CSPCC/Progress through Calculus) indicate that, for many students intending to pursue STEM fields, Calculus I often functions more as a screening point than a catalyst, with course experiences and placement practices influencing decisions about whether to continue in the calculus sequence [9],[10]. Meta-analytic work likewise shows that grades in the first college mathematics course are among the strongest academic predictors of retention in math-intensive fields; students earning below a C in their first math course are substantially more likely to exit STEM [8], [11], [12], [13].

In engineering specifically, multi-institution and program studies identify Calculus I as a bottleneck: success in this course is highly predictive of persistence, while starting below calculus is associated with longer pathways and higher exit rates from engineering. Research also associates early math performance and placement with first-year engineering retention, underscoring the salience of math during the initial year. For civil engineering programs, faculty reports and regional reviews document how math sequencing constrains the timing of statics, structural analysis, surveying, and hydraulics, making mathematics progression a practical bottleneck that programs must manage through advising and early alerts [5], [6], [14], [15].

Differences in high school preparation and institutional placement practices contribute to variation in college mathematics readiness. The Dana Center synthesizes evidence that misplacement, misaligned content, and elongated developmental sequences depress progression, while multiple-measures placement, mathematics pathways, and co-requisite supports improve access to and success in college-level math. Rigorous evaluations from the "What Works Clearinghouse" report positive effects of Dana Center Mathematics Pathways (DCMP) on developmental progression and early college math completion [16].

Evidence from Tennessee's statewide corequisite reform shows large, causal gains in gateway math completion when underprepared students are mainstreamed into college-level courses with concurrent support, relative to prerequisite remediation; alignment of math course choice with program requirements amplified these effects. Complementary work on developmental redesign finds that accelerated and corequisite models outperform traditional sequences on college-math completion and credit accumulation. Together, these studies support placement and support structures that shorten time to gateway completion and reduce equity-impeding attrition in early math [17], [18].

Beyond placement and preparation, classroom experiences affect persistence. Seymour and Hewitt's landmark qualitative study [19], and its updated sequel [20], connect STEM attrition to pedagogical climate and lack of support rather than to student deficits, highlighting the importance of learning environments and attitudes toward the field. At scale, a meta-analysis of active learning in undergraduate STEM shows significantly lower failure rates and higher exam performance compared with traditional lecturing, implying that evidence-based pedagogy in gateway mathematics can materially improve persistence [19], [20], [21].

In engineering education, studies have also foregrounded noncognitive contributors. For instance, among students earning a C in their first mathematics course, measures such as value/interest and test anxiety predict first-year retention, pointing to the need for supports that address motivation, belonging, and self-efficacy alongside content mastery. Program-level interventions that integrate introductory calculus support, decouple high-churn sequences (e.g., phasing physics relative to calculus), and add spatial visualization training report significant gains in retention for at-risk engineering cohorts, further underscoring the role of targeted supports beyond placement [6], [22], [23].

Current ASCE commentary on the Civil Engineering Program Criteria (CEPC) emphasizes application of mathematics through differential equations and probability and statistics, integrated with calculus-based physics and chemistry, and supported by numerical methods all of which serve as direct inputs into civil engineering analysis and design. The CEBOK3 places mathematics among the foundational outcomes, aligning quantitative skills with engineering fundamentals and technical depth outcomes required for responsible charge. Consequently, delays in mathematics progression (e.g., starting below calculus) propagate to mechanics, materials, transportation, environmental, structural and design coursework, elevating risks of out of sequence enrollment and extended time to graduation. Program-level evidence from civil engineering programs further documents active strategies, advising to maintain math-course sequence, early alerts, and schedule planning to mitigate these bottlenecks [6], [23], [24].

The literature consistently indicates that first-math course placement and performance powerfully shape persistence in math-intensive fields. Also, including structural reforms such as multiple-measures placement, math pathways, and corequisite support helps to improve gateway math completion and early credit momentum. It also shows that classroom climate and evidence-based pedagogy (e.g., active learning) further reduce failure and withdrawal. Within civil engineering, the interdependence of math with core technical courses makes mathematics readiness a program-flow issue as much as an academic one.

The objectives of this paper are to a) quantify the relationships between grades in early mathematics courses and success in civil engineering programs, b) identify the specific math courses most predictive of performance in civil engineering core courses, and c) discuss implications for readiness, placement, and co-curricular supports that align with ABET and CEBOK3 expectations while improving retention and time-to-degree.

**Data**

The data used in this paper is for civil engineering students at the University of Arkansas. The data includes all students that took classes between 2013 and 2022 and were registered as a civil engineering undergraduate. It is also important to note that engineering students do not declare a major until the second semester at the University. Because of this, most students' first semester courses are not captured in the data, because they were not yet listed as civil engineering students. There were data from 1435 students. However, there were several missing data in the database.

Many studies in the literature have used DFW rate as a yardstick. DFW rate is the proportion of students in a course who earn a D or F grade, or who withdraw and is good for reporting the proportion of students in a cohort that did not earn a passing grade, and this measure is thus especially useful when considering types of support or scaffolding that may improve success. A reduction in DFW rate suggests that a proposed support is having a helpful effect.

In addition to the DFW rates, we used GPA as a comparison tool. Annual GPA was calculated for different courses used the equation 1.

$$GPA = \frac{4*A+3*B+2*C+1*D+0*F}{(A+B+C+D+F)} \tag{1}$$

Where A, B, C, D, and F are the number of students who got A, B, C, D, and F grades respectively. This provides a single number as a representation of the average success of the cohort that took a particular course during a particular time period. The GPA values reported exclude any students that withdrew from a course. While some students withdraw near the end of a semester if a passing grade seems unattainable (and thus it would be appropriate to assume a grade of F), many others withdraw for a variety of reasons that are unrelated to their perceived probability of academic success (such as illness, injury, finances, life events, schedule conflicts, work priorities, etc.). Thus, discounting the W grades focuses the results on known grades achieved.

Finally, the data used is anonymized, so it is not possible to determine if a particular student took the same course several times before earning a passing grade. Because of this, there is necessarily a reduction in average GPA for every value shown. This is because any student that is in the data for a course multiple times had a D or an F at least one time. Every student that earned better than a D on the first try will not have reattempted the same course.

## Data Analysis

A heatmap was developed based on the absolute differences between the courses' average GPA values across selected set of mathematics and engineering courses. It helps to visualize how similar or different the GPAs are for the selected courses. Figure 1 shows the heatmap based on aggregated data.

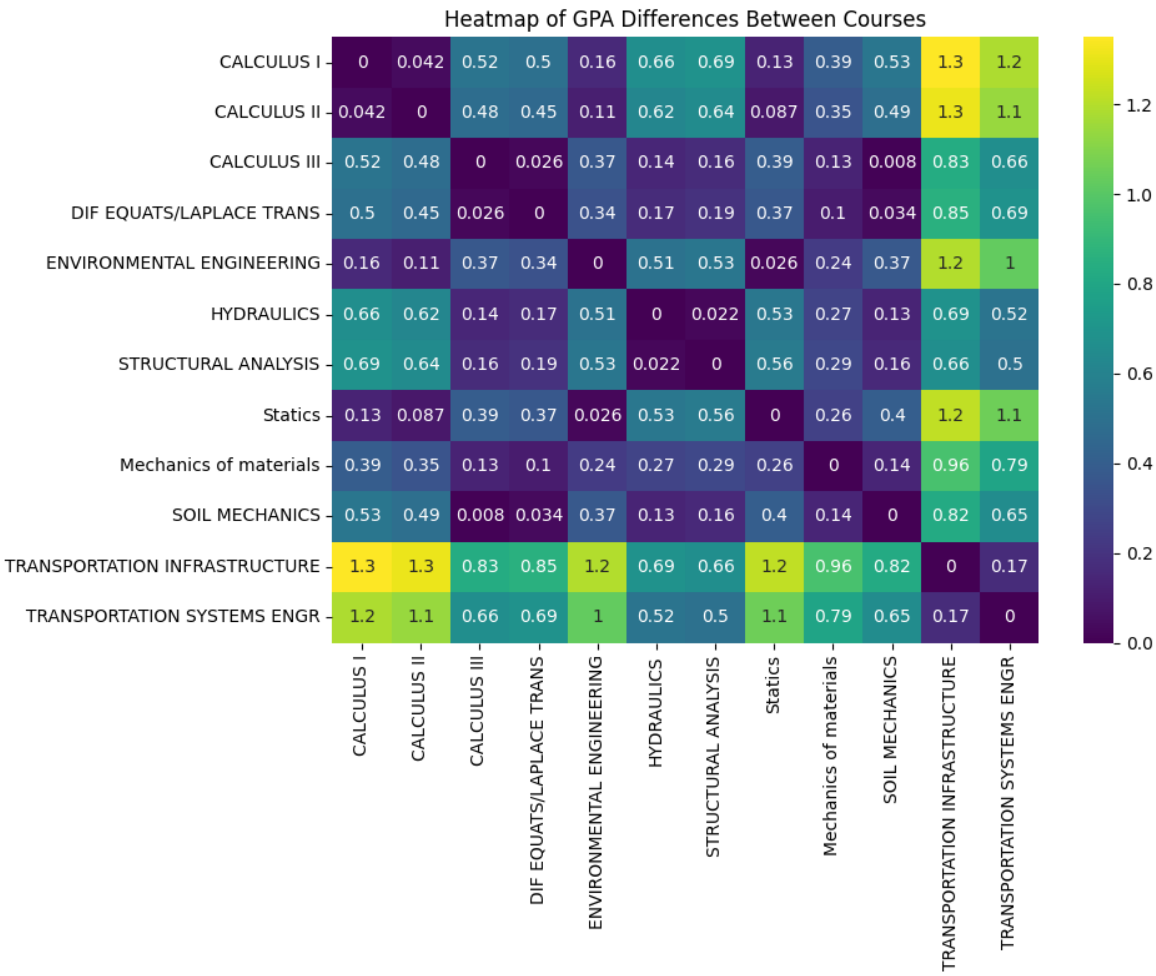


Figure 1. Heat map showing absolute differences between selected courses' average GPA values

Darker areas in Figure 1 indicate courses whose average GPAs are comparable, while lighter areas represent courses with larger GPA differences. This allows to quickly identify which courses tend to grade at comparable levels and which ones differ significantly in grading patterns. The result offers a visual comparison of course difficulty and student performance trends using the summary GPA data.

A comparison was made between the GPAs and DFW rates of Math courses such as Calculus I, Calculus II, Calculus III, Differential Equations and Civil Engineering core courses such as Statics, Mechanics of Materials, Soil Mechanics, Environmental Engineering, Structural Analysis, Hydraulics, Foundation Engineering, Reinforced concrete design, Transportation systems engineering, Transportation Infrastructure etc. Figure 2 shows the graph of GPAs vs. DFW rates.

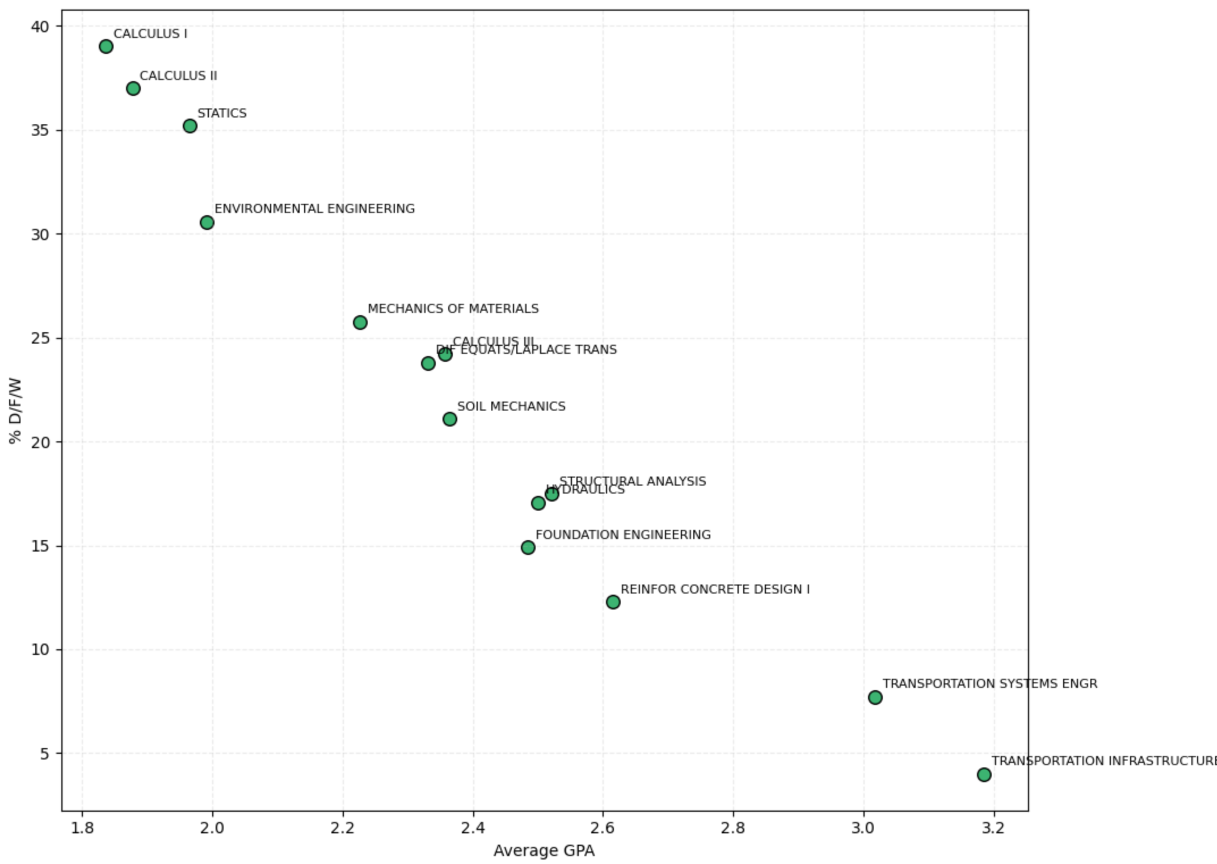


Figure 2. Average GPA vs. DFW rates for Math and Civil Engineering Core Courses

Figure 2 shows that although both areas require strong analytical skills, students consistently achieve higher GPAs in Statics than in Calculus I or II, with Calculus III falling closer to Statics in performance. This pattern suggests that early-stage calculus presents a greater barrier for student success, while Statics benefits from both stronger student preparation and more context-rich problem solving.

Figure 2 reveals a clear inverse relationship. Courses with lower GPAs tend to exhibit higher DFW rates, indicating greater difficulty or lower success rates among students. Conversely, courses with higher GPAs generally show lower DFW percentages, reflecting stronger student performance. Mathematics courses, especially Calculus I and Calculus II, stand out with some of the highest DFW rates and lowest GPAs, marking them as early bottleneck courses in the curriculum. Calculus III performs moderately better, aligning with patterns seen when students continue from earlier math foundations into more advanced topics.

Figure 2 highlights significant variation in student performance across the curriculum, with early math courses posing the greatest challenge, while upper-level engineering courses generally see stronger outcomes. These trends provide valuable insight into potential intervention points for improving retention and supporting student success throughout the engineering pathway.

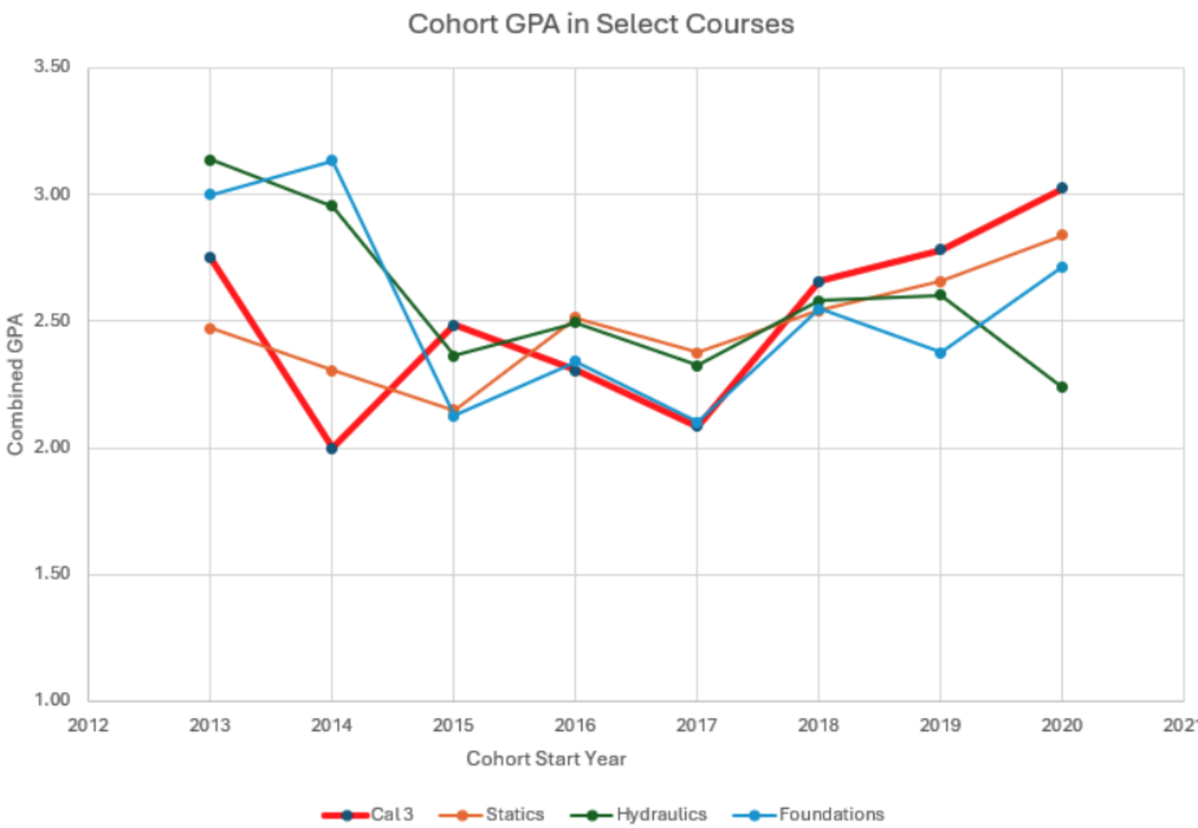


Figure 3. Comparison of GPA in Math and Core Courses for different cohorts

Figure 3 shows the plot of grades over 3 years for each annual cohort. When examining the 2013 cohort, the four relevant data points include Calculus III and Statics in 2013, Hydraulics in 2014, and Foundations in 2015. These three engineering courses are appropriate indicators of student performance because they require students to engage in complex, multi-step problem solving, particularly relative to the problem-solving expectations at the point in their academic progression when each course is taken.

The plot illustrates that, in nearly all cases, cohorts with higher average performance in Calculus III also demonstrated stronger outcomes in the three subsequent problem-intensive engineering courses. The primary exceptions are the relatively low Calculus III average in 2014 and the lower Hydraulics average observed for the 2020 cohort (reflected in the 2021 Hydraulics grade).

**Analysis of Grade Relationships Across Calculus I, II, and III Courses**

Student performance in Calculus I, Calculus II, and Calculus III was examined to assess whether early outcomes in the calculus sequence predict subsequent success and to identify points at which students may be at elevated academic risk. Course grades were converted to an ordinal numeric scale (A = 4, B = 3, C = 2, D = 1, F = 0; W = 0). Because grades are ordinal in nature, Spearman rank-order correlation coefficients were computed for students who completed pairs of courses within the sequence. Table 1 shows the results of the correlation analysis for student grades across Calculus courses. Sample sizes vary across course pairs and include only students with available grades in both courses.

Table 1. Result of Correlation Analysis Across Calculus Course Grades

| Course Pair | Sample Size | Spearman coefficient ρ |
|---|---|---|
| Calculus I vs. Calculus II | 204 | 0.362 |
| Calculus II vs. Calculus III | 259 | 0.469 |
| Calculus I vs. Calculus III | 155 | 0.289 |

Although the results indicate statistically meaningful, positive associations among student grades across all three courses, the strongest relationship is observed between Calculus II and Calculus III ($\rho = 0.469$), suggesting that performance in Calculus II is more predictive of success in Calculus III than performance in Calculus I alone. While Calculus I performance is modestly correlated with later outcomes, its direct association with Calculus III is weaker ($\rho = 0.289$), indicating that intermediate performance plays a more critical role. It was also noted that many students experience small shifts in performance, typically within one letter grade, across courses. Despite this variability, distinct performance thresholds emerge, particularly in Calculus II. Students earning A or B grades in Calculus II demonstrate a high probability of earning A or B grades in Calculus III, indicating strong persistence and mastery whereas students earning a C in Calculus II exhibit substantial outcome variability in Calculus III, with grades distributed across B, C, and D. This group represents a critical transition population. It was observed that Calculus II functions as a gateway course within the calculus sequence as data analysis showed that weaker performance in Calculus I does not necessarily preclude later success in Calculus courses.

**Relationship Between Calculus Performance and Civil Engineering Core Courses**

Mechanics I and Mechanics II are required core courses for Civil Engineering sophomores and play a critical role in student progression and retention within the program. To examine how mathematical preparation relates to student success in disciplinary coursework, these two courses were analyzed alongside one required core course each from the sophomore, junior, and senior years.

A Math Readiness Index (MRI) was estimated to represent students' overall calculus performance. The MRI was computed as the average of the available numeric-equivalent grades in Calculus I, Calculus II, and Calculus III. Spearman rank-order correlation coefficients were then calculated to assess the association between MRI and grades in selected Civil Engineering core courses. The results of this analysis are presented in Table 2.

Table 2. Correlation coefficients MRI vs. Civil Engineering Core Courses

| **Course Pair** | **Sample Size** | **Spearman coefficient (ρ)** |
|---|---|---|
| Mechanics I vs. MRI | 683 | 0.484 |
| Mechanics II vs. MRI | 633 | 0.445 |
| Structural Analysis vs. MRI | 622 | 0.420 |
| Structural Materials vs. MRI | 765 | 0.270 |
| Hydraulics vs. MRI | 629 | 0.400 |
| Foundation Engineering vs. MRI | 765 | 0.330 |

The analysis indicates moderate positive associations between mathematical readiness and performance in most Civil Engineering core courses. The strongest relationships are observed for Mechanics I ($\rho = 0.484$) and Mechanics II ($\rho = 0.445$). Moderate correlations are also present for Structural Analysis and Hydraulics, while weaker associations are observed for Structural Materials and Foundation Engineering.

To further examine student progression and retention, DFW rates (D, F, or W outcomes) were calculated for each course and are summarized in Table 3 and shown in Figure 4.

Table 3. DFW Rates for Different Courses

| **Course** | **N** | **DFW Count** | **DFW %** |
|---|---|---|---|
| Calculus III | 726 | 54 | 7.4% |
| Calculus II | 880 | 32 | 3.6% |
| Calculus I | 650 | 34 | 5.2% |
| Mechanics II | 716 | 55 | 7.7% |
| Mechanics I | 767 | 69 | 9.0% |
| Structural Analysis | 724 | 34 | 4.7% |
| Structural Materials | 878 | 11 | 1.3% |
| Hydraulics | 729 | 34 | 4.7% |
| Foundation Engineering | 712 | 45 | 6.3% |

Table 3 shows that Mechanics I exhibits the highest DFW rate (9.0%), followed by Mechanics II (7.7%). Among the calculus sequence, Calculus III has the highest DFW rate (7.4%), whereas Calculus II exhibits the lowest (3.6%).

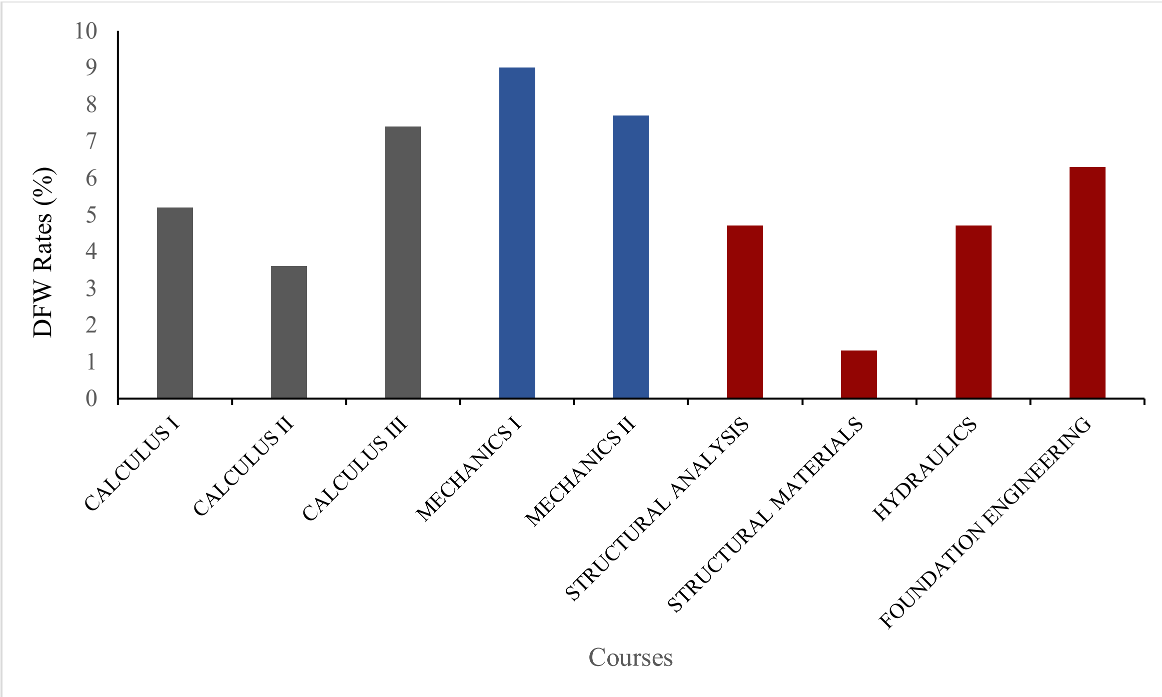


Figure 4. DFW rates (%) for Calculus courses and Selected Civil Engineering Core Courses

A correlation analysis of DFW rates of Calculus courses and Civil Engineering core courses revealed that performance in Calculus III exhibits the strongest associations with most Civil Engineering core courses, particularly Mechanics I ($\rho \approx 0.45$), Mechanics II ($\rho \approx 0.42$), and Hydraulics ($\rho \approx 0.37$), highlighting the importance of advanced calculus concepts for success in these courses. In contrast, Structural Analysis aligns most strongly with Calculus II, which is consistent with the shared emphasis on conceptual understanding and analytical methods introduced at that level of mathematics. Structural Materials shows comparatively weaker dependence on calculus performance, a finding that aligns with its application-focused nature and its relatively low DFW rate.

## Conclusion

Accreditation bodies such as ABET and ETAC, along with professional organizations including ASCE, consistently emphasize the importance of a strong mathematical foundation for success in Civil Engineering practice. This expectation is widely shared by both faculty and industry professionals. However, a substantial proportion of students entering Civil Engineering programs are not adequately prepared to begin at the traditional entry point of Calculus I. Placement into lower-level mathematics courses and early struggles in calculus frequently delay academic progress and contribute to student attrition.

Motivated by these persistent challenges, this study investigated the relationship between student performance in early mathematics coursework (Calculus I-III) and subsequent success in selected core Civil Engineering courses. Using a combination of correlation analysis, DFW rate comparisons, and longitudinal visualizations, the findings consistently demonstrate that student outcomes in engineering are closely linked to performance in mathematics. In particular, MRI, a combined metric of all three Calculus courses exhibits meaningful and sustained associations with success in foundational Civil Engineering courses. Correlation patterns further reveal strong alignments between specific mathematics and engineering subjects, including relationships between Calculus III and Soil Mechanics, Calculus II and Mechanics I, and Calculus III and Hydraulics, underscoring the integral role of mathematical concepts in applied engineering contexts.

A key contribution of this study is the identification of Calculus II as a pivotal transition point in the curriculum. Students earning grades of C or below in Calculus II are significantly more likely to experience difficulties in subsequent mechanics courses, whereas those earning A or B grades show strong persistence and academic success. While Calculus I remain important for initial preparation, its predictive strength is comparatively weaker, indicating that the deeper conceptual consolidation achieved in Calculus II plays a more decisive role in shaping student trajectories.

Taken together, these findings highlight the importance of early, data-informed interventions in Civil Engineering education. Targeted academic support in Calculus II, proactive monitoring of students earning C-level grades, and strengthened instructional scaffolding in Calculus I represent promising strategies for improving student outcomes. Addressing mathematical readiness at these critical transition points has the potential to reduce student attrition, improve retention, support alignment with accreditation standards, and promote successful progression to degree completion and professional practice.

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