

# mathematics at work

*Civil Engineering*

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$\frac{\partial^2 \Omega}{\partial u^2} e^{i\theta} \quad x - \mu$$

$$\frac{n!}{r!(n-r)!} \quad \delta x \rightarrow 0$$

$$\cos^{-1}$$

$$\sin^{-1}$$

$$\sqrt{a^2 + b^2}$$

$$\sum_{i=1}^n \Delta x$$

# Mathematics in Civil Engineering Technology

Civil engineering technicians are a key element in the planning, construction and maintenance of the structures and facilities that make up the United States' infrastructure. The nearly 600,000 bridges, 4 million miles of roads, thousands of water treatment and distribution plants, and scores of high-rise buildings throughout the United States are made possible by precise applications of mathematics and physics. To ensure our buildings, roads and bridges remain safe and sound for decades to come, civil engineering technicians must have an educational background that helps them remain on the cutting edge of emerging technologies, as well as use mathematics to problem solve in a wide variety of job settings.

## Available Civil Engineering Technology Jobs

Within the civil engineering industry, there are a variety of entry-level jobs that pay well and provide opportunities for advancement — jobs for high school graduates with postsecondary training or education but less than a four-year college degree. Individuals pursuing this career pathway have many opportunities to work for federal, state or local governments; join any branch of the armed forces; or enter the private sector. With a growing commitment from our federal government to reinvest

in public works to grow our economy and secure our infrastructure, skilled civil engineering technicians will remain in high demand for years to come.

## Core Mathematics Knowledge in Today's Civil Engineering Technology Jobs

Developed by secondary, postsecondary, business, industry and government leaders, the national Career Cluster Pathway Plans of Study for *Design/Pre-Construction* and *Science, Technology, Engineering and Mathematics* recommend a set of rigorous mathematics courses for students to take at both the secondary and postsecondary levels in traditional or vocational settings to pursue a career track in civil engineering technology. These Plans of Study show in detail how the foundation provided by courses such as Algebra I, Geometry, Algebra II, Trigonometry and Calculus equips high school graduates with the mathematical knowledge and skills needed for success on the job. High school students considering civil engineering technology need to understand the advanced mathematical and technological skills required in the field to meet the demands of this high-growth industry. For more information on the Career Clusters Initiative, see [www.careerclusters.org/resources/web/pos.cfm](http://www.careerclusters.org/resources/web/pos.cfm).

| Jobs                              | Median yearly salary | Percentage of total jobs by education/training (ages 25–44)* |              | Number of total jobs |         |          |
|-----------------------------------|----------------------|--|--------------|----------------------|---------|----------|
|                                   |                      | High school  | Some college | 2006                 | 2016    | % change |
| Civil engineering technicians     | \$40,600             | 27%  | 54%          | 90,700               | 99,900  | 10%      |
| Architectural and civil drafters  | \$42,000             | 13%  | 62%          | 115,500              | 122,500 | 6%       |
| Surveying and mapping technicians | \$32,300             | 42%  | 51%          | 75,600               | 90,200  | 19%      |

\*Remaining percentage of workers in occupation have a bachelor's degree or higher

Source: Bureau of Labor Statistics, U.S. Department of Labor, *Occupational Outlook Handbook, 2008–09 Edition*.

# Ensuring College and Career Readiness: The American Diploma Project

In 2001, Achieve and several partner organizations launched the American Diploma Project (ADP) to identify a common core of English and mathematics academic knowledge and skills, sometimes referred to as “benchmarks,” that American high school graduates need for success in college and the workforce. These ADP benchmarks, released in the 2004 report *Ready or Not? Creating a High School Diploma That Counts*, are the result of two years of intensive research conducted in colleges and universities as well as workplaces across the country.

The real-world expectations identified by ADP are significantly more rigorous than many current high school graduation standards — which helps explain why many high school graduates arrive at college or the workplace with major gaps in their English or mathematics preparation.

To help pinpoint the academic knowledge and skills required for future employment, ADP commissioned leading economists to examine labor market projections for the most promising occupations — those that pay enough to support a family and provide real potential for career advancement. ADP then surveyed officials from 22 industries, ranging from manufacturing to financial services, about the most useful skills for their employees to bring to the job.

ADP also worked closely with two- and four-year post-secondary faculty from five partner states to determine the prerequisite English and mathematics knowledge and skills required to succeed in entry-level, credit-bearing higher education courses. These conversations revealed an unprecedented convergence of the knowledge and skills employers and postsecondary faculty say are needed for new employees and freshmen beginning credit-bearing coursework to be successful.

## “Mathematics at Work” Series

Following up on the work of ADP, Achieve has produced a series of “Mathematics at Work” brochures to examine how higher-level mathematics is used in today’s workplaces. The brochures present case studies drawn from leading industries nationwide to illustrate the advanced mathematics knowledge and skills embedded in jobs that offer opportunities for advancement and are accessible to high school graduates.

The series underscores the value of a rigorous high school curriculum in mathematics. All high school graduates — regardless of whether they enroll in college, join the workforce or enter the military — benefit from acquiring a comprehensive knowledge base and skill set in mathematics.

To view or download the ADP benchmarks, go to [www.achieve.org/ADPbenchmarks](http://www.achieve.org/ADPbenchmarks). To view or download a PDF of additional “Mathematics at Work” brochures, go to [www.achieve.org/mathatwork](http://www.achieve.org/mathatwork).

The background of the bottom section features several mathematical symbols and formulas in a light blue color. On the right side, there is a dashed arrow pointing to the right, with the expression  $\sin^{-1} \theta$  positioned above it. In the center, there is a fraction  $\frac{x - \mu}{\sigma}$  with a downward-pointing arrow below it. To the right of the fraction is a summation formula  $\sum_{i=1}^n (x_i - \bar{x})^2$ .

# Mathematics engineers

## Career Preparation for Civil Engineering Technicians

The vast majority of the 100,000 civil engineering technicians employed in the United States — including the nearly 10,000 workers who will be hired in the next 10 years — will receive associate degrees from community colleges, technical schools or other comparable postsecondary institutions. These two-year programs in civil engineering technology require applicants to have a range of skills and knowledge in math and science. High school graduates entering these programs need strong foundations in subjects like algebra, geometry, physics and chemistry to succeed in commonly required postsecondary courses such as Precalculus/Trigonometry, Drafting and Design, Topographic Surveying, Soil Mechanics, and Strength of Materials.

*“If and when technology fails us in the field — batteries run out unexpectedly, the satellite signal is lost or desert heat waves distort survey data collection — we must rely on our math and science skills to get our job done safely and complete the mission.”*

Sgt. 1st Class Paul D. Welborn  
Technical Engineer, Instructor/Instructional  
Program Developer, U.S. Army

It is no surprise that the wide variety of associate degree programs in civil engineering technology share a common core of expectations and learning objectives. ABET, Inc., is the leading accreditor for college and university programs in applied sciences, computing, engineering and engineering technology. ABET — composed of almost 30 professional and technical organizations representing disciplines in applied science, computing, engineering and engineering technology — has developed rigorous criteria for the accreditation of engineering technology programs.

Included within these criteria are learning outcomes for students — what ABET believes are the minimum units of knowledge and skills that every graduate from an accredited associate degree program in civil engineering technology should possess. Among the expectations for graduates are:

- Conducting standardized field and laboratory testing on civil engineering materials (properties of materials, volumes of geometric shapes, physical forces and stresses, measurement, statistics)
- Using modern surveying methods for land measurement and/or construction layout (right-triangle trigonometry; geometric figures; powers and square roots; unit conversions for lengths, areas and volumes)
- Determining forces and stresses in elementary structural systems (functions, vectors and matrices; chart interpretations; units and unit conversion)
- Estimating material quantities for technical projects and performing cost estimates (proportions, reading and interpreting charts, equations with multiple variables, interest computations)

In addition to possessing a range of mathematical skills, today's civil engineering technicians must be able to communicate via written, oral, graphical and electronic media. They must be able to clearly communicate technical concepts not only to their co-workers, but also to clients or customers who may not have technical backgrounds. Teamwork skills also are critical because the civil engineering field relies heavily on team-based approaches to the analysis of complex problems and the design of solutions to those problems. ABET standards for engineering technicians stress the importance of creativity, analysis and the ability to function effectively on teams.



## Bridging the Divide: The Mathematics of Infrastructure

The infrastructure of the United States — in particular the 4 million-plus miles of road and nearly 600,000 bridges — is widely acknowledged to be in dire need of structural and functional improvement to ensure safety. Thousands of new roads, bridges and water supply systems also are currently under construction or being planned and must be built to last. Civil engineering technicians will play an increasingly critical role in shoring up America's current infrastructure and in building the next generation of roads, bridges and other public infrastructure.

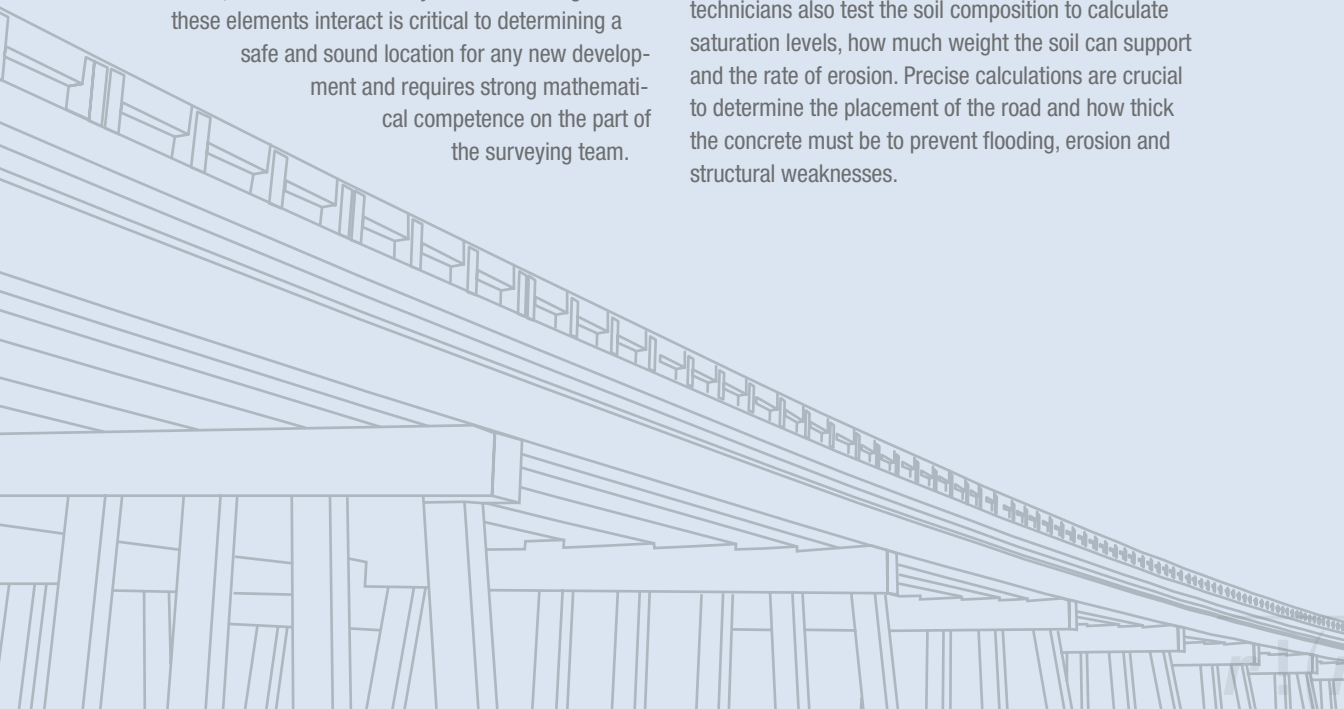
### Surveying the Land

#### *Measurement, Geometry and Trigonometric Functions*

No bridge, road or structure can be constructed on a site before a team of engineers, engineering technicians and surveyors examines the land and maps features such as elevations, utilities and waterways. Understanding how these elements interact is critical to determining a safe and sound location for any new development and requires strong mathematical competence on the part of the surveying team.

Before building a new road, for example, civil engineering technicians are on the front line of the initial survey, using cutting-edge equipment to map the topography, which is the horizontal and vertical shape of the land. They must calculate multiple discrete distances from one curve in the landscape to the next to determine the final vertical and horizontal lengths and widths of the entire roadway, which requires a firm understanding of measurements, geometry and trigonometric functions of angles. Once the technicians compute the individual alignments, they can place the road's center line, shoulders and ditches accurately and, ultimately, design the entire highway.

Evaluating the water runoff and testing the soil at a site are two other vital tasks. If a proposed locale includes a creek, the civil engineering technicians must determine the area and volume of the channel — which is commonly trapezoidal in shape — and estimate how much water is present during its peak season. The technicians also test the soil composition to calculate saturation levels, how much weight the soil can support and the rate of erosion. Precise calculations are crucial to determine the placement of the road and how thick the concrete must be to prevent flooding, erosion and structural weaknesses.



$$[X_i - \bar{X}]^2$$

$$e^{i\theta}$$

## Civil Engineering Technicians in the Military: Opportunities across the Armed Forces

In addition to the civilians employed as civil engineering technicians, thousands of officers and enlisted members within the armed forces work on infrastructure projects. While the Army Corps of Engineers may be the most well-known organization that provides vital engineering and design management, individuals can hone their civil engineering skills across all branches of the military. Civil engineering technicians in the armed forces use their knowledge and skills in a variety of ways such as building temporary roads and bridges in combat areas, constructing military bases at home and abroad, and managing permanent civilian projects like hydroelectric dams.

Civil engineering technicians in the military — in job titles such as technical engineer (Army), engineer assistant (Marine Corps) and engineering aide (Navy) — receive training upon enrolling in the services and typically learn many of the required skills on the job but often are expected to have completed algebra, geometry and even trigonometry in high school. These positions provide a clear pathway to advancement because many of these technicians go on to manage projects and train incoming engineer assistants and equivalent officers. Those who leave the armed forces with civil engineering technology training are sought after widely by private firms due to their technical and leadership skills.

For more information, see [www.todaysmilitary.com/careers](http://www.todaysmilitary.com/careers).

## Ensuring the Soundness of Bridges and Roads

### *Physical and Materials Properties, Proportions and Force*

Once the routing for the proposed road has been established, a civil engineering technician's job has just begun. Technicians are responsible for another vital task prior to construction: testing the strength (or load-bearing capacity) of the roadway materials. For example, technicians calculate the strength of concrete in pounds-force per square inch by mixing a sample, pouring it into a cylindrical mold, curing it and applying pressure until the concrete breaks. Calculating the amount of compression the concrete can handle before it literally cracks requires a strong understanding of the physics of tension and compression. Proportions play a role as well because different concrete mixtures — based on the ratio of water, gravel and sand — inevitably will have different load-bearing capacities.

Bridges, however, can be made of multiple materials, such as reinforced concrete (steel re-bars encased in

concrete), requiring civil engineering technicians to calculate the strength and durability of various materials both in the aggregate and individually to ensure that no element of the bridge will be a weak link. The type and ratio of materials involved in designing a bridge depends on a number of factors including its length and width, the amount of weight it needs to sustain, and the tolerance of each material — not to mention the project's budget.

Calculating the weight a bridge must sustain involves taking into account not only the weight of the bridge materials, but also the weights of the vehicles that will be traveling on the road, their rates of speed and how many are expected to be on the bridge at any given time. To help with these calculations, technicians often use trend data and the results of computer-based models that predict traffic patterns. Throughout the surveying and engineering processes, the civil engineering technicians rely on their proficiency with computer-aided design and geographic information systems (GIS) to design the plans and share information with other project team members.

$$n!$$
$$(n-r)!$$

$$\sum_{i=1}^n X_i^2$$

$u^2$  $\lim_{\delta x \rightarrow 0}$ 

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

## Mathematics + Teamwork = Success

Keeping the nation's infrastructure safe and sound takes a lot of hard work from a number of highly skilled individuals. Civil engineering technicians constantly are engaged as critical members of teams of engineers, technicians, surveyors and equipment operators that plan, design and develop infrastructure that supplies safe drinking water, protects the environment, and provides transportation systems that make it possible for Americans to get to work safely and on time. At every stage of an infrastructure project, strong math and teamwork skills are instrumental to success.

When civil engineers and civil engineering technicians work together to develop a design plan for a road, they upload the design parameters, like the road thickness and location of the safety railing, onto a memory card that links the design to the GIS. Modern construction equipment uses GIS data to read those memory cards, guiding the bulldozer or road grader where to go and providing information about what to do. Civil engineering technicians must review and check the calculations constantly and, working with equipment operators, make midcourse adjustments to ensure the road under construction reflects the actual design. Without an understanding of trigonometric geometry on the part of civil engineering technicians, neither the design nor its implementation would succeed.

While these technicians may be responsible for testing the tension and compression limits of the construction materials used, they also are tasked with ordering the right amount. The volume of concrete needed to complete a project, for example, is related directly to the calculations the civil engineering technician performs when determining the concrete's strength, the soil's properties and the potential water runoff. Not only must the civil engineering technicians ensure the accuracy of their initial calculations, but they also must work with third-party vendors to keep the project on budget.

Research gathered by ADP shows that collaboration and communication skills are important factors for success both in the workplace and in the college classroom. In the planning, design and construction of infrastructure projects, civil engineering technicians must apply their mathematical knowledge continually as contributing members of a larger team. The breadth of knowledge and skills that civil engineering technicians need to be successful in the civilian and military sectors is reflected in the mathematics that students must take in associate degree courses of study or equivalent training programs. Students interested in pursuing the crucial and exciting civil engineering technician career pathway must graduate high school with college- and career-ready expectations, particularly in mathematics.

“Civil engineering technicians must **compute** mathematically to solve numerical problems, they must **visualize** mathematically, and they must **think** mathematically to respond quickly and understand the consequences when errors occur or when circumstances change. The ability to visualize and think mathematically can be far more valuable than the ability to only write formulas and ‘crunch’ numbers. Technicians must be able to recognize when the results from computations, measurements or tests just don’t look right.”

Dr. David E. Hornbeck, P.E.  
Professor Emeritus of Civil Engineering Technology  
Southern Polytechnic State University

$\cos^{-1} \theta$   
 $\sqrt{a^2 + b^2}$   
 $(X_i - \bar{X})^2 e^{i\theta}$

## About Achieve

Achieve, Inc., created by the nation's governors and business leaders, is a bipartisan, non-profit organization that helps states raise academic standards, improve assessments and strengthen accountability to prepare all young people for postsecondary education, careers and citizenship.

## About the American Diploma Project (ADP) Network

In 2005, Achieve launched the ADP Network — a collaboration of states working together to improve their academic standards and provide all students with a high school education that meets the needs of today's workplaces and universities. The ADP Network members — responsible for educating nearly 85 percent of all our nation's public high school students — are committed to taking four college and career readiness action steps:

1. Align high school standards with the demands of college and careers.
2. Require all students to complete a college- and career-ready curriculum to earn a high school diploma.
3. Build college- and career-ready measures into statewide high school assessment systems.
4. Hold high schools and postsecondary institutions accountable for student success.

The world has changed, and high schools must change with it. The ADP Network is leading the charge in ensuring that all high school students graduate with a degree that works.

Visit our Web site for more information about the ADP Network and the ADP benchmarks ([www.achieve.org/ADPBenchmarks](http://www.achieve.org/ADPBenchmarks)) and to view additional "Mathematics at Work" brochures ([www.achieve.org/mathatwork](http://www.achieve.org/mathatwork)).

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