The Official Newsletter of AMERICAN COMPANIES
serving as consulting engineers in geotechnical, materials, environmental and forensic disciplines

The American Edge

BUILDING TECHNOLOGY

Winter 2001-02

The risk of building to the clouds

With a unique design, the twin towers should have endured the worst of times, but not the very worst

In September of the first year of the third millennium, Americans witnessed a catastrophe that, to a great extent, played out in our country's largest city. Classic architectural symbols were utterly destroyed in a matter of hours that Tuesday, entombing thousands of people unable to escape their workplace. As the scale of the disaster sank into the collective consciousness, a need grew to understand how the twin towers were built and how their collapse and the resulting death toll may relate to their design. Public officials, industry, and the engineering community have focused time and effort on the same issue as part of a larger question: what steps must we take to make buildings and other structures safer?

While investigations on many fronts are not yet concluded, it's generally believed the impact of the planes compromised the structural integrity of each tower of the World Trade Center (WTC) when they hit and knocked out perimeter columns and some of the interior core structure. The two 767s may have hit the towers at speeds around 300 mph. Ensuing explosions from fuel – each had 75 percent of its capacity – then caused further damage: as fires burned, structural steel on the breached floors and above, softened, warped and weakened.

Ultimately, the frame and concrete floor slabs, plus building contents, became a consolidated weight crushing lower portions of the frame. It is believed the intense heat from the fire caused more of an implosion collapse than the towers falling over and knocking into adjacent buildings in a super-destructive domino effect.

American Engineering Testings' metallurgist agrees with the conclusions of an account from *Architecture Week* (October 17, 2001), citing the explosion and burning of about 18,000 gallons of fuel at each building, as gradually weakening the steel structure to the point of collapse. At around 900 to 1100 degrees Fahrenheit, structural steel loses about half its tensile strength. If initial estimations are correct, the fire reached temperatures from 1,000 to 3,000 degrees F. The collapses would then be due in large part to the effects of fire on the steel, possibly starting with the failure of the truss system supporting one floor, followed by buckling of the adjacent perimeter and core columns. Once one story collapsed, the massive weight of floors above successively crushed the undamaged floors below in a catastrophic failure of the entire structure.

Implosion expert Mark Loizeaux of Controlled Demolition, Inc., observed the collapses on TV and felt each tower collapsed in a different way. The North tower, which was hit around the 90th floor, failed in a telescoping fashion. He believed the South tower, hit around the 60th floor, failed similar to the way a tree is felled, which apparently resulted in a wider swath of destruction to neighboring properties.

American Petrographic Services petrographers Scott Wolter and Gerard Moulzolf, who analyzed damaged concrete from the Pentagon, requested a concrete sample from the WTC for forensic examination. But as they surmised, specimens weren't available. As concrete disintegrates at temperature levels associated with the crashes, and the cast-in-place concrete floors collapsed onto each other as would a house of cards, literally nothing but powder was left of the concrete. It was pulverized by these actions, leaving little cohesive debris. In fact, much of the dust that arose from the collapse was cement paste and aggregate flour.

The towers first appear on the skyline

The towers were part of a seven-building complex designed by architect Minoru Yamasaki,

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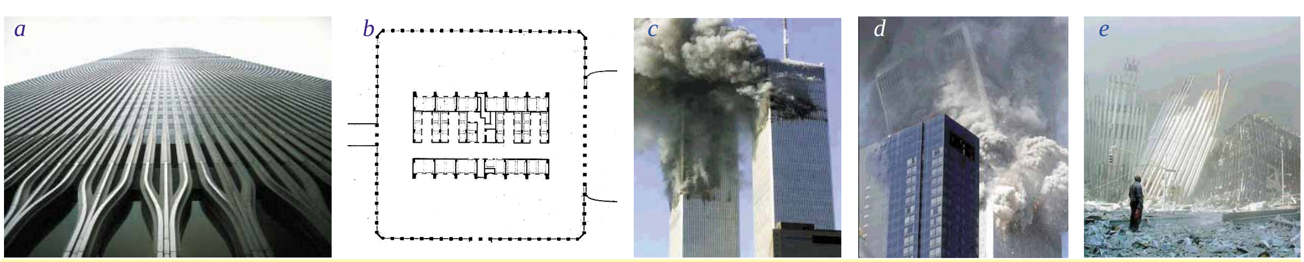

a: Looking up, up, up, before Sept. 11, 2001, photo by Lawrence A. Martin; b: Typical tower floor plan, drawing by Minoru Yamasaki Assoc., Inc.; c: Both WTC towers burn, photo by Doug Kanter/AFP, MSNBC; d: Top of South Tower collapses, CNN photo; e: The aftermath, MSNBC photo

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The risk of building, continued from page 1

Yamasaki and Associates, with Emery Roth & Sons. The complex covered eight city blocks and had an 800 by 400 foot foundation box, 65 to 100 feet deep, with three-foot-thick retaining walls. Each tower had 110 floors and were considered by some the tallest in the world.

The $1.5 billion complex was completed in phases starting in 1966. Original plans of owner Port Authority of New York and New Jersey called for a single 150-story tower, but not long into the project it was concluded that this design was impractical.

But even at 110 stories, the twin towers were designed differently from others before them because the external sheathing carried the load for the structure; each floor was suspended from the exterior walls to the central core. Light, economical structures, the tower design employed tube construction with closely spaced columns and beams on the outer walls. There were no columns in the tower office spaces. Stairs and elevators were incorporated into the core of the towers. Older structures like the Empire State Building used heavy internal supports and thick masonry, which while very different from the towers, may not have survived a similar airliner attack.

Investigating the disaster

Most engineers agree there is nothing that could have saved the twin towers from an attack like the one suffered. True or not, many industry and governmental organizations formed commissions to inquire into various aspects of the disaster. For example, the American Institute of Steel Construction is reviewing the fire-resistant performance of the steel and whether to boost requirements for fire protection on columns. Europe has already considered beefing up its structural codes so they are resistant to progressive collapse.

Forensic activities centering on the September 11 attacks are propelled by research grants from the National Science Foundation, the American Society of Civil Engineers (ASCE), the American Institute of Steel Construction (AISC) and other private and public agencies.

Implications for the urban skyscraper

The goal of high rise construction is to maximize usable space, while minimizing area loss associated with the structural frame (core walls and columns). Utilization of high strength materials like *high performance concrete* and structural steel have facilitated the refinement of this goal. Designers of the WTC achieved high efficiency by structurally supporting the floors between the core wall and the exterior sheathing.

The design community will be confronted with numerous challenges, contends Terry Swor, president of AET. Namely, is it economically possible to improve the resilience of the structural frame without compromising the goal of maximum useable space? Is it possible to incorporate super-efficient egress systems into the resilient frame to get occupants quickly and safely out of the structure? Further, the new International Building Code permits the elimination of fireproofing on structural steel components if the design incorporates a suppression system like sprinklers. In situations such as the WTC attacks, will these systems function as designed?

At the invitation of the U.S. Army Corps of Engineers, the American Council of Engineering Companies (ACEC) is serving on the Steering Committee of The Infrastructure Security Partnership. This is a coalition of design and construction industry groups and federal agencies formed since September 11 to examine the security of the nation's infrastructure.

Two teams, formed by the American Society of Civil Engineers within 24 hours of the attacks, have been investigating the structural performance of the WTC and the Pentagon. The effort is spearheaded by W. Gene Corley, SE, who was a principal investigator of the performance of the Murrah Building in the Oklahoma City bombing. The teams are scheduled to issue their joint report in April. Computer modeling tools are helping them study the impact of the crashes on the structures, one modeling the fire spread and temperature rise. Another can model the overall structure and predict how various modifications might have altered its behavior.

While repercussions still echo throughout the world, a professor at the University of California, Berkeley, who is an expert on steel buildings, works on a way to reinforce key buildings without boosting their construction costs by more than one to two percent. Professor Abolhassan Astaneh-Asl thinks the twin towers were exceptionally well-designed and built. His current strategy involves testing thick concrete-and-steel shear walls as reinforcement of their regular exterior skins, which he expects would create a tough outer membrane to withstand the shock of a direct impact. An equally important function of the membrane in a scenario like the airliner attacks would be minimizing the amount of fuel that gets into the building.

The $1.5 billion World Trade Center complex, covering eight city blocks, was constructed in phases starting in 1966. One World Trade Center (above) was completed in 1972 and the second tower in 1973.

Photo: Minoru Yamasaki Associates, Inc.

Architecture Week magazine (October 17, 2001) suggests designing office buildings to withstand catastrophic events like those of September 11 may be structurally possible, but not economically practical. Instead, attention should focus, in part, on improving evacuation methods as well as fire suppression systems.

Kenneth Green, PE, is president of the Council of American Structural Engineers, Minnesota Chapter. He noted that one outgrowth of September 11 for structural professionals is involving them more uniformly in Urban Search and Rescue teams. (The Urban Search and Rescue teams for the WTC did include a number of structural engineers already trained in US&R.) The other area given intense scrutiny, he says, is preventing or minimizing loss of life during an emergency "by improving systems that get people out or to a safe zone."

What might replace the WTC complex in New York? Tall replacements are unlikely, say city officials. We will probably see, instead, a

Concrete samples from the Pentagon crash site have been analyzed by American Petrographic Services in the Saint Paul lab. Details on this project will appear in an upcoming issue of the American Edge.

series of smaller structures. Of the many initial ideas, the one most talked of is a site featuring a victim's memorial and possibly several structures that would not exceed 50 or 60 stories. Most developers express the view that it's economically impractical to build very large structures there anytime soon.

In the 1960s, architect Yamasaki said of the dramatic complex he was in the midst of creating:

> The World Trade Center should, because of its importance, become a living representation of man's belief in humanity, his need for individual dignity, his belief in the cooperation of men, and through this cooperation, his ability to find greatness.

We now, unfortunately, see irony and tragedy in words meant to inspire. Can we not only regenerate, but learn and improve from terrible events? And will a new World Trade Center represent greatness again, and *security* as well? A

Emission testing

American Engineering Testing provides a highly trained, experienced staff to perform emissions monitoring and testing using state-of-the-art equipment. We offer our testing services to a variety of industries and consultants. Emission monitoring and testing, also known as stack testing, can be used to fulfill a number of needs:

- *Federal regulatory requirements*
- *State air permit requirements*
- *Internal pollution prevention requirements*
- *Engineering testing*
- *Mass balance & recovery determinations*
- *Research and development*

AET's emission monitoring and testing capabilities include sampling and analysis for a variety of pollutants, such as:

- *Volatile and semi-volatile organics*
- *Hazardous air pollutants (HAPs)*
- *Acid gases*
- *Particulate matter (PM/PM_{10})*
- *Opacity*
- *Metals*

By utilizing our emission monitoring and testing services, clients can demonstrate compliance with applicable regulations and, in some cases, improve production efficiencies, reduce operational costs and decrease waste. Here are some projects where this was accomplished:

A client requested an engineering testing program for an ethanol production plant. The program included monitoring for particulate emissions during several experimental operating conditions. Based upon the test results, the client was able to propose modifications to the ethanol plant's operating permit, allowing the plant more operational flexibility while maintaining compliance with air pollution regulations.

A large, multi-national manufacturing company requested that AET determine the pollution control efficiency of a thermal oxidizer controlling several process lines. The testing was performed at various oxidizer temperatures to find the minimum operating temperature at which compliance with air pollution regulations could be demonstrated. Results showed the client could lower the oxidizer temperature and still keep the facility in compliance; the company dramatically lowered oxidizer operating costs by reducing natural gas consumption.

For more information on AET's emission monitoring and testing services, contact Ashley Larson at (651) 659-9001.

NONDESTRUCTIVE TESTING

DISSIMILAR METAL CORROSION

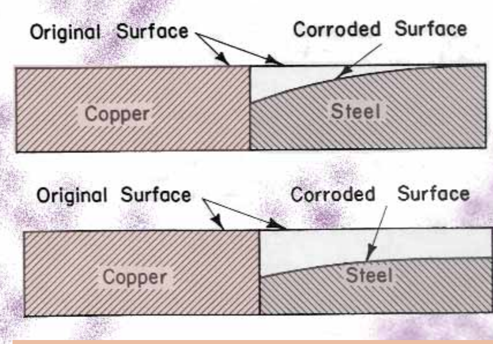
When is it a good thing and when is it a problem?

Each metal element has its own characteristic electropotential. When two dissimilar metals are in contact with each other and exposed to a conductive solution, a potential is set up between the two metals and a current flows. The resulting electrochemical reaction causes corrosion to the more active metal. A typical example of this type of behavior occurs in a dry cell battery. Two dissimilar metals are connected together in a highly conductive electrolyte, creating the desired current flow at the expense of anodic corrosion. The reaction explains why batteries wear out and can only be recharged if the reaction is forcibly reversed.

Some types of dissimilar metal corrosion are desirable. These types include dry cell batteries, sacrificial zinc anodes, and galvanized (zinc) coating protection. Zinc is a highly active metal, and will sacrificially corrode to protect the base metal, typically steel. Examples of this type of protection are galvanized fencing, aluminum-coated steel sheeting, and underground magnesium anodes.

Unfortunately, dissimilar metal corrosion is usually harmful. Water systems with steel couplings connected to copper couplings can fail catastrophically. Bi-metal valves can also fail, especially in a salt water environment. Printed circuit boards are also susceptible to this type of chemical attack, and must be kept in a moisture-free environment to prevent the electrochemical reaction.

Dissimilar metal corrosion can be prevented by either breaking the electrical connection or simply avoiding the use of different contacting metals. Dielectric couplings are often used in water systems to separate the electrical contact between the steel and copper. Aluminum is sometimes coated with a protective film to provide the insulating barrier when aluminum (active) is in contact with copper (noble). The elimination of moisture or electrolyte will also provide the reaction, but sometimes this is impossible. The best fix is to use good engineering practice when designing systems to avoid dissimilar metal contact. Good engineering practice is also advisable to eliminate other potential problems, such as crevice corrosion.



Top: The extent of corrosion of steel in a tap water environment. Lower: The extent of corrosion of steel in a sea water environment.

For more information, contact the metallurgy department at 651-659-9001.

Staff notations

Mike Kunz, PG, CHMM, senior environmental scientist, has been elected treasurer to the Executive Committee for the Architectural Engineering, Land Surveying, Landscape Architects, Geo-Science & Interior Design State Licensing Board.

Kate Kleiter, PG, has been promoted to principal hydrogeologist. She was also elected president of the Minnesota Chapter of the American Institute of Professional Geologists for 2003.

Mark Sandvig was appointed regional project development manager for the nondestructive testing division. Mark has also been elected treasurer for the American Welding Society, Northwest Section, for 2002-2003.

Scott Gruenhagen has assumed the role of work coordinator, Saint Paul nondestructive testing.

Lab accreditation

American Engineering Testing has recently undergone a laboratory assessment by the American Association for Laboratory Accreditation (A2LA) in pursuit of accrediting our laboratories in geotechnical, construction materials, petrographic, nondestructive and metallurgical engineering and testing.

A highly sought-after accreditation, it signifies that the company's personnel and quality system have been assessed by a third party and found to meet the internationally recognized quality assurance standard. The standard is formally known as ISO/IEC Standard 17025, *General Requirements for the Competence of Testing and Calibration Laboratories.* AET, Saint Paul, anticipates receiving formal accreditation in March 2002.

AET has won engineering awards for the Minneapolis Convention Center Expansion – Structural Systems project. From the Minnesota Society of Professional Engineers, the project won the 7 Wonders of Engineering award. The Consulting Engineers Council of Minn. has awarded it an Honor Award for outstanding engineering achievement.

Maturity Method Testing presentations show importance for fast track

Eric Pederson, PE, and John Amundson, PE, recently gave presentations on the topic of maturity testing of concrete. One was given at the American Concrete Institute's convention in Dallas, Texas last October. The two engineers also gave a presentation on maturity testing at the 51st Concrete Conference, held at the Earle Brown Center at the University of Minnesota, Saint Paul campus, in December.

Top: Eric Pederson, PE
Bottom: John Amundson, PE

Both talks focused on procedures of the testing method and the benefits as a concrete strength development prediction tool. Perhaps the biggest benefit of using the maturity method instead of other commonly-used methods is the ability to quickly and accurately predict when the concrete will attain its required strength (to proceed with stripping of forms or tensioning of cables).

For more information on this topic, contact Eric Pederson, construction materials division, 651-659-1312.

Third South Dakota office opens

Last fall, AET opened its ninth regional office in the Upper Midwest near Sioux Falls, South Dakota. The third in the state, it will serve as a base of operations for providing nondestructive testing services to South Dakota, Iowa, Nebraska and southwest Minnesota. Clair Christians manages the new office, located at 107 West Oak Street in Beresford. Telephone: 605-763-8061, fax: 605-763-8063.

Environmental consulting seminar

A free half-day seminar will be presented by the environmental services division of AET on the topic of ***What environmental consultants do and how they can help you.*** It is geared for real estate professionals, construction managers, new corporate environmental managers, public agencies, bankers, lawyers, and others involved in environmental management or cleanup activity.

The seminar will be held at 8:00 a.m., March 14, 2002, at AET's corporate office, 550 Cleveland Ave. No., Saint Paul. Staff will present information on what constitutes a good proposal, what environmental rules you must be aware of, what PIDs are, and how best to prevent project delays and cost overruns due to environmental problems. Contact Kate Kleiter for more information at 651-659-1319 or kkleiter@amengtest.com.

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Published four times a year by American Engineering Testing for our clients and associates.

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