Comments on NIST Recommendation Nos. 5, 7, and 9

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NIST Recommendation Nos. 5, 7, and 9

Recommendation No. 5
NIST Recommends That The Technical Basis for The Century-Old Standard for Fire Resistance Testing of Components, Assemblies, and Systems should be Improved through a National Effort.

Recommendation No. 7
NIST Recommends The Nationwide Adoption and Use of The Structural Frame Approach to Fire Resistance Ratings

Recommendation No. 9
NIST Recommends The Development of Performance Based Standards and Code Provisions as an Alternative to Current Prescriptive Design Methods. Tools, Guidelines, and Test Methods Necessary to Evaluate The Fire Performance of The Structure should Form a Whole System

Early Fire Resistance Investigations in U. S. A.

In 1920s

National Bureau of Standards (NBS) Conducted Burn-Out Tests of Specially Constructed Buildings of 16x30x9 ft and 30x60x9 ft. The Reports were Published in 1922 and 1926.

Started in 1925

NBS Fire Tested Sixty 8'- 9" High R/C Columns of 12 to 20 inch Square and Circular X-Sections Designed in Accordance with The Prescriptive Code Developed based on The Working Stress Theory

Fire Tests were Carried out Following The ASTM E 119 Standards

Test Data were Used to Determine Structural Fire Ratings of Columns as Required by The Prescriptive Codes

Revisions of ACI-318 Code

1941 - 2005	14 Revisions were Made
1941 - 1971	The Working Stress Theory (WST) was Used
1963 - 1971	Shifting from WST to Strength Design Theory, SDT
1971- Present	The Strength Design Theory has been Used

ACI 318 Refers Fire Safety Design to ACI 216
"Standard Method for Fire Resistance of Concrete and Masonry Construction Assemblies"

Impact of ACI Code Changes

- Columns Designed Based on SDT are Thinner Than Companion Columns Designed Following WST
- Thinner Columns Generally Have Weaker Fire Resistances
- Building Officials Questioned Fire Resistances of Columns Designed in Accordance with SDT
- PCA & NRC were Asked to Update Column Fire Ratings

The Joint PCA/NRC Column Fire Test Program, 1980 - 2000

- Fire Tests of 40 Columns; 12’-9” High, Various X-Sections, Made with Carbonate, Siliceous, Lightweight, and High Strength Concrete
- Columns were Designed, Cast, Cured at PCA Fire Laboratory and Shipped to NRC in Ottawa
- Columns were Fire Tested at NRC Fire Laboratory Using Its Column Furnace Equipped with a 1000 ton Hydraulic System
- Results were Published in PCA and NRC Publications and have been Used to Determine Structural Fire Ratings of Columns as Required by Prescriptive Code
- Average Cost for Each Test was approximately US $30,000.

PCA/NIST Fire Tests of Concrete Beams and Slabs 1970's to 1980's

- Programs were partially Funded by NBS and Tests were Conducted at PCA Fire Lab Using Its Large Floor and Beam Furnaces Equipped with Appropriate Load Systems
- A Dozen of 18X14 ft Flat, Pan-Joist, and Waffle Concrete Slabs were Tested to Determine Structural Fire Ratings of Different Slab Types and Effect of In-Plane Restraints. The Test Data were Published in PCA Publication and ACI SP-80
- More Than a Dozen of 40 ft Long Rectangular, T, Double-T Concrete Beams were Tested to Determine Structural Fire Ratings of Different Beam Types Including Effects of One End Continuity and Two End Continuity. Results were Published by PCA
- The Same Results were Used to Develop Rational Design of Reinforced Concrete Members for Fire Resistance. The Engineering Principles were Published in The Fire Safety Journal, 1986
- Published Data were Used by Designers, Engineers, and Building Officials
- A Special Project Involving Flexural and Shear Behaviors of Beams in Fire was Carried Out by PCA and The result was Published by NBS. GCR-87-536
- The Average Cost Per Test was approximately $25,000.

Standard Fire Test Procedures

ASTM E-119, ISO-834, CEN/TC127, DIN1045, JISA1304, and CNS-12514

Cross References Resulted to almost Identical Requirements:

- Furnace Sizes
- Time-Temp. Curves, **Exceedingly Conservative**
- Specimen Dimensions
- Support Conditions, **?able**
- Load Applications
- End Point Criteria, **?able**

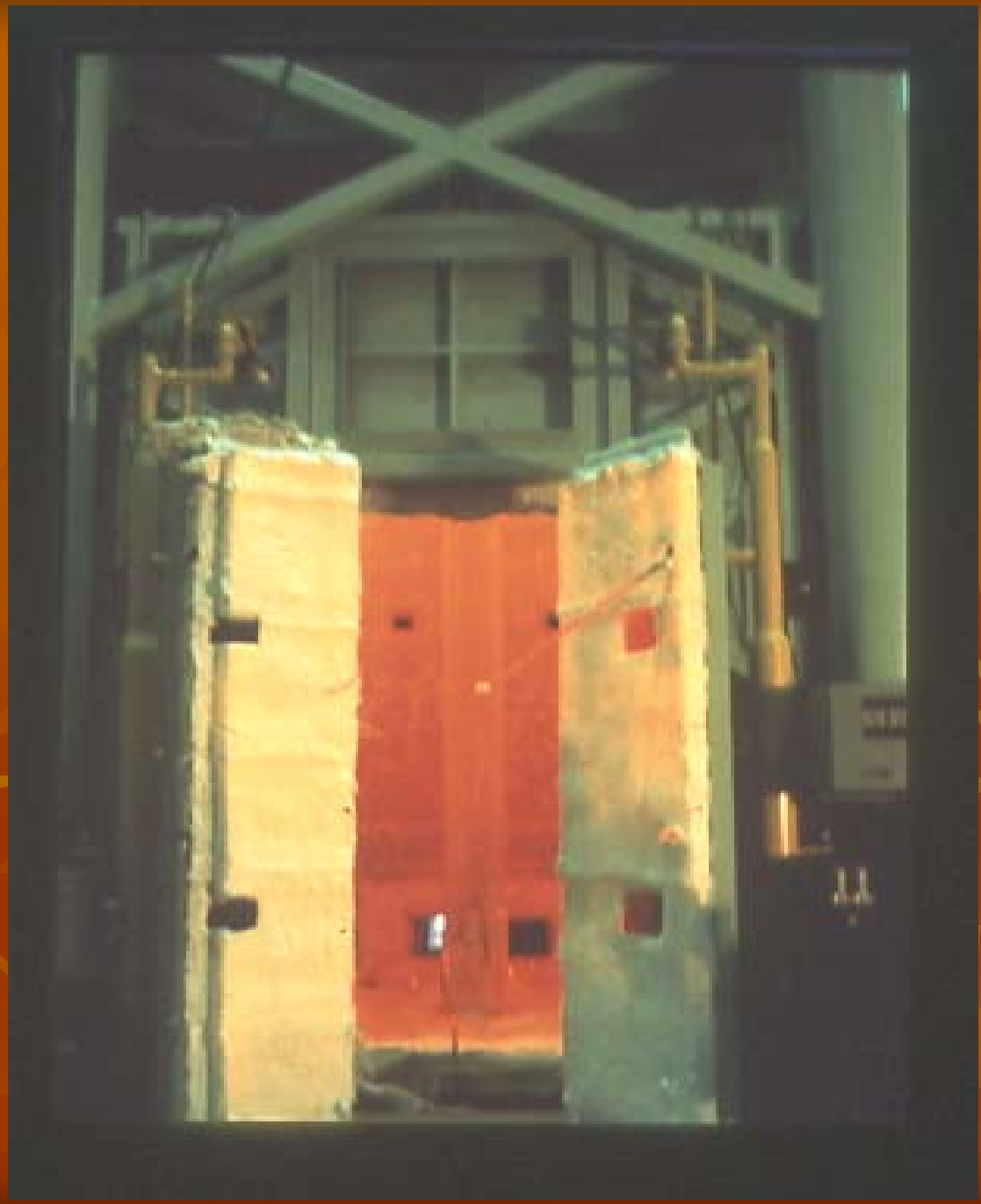
Support Conditions: A-6.1.2 of ISO-834-1975:

- **The Areas of Supports are to be Protected against Fire to The Same Degree as Provided in Practice**
- **Positioning Supports outside Furnace is a Common Laboratory Practice in U. S. and Abroad**
- **Fire Test must be Terminated when a Large Deflection or a Collapse Becomes Imminent**

  Why: To Protect Instrumentation and Facilities

Tests without Support Areas Exposed to Fire

- **Failures Occur in The Fire Exposed Regions Only**
- **The Beam/Column Joint (Critical as Described in FEMA & NIST Reports) was not Included in The Test**
- **Since Element Fire Tests do not Cover The Entire Specimen Their Structural Fire Ratings need to be Carefully Evaluated**



Comments on PCA/NRC Column Tests

- All Tests were Conducted Following The ASTM E-119 Procedure
- Columns were Subjected to Fire on 4 sides and a Concentric Load
- Top and Bottom Ends (~ 1 Ft.) were not Exposed to Fire
- Few were Subjected to Same Fire Exposure and a Combined Concentric/Eccentric Load
- Test Data Represent Structural Fire Ratings of Interior Columns
- But The Same Data have been Used to Assess Structural Fire Ratings of Edge and Corner Columns
- The Validity of Such Applications is Theoretically Unsound, The Next Slide Explains The Reason Why

Explanation

- **Edge & Corner Columns are Exposed to Fire on 3 and 2 Sides, respectively**

- **Uneven Circumferential Temperature Distributions Tend:**

  1. To Cause Greater Thermal Stresses on The Exposed Sides

  2. To Increase Load Eccentricity and Results to a Greater Bending Moment

  3. To Induce Buckling Failures of Concrete or Steel Columns; The Buckling Failure of Exterior Columns in The Fire Engulfed Stories and Triggered Collapses of WTC Towers is a Good Example

Confusing End Point Criteria of ASTM E-119

1. Heat Transmission – When Temperature Rise on The Unexposed Surface Reaches 250 F Average or 325 F at a Single Point, The End Point is Met

2. Steel Temperature – When The Temperatures of Reinforcing Bars (including the Structure Steel) or Prestress Steel Reaches 1100 F or 800 F respectively, The End Point is Met

3. Structural End Point – When a Structural Failure Becomes Imminent, The End Point is met.

Note:

The Term "Fire Rating" has been Commonly Used to Describe The Elapse Time of a Fire Test without Identifying which Criterion was Based upon Seems Confusing because, Heat Transmission and Structural Failure are Two Different Physical Behaviors. Thermal Fire Rating and Structural Fire Rating may be of Appropriate Terms for Use in Performance Based Codes

Where Does Performance Based Codes Stand?

- The Concept of Performance Based Code Emerged before 1980
- NIST Recommends That Structural Fire Resistances Should be Enhanced by Requiring Performance Objectives
- Code Officials Recognize The Need for Fire Safety Designs Emphasizing Performance
- The First Version of “ICC Performance Code for Buildings and Facilities Manual” was Jointly Published by BOCA, ICBO, and SBCCI in 2001
- The PBC Legal Responsibility Sharing among Engineering Firms, Building Owners, and Building Officials is in The General Public Interest
- The Trend of Performance Based Code Application to Fire Safety Design is on The Rise
- Fire Tests of Beam-Column Frames will Serve The PBC Purpose

Structural Fire Safety Studies in Taiwan

- Architecture and Building Research Institute (ABRI)
- Recognizes The Need for Beam/Column Frame Fire Tests and Built a B/C Furnace Equipped with a 2000-ton Actuator, 2005
- The Planning, Design, and Construction Took nearly 4 Years
- The Cost was Approximately U.S.$ 2 Millions.

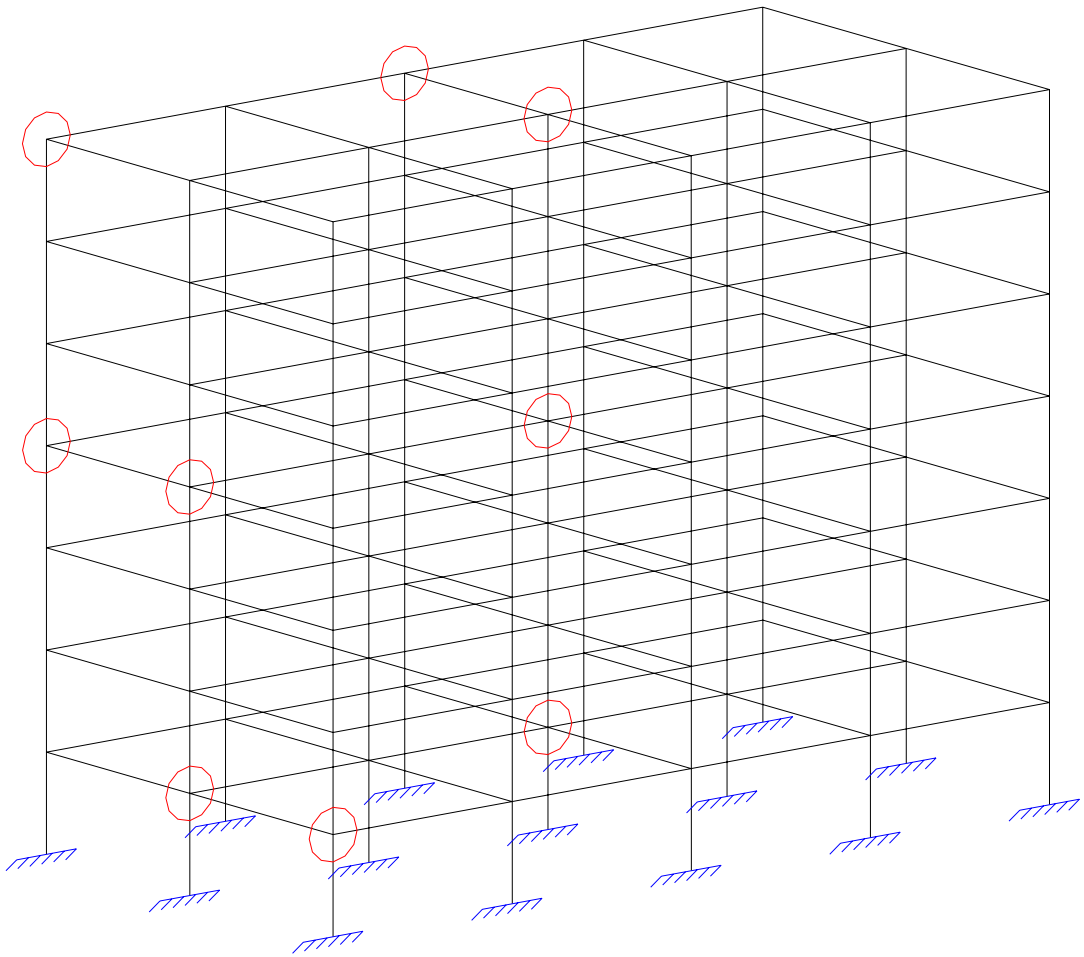
The ABRI B/C Furnace

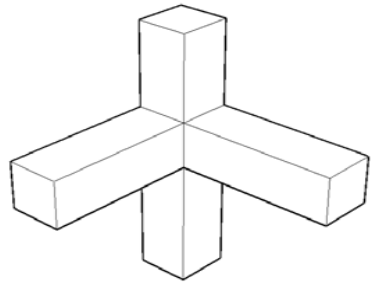
- The Furnace Measures 7 m High, 4.95 m Wide, 8.95 m Long
- It is Equipped with Sophisticated Heating, Loading, and Data Acquisition Systems
- A 2000-ton Actuator is Located Directly Underneath The Test Column
- An Expensive Exhaust-Air Purification Unit was Installed to Meet The EPA Air Quality Control Requirement
- National Science Council of Taiwan and ABRI have jointly Funded Research Projects

The Newly Constructed ABRI Beam-Column Furnace

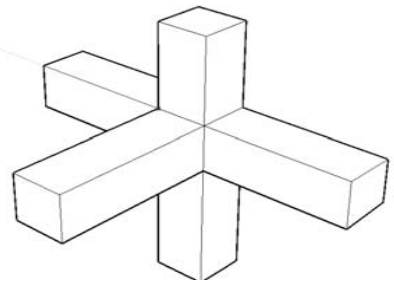
Engineering Consideration on Fire Tests

Interior, Edge, and Corner Beam-Column Assemblies at the Roof, Mid-Height, and Ground Floor Levels

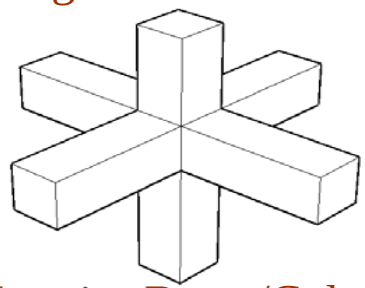




Corner Beam/Column



Edge Beam/Column



Interior Beam/Column

Possible Beam-Column Combinations

Concrete Frames	Steel Frames
1. Normal weight concrete beams, slabs, and columns	1. H-steel for beams and columns
2. Normal weight concrete columns/beams and lightweight concrete slabs	2. H-steel for columns and trusses beams
3. High strength concrete columns and normal weight concrete beams and slabs	3. Box column and H-steel beams
4. High strength concrete columns, normal weight concrete beams, and lightweight concrete slabs	4. SRC columns and H-steel beams
5. FRP-sheltered concrete systems	5. SRC columns and truss beams
	6. Composite beam-column connections
	7. Durability of fire proofing

At Least 40 Tests Will Be Needed for A Decent Study Program. The Estimated Cost is US$2 Millions

Another B/C Furnace Is Under Design in Taiwan

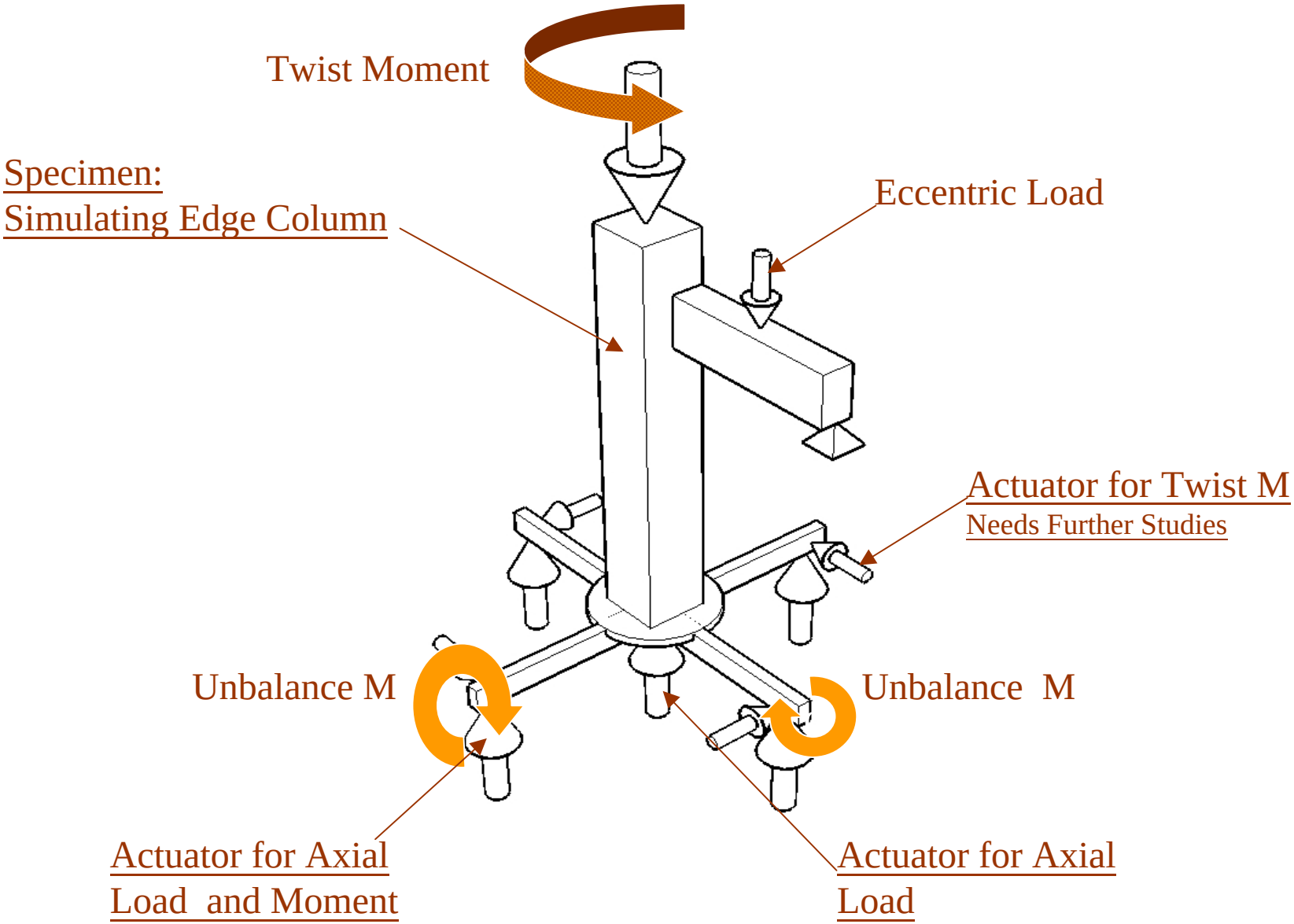
Fire Research Laboratory of National Cheng Kung University Plans to Build a Beam/Column Furnace Equipped with 5 Actuators Capable of Generating a Total Load of ~ 1000 tons.

The Uniqueness of The Design Involves The Capability of Applying Axial Load or a Combination of Axial Load, Moments in Orthogonal Directions, and a Twist Moment to Enhance The Flexibility of Test Simulations

Reaction Forces and Unbalance Moments on X-Y-Z Axes at The Column Base can be Controlled and Measured through The Use of Commercially Available High Speed Software and Data Acquisition System. This will be a Big Step forward from The Century Old Fire Test Method.

The Next Slide Shows The Conceptual Loading System. The Furnace Construction Contract was Signed in June, 2005 and The Loading System will be Signed Separately Later.

Conceptual Beam/Column Loading System



Conclusion

- Performance-Based Codes Demands Structural Fire Tests
- NIST Recommends Structural Frame Tests for Fire Resistance Ratings
- The Current Structural Fire Test Procedures should be Improved through National and International Efforts
- Fire Tests of Beam/Column Frames shall Open a New PBC Chapter
- Test Data will be Needed in Designing Fire Safety of Buildings
- Fire Tests of Structural Frames may Exceed $30,000/Test, Expensive
- Domestic and International Collaborations will be Logical Solutions
- Collaborations Offer Opportunity for Tech Exchange & Cost Sharing

Suggestions for Collaborative Studies

- Structural Fire Tests of Corner, Edge, and Interior Beam-Column Frames

  Experimental Program shall be Designed Focusing on High-Rise Buildings and Coordinated/Supervised by an International Committee

- Rational Designs for Fire Safety of Concrete and Steel Buildings

  Engineering Principles shall be Developed by Structural/Fire Safety Engineers Based on The Obtained Test Data. The Task shall be Supervised by The Same Committee

- Software for Rational Designs of Fire Safety Buildings

  Computer Programs shall be Developed from Rational Design Theory through a Joint Effort of Engineers and Numerical Experts. The Work shall be Supervised by The Same Committee

- Software for Building Fire Evaluation including Bomb or Plane Explosions

  The Developed Software shall then be Expanded to Cover Terror Explosions in Buildings. The Program shall be Supervised by The Same Committee and Fire Protection Experts (Fire Fighters)

** **The above Mentioned Subjects are conceivably within PBC Requirements. Hopefully, They Meet The Ultimate Objective of This Conference, "Fire Safety Investigation of The World Trade Center Disaster" as well**

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Thank You

For questions, please contact: tdlin@aol.com