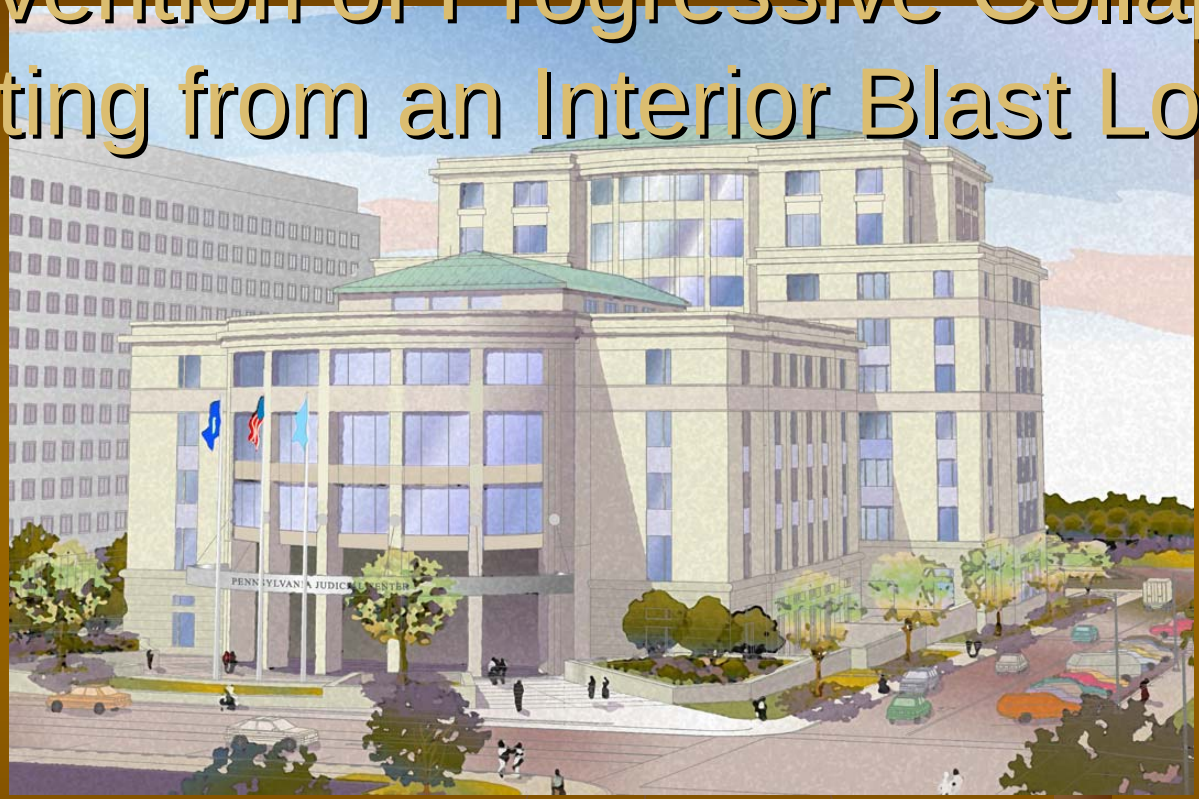
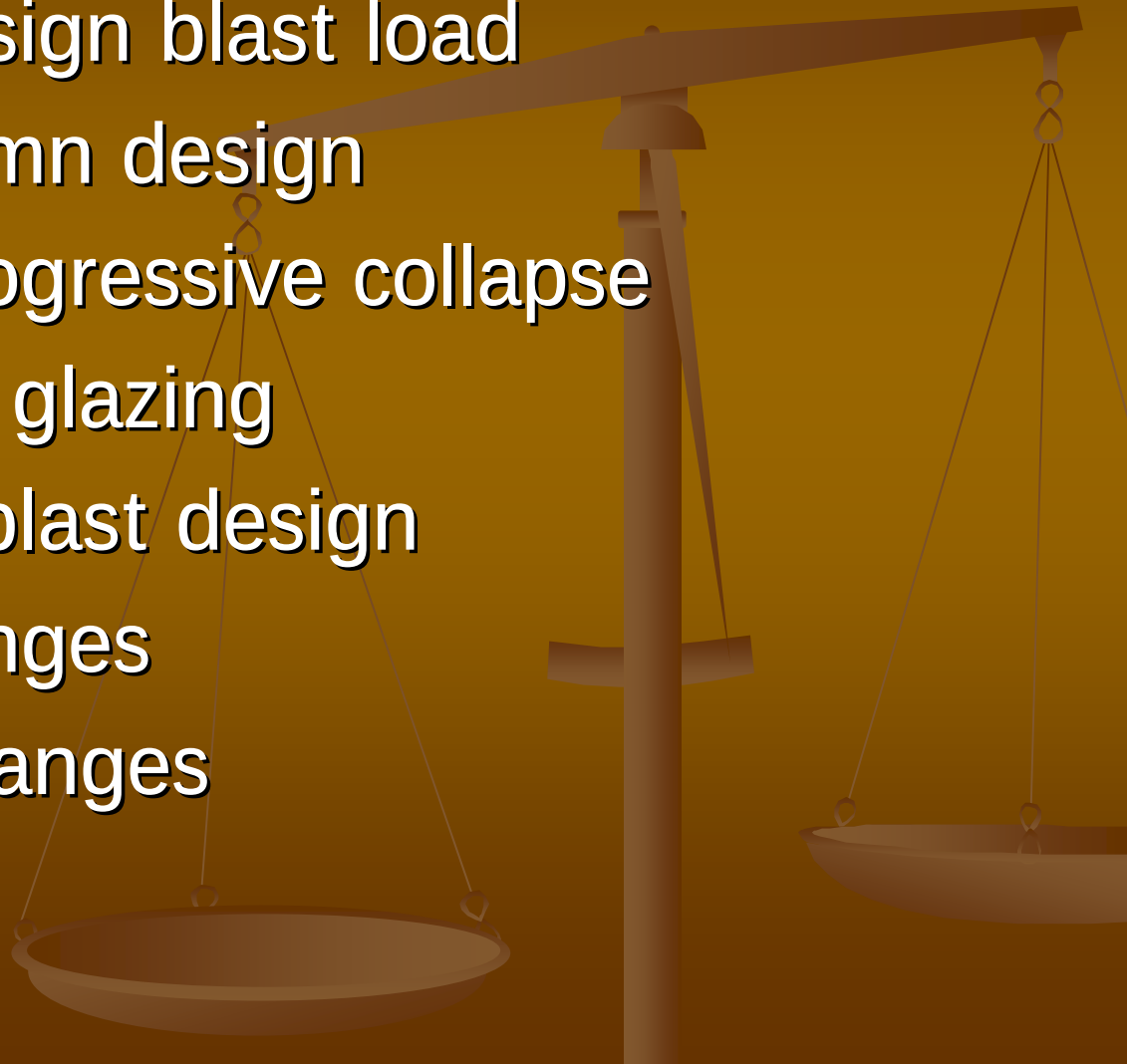
Pennsylvania Judicial Center:
Prevention of Progressive Collapse Resulting from an Interior Blast Loading



Brian M. Barna
Structural Option
AE Senior Thesis – Spring 2007

Introduction of Topics

- Defining the design blast load
- Composite column design
- Mitigation of progressive collapse
- Blast design for glazing
- Cost impact of blast design
- Mechanical changes
- Architectural changes



Building Background

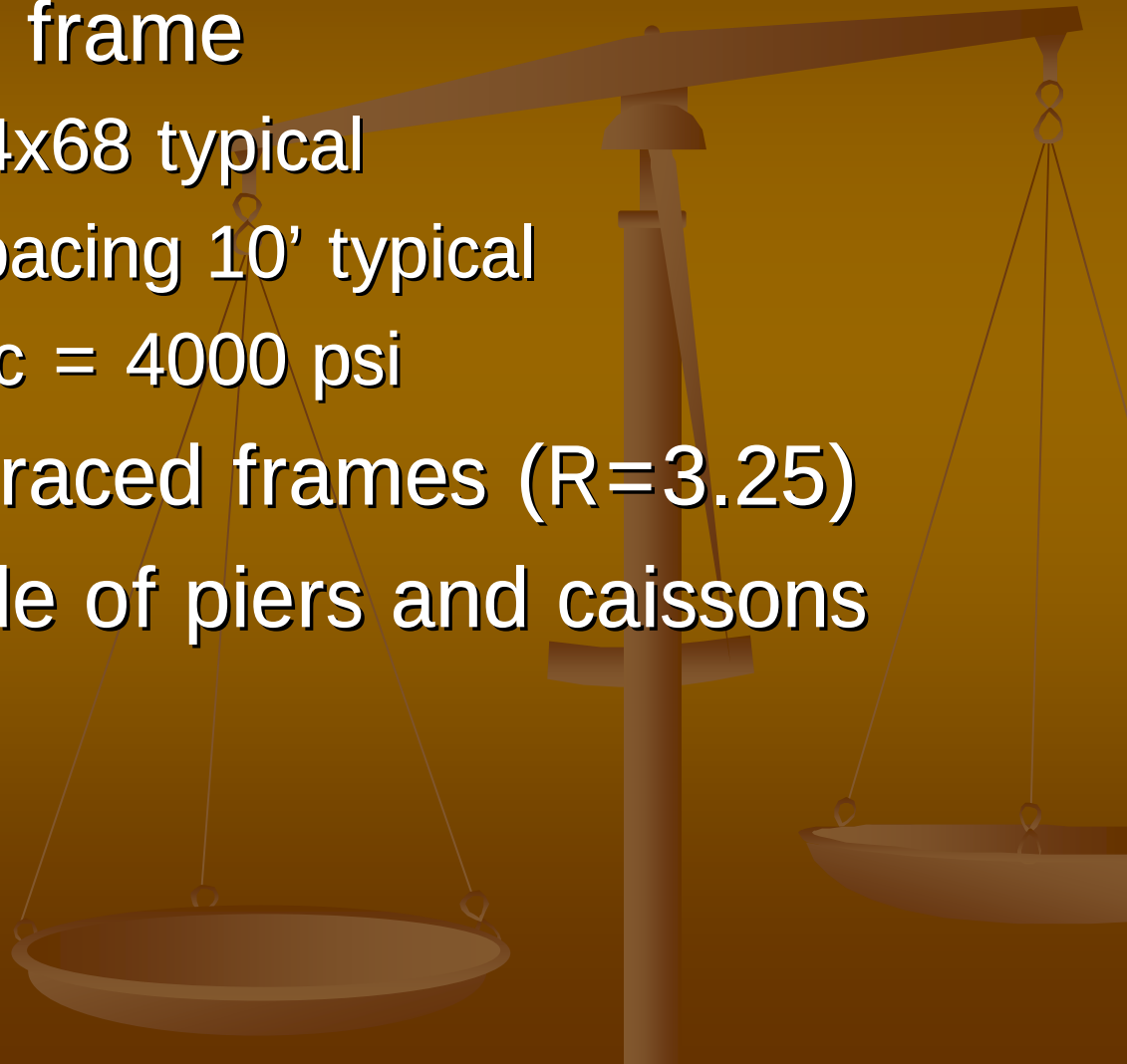
- Nine stories
- 425,000 sq. ft
- Harrisburg, PA
- $90-95 million
- Construction from Fall 2006 – Fall 2008
- Center of Unified Judicial System
- Courtrooms and offices

Building Background

- Owner: Pa. State Government
- A/E Firm: Vitetta
- Construction: Heery International

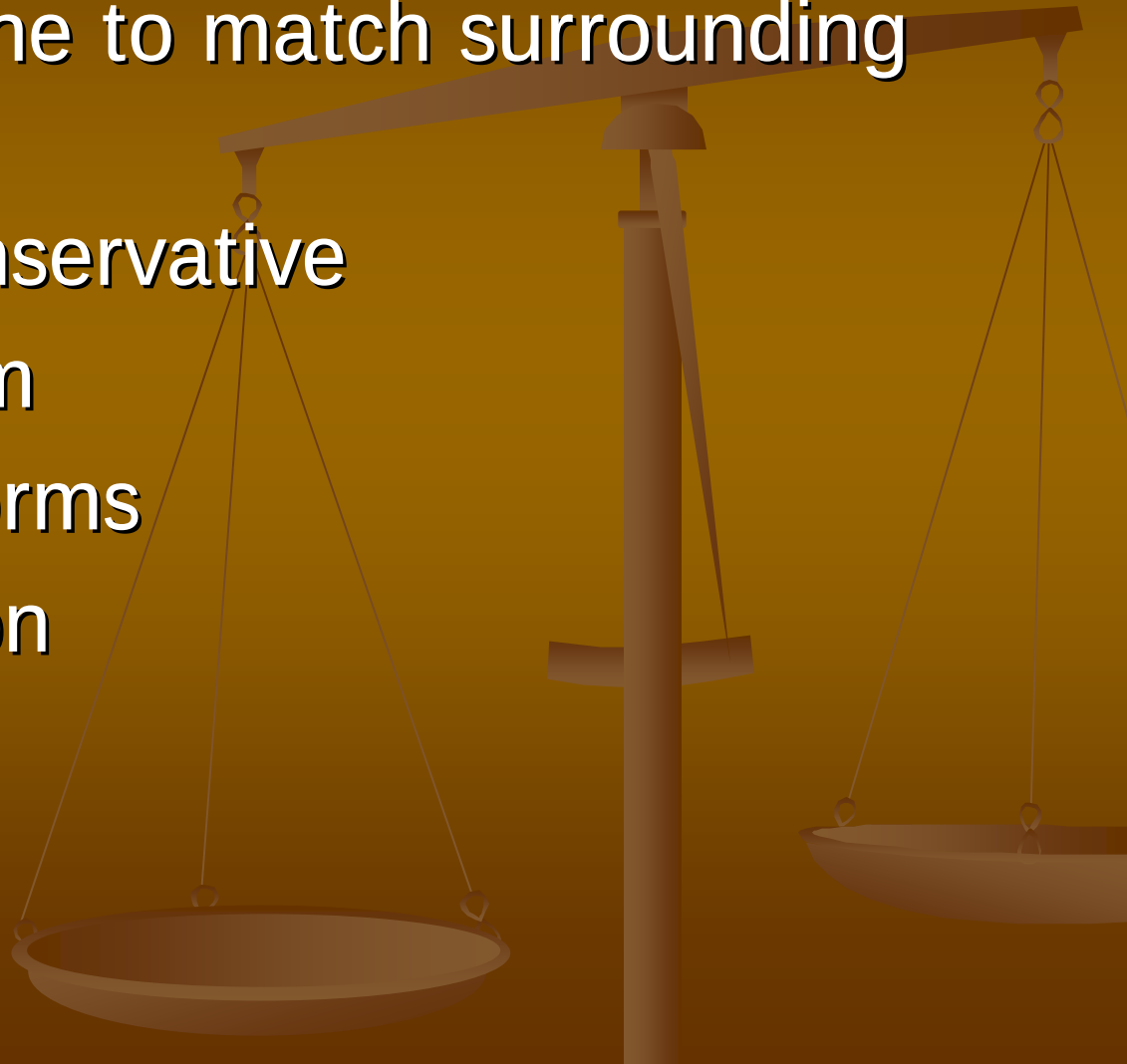
Structural Features

- Composite steel frame
  - W16x36 to W24x68 typical
  - Spans $\leq$ 42', Spacing 10' typical
  - LW Concrete, f'c = 4000 psi
- Concentrically braced frames (R=3.25)
- Foundation made of piers and caissons

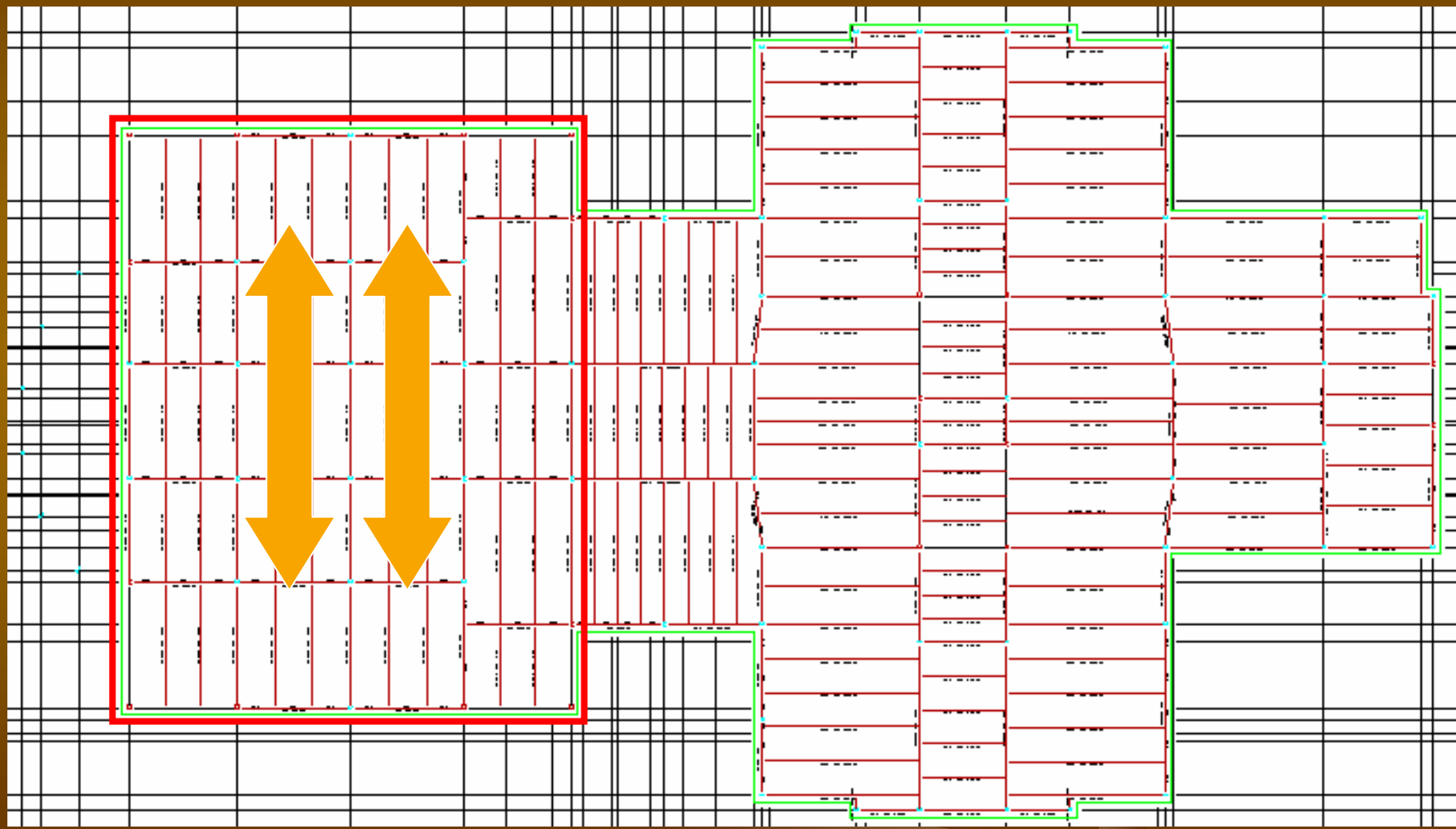


Architectural Features

- Indiana limestone to match surrounding buildings
- Modern and conservative
- Five story atrium
- 3 rectangular forms
- Future expansion

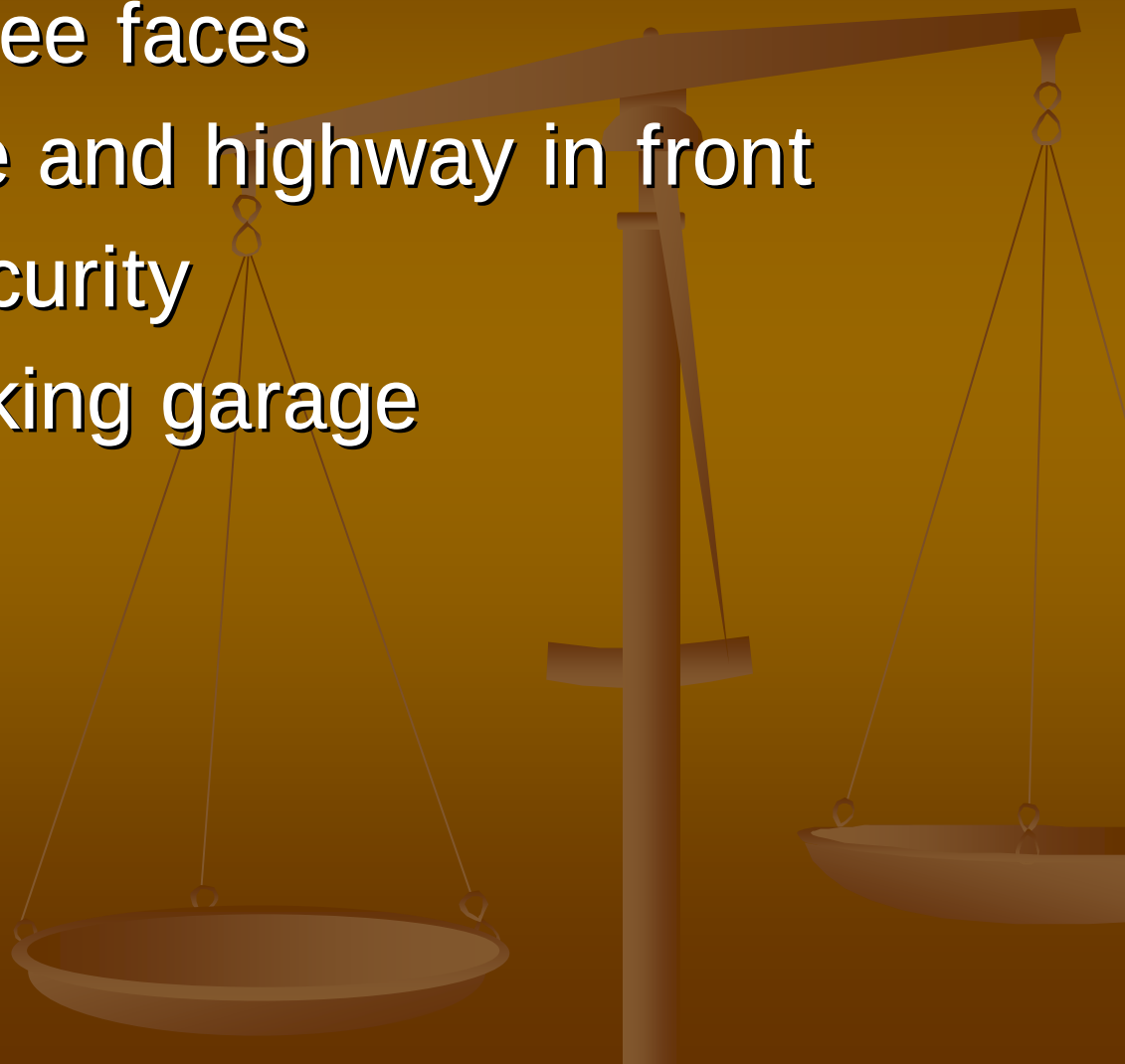


Typical Floor Plan

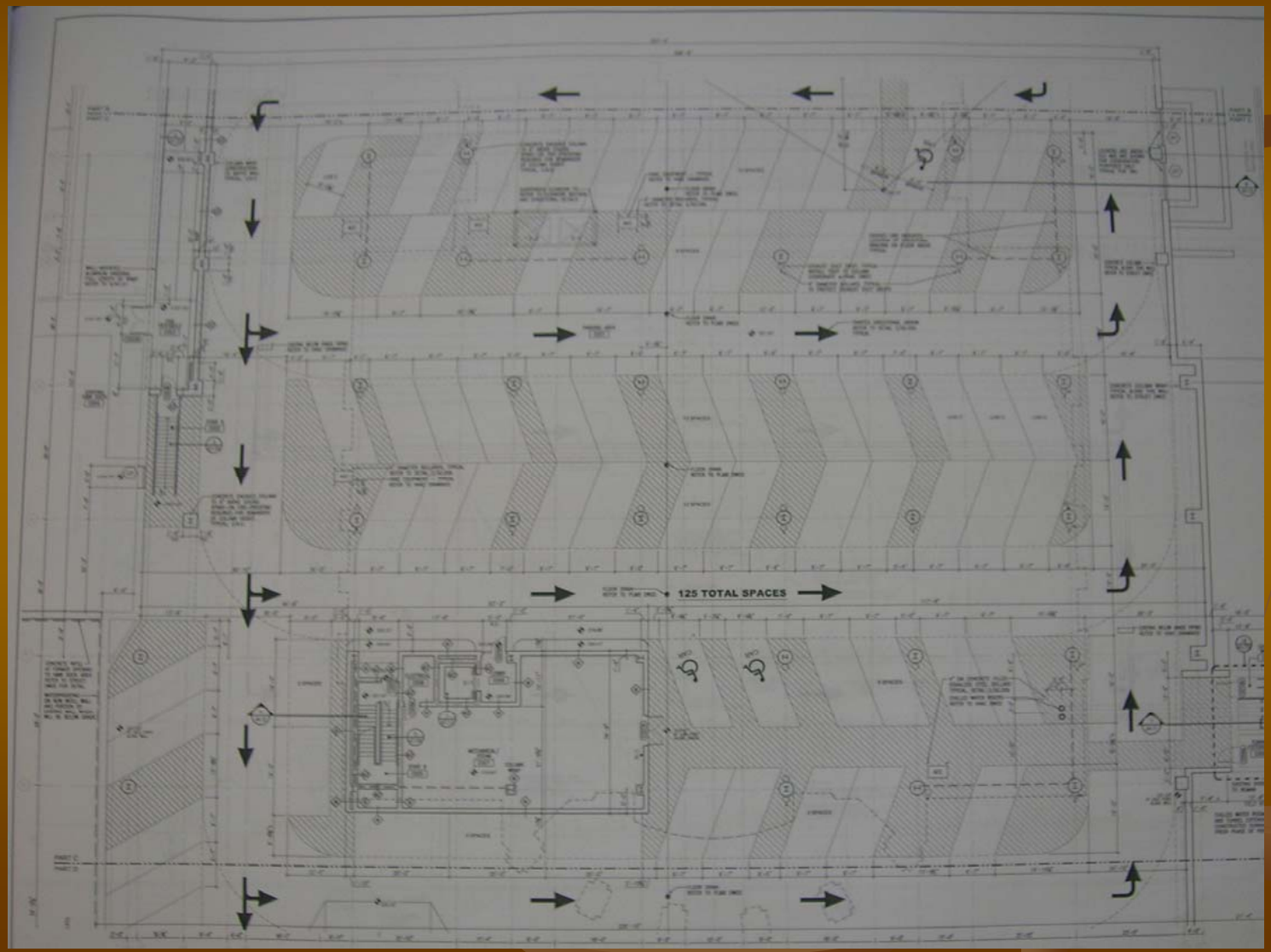


Selection of Design Blast Location

- Bordered on three faces
- Gathering space and highway in front
- High level of security
- Lower level parking garage



Parking Garage Plan



Selection of Design Blast Force

- Define load as a max loaded car bomb
- 1000 lbs
- TNT Equivalency

ATF	VEHICLE DESCRIPTION	MAXIMUM EXPLOSIVES CAPACITY	LETHAL AIR BLAST RANGE	MINIMUM EVACUATION DISTANCE	FALLING GLASS HAZARD
	COMPACT SEDAN	500 Pounds 227 Kilos *(In Trunk)*	100 Feet 30 Meters	1,500 Feet 457 Meters	1,250 Feet 381 Meters
	FULL SIZE SEDAN	1,000 Pounds 455 Kilos *(In Trunk)*	125 Feet 38 Meters	1,750 Feet 534 Meters	1,750 Feet 534 Meters
	PASSENGER VAN OR CARGO VAN	4,000 Pounds 1,818 Kilos	200 Feet 61 Meters	2,750 Feet 838 Meters	2,750 Feet 838 Meters
	SMALL BOX VAN *(14 FT BOX)*	10,000 Pounds 4,545 Kilos	300 Feet 91 Meters	3,750 Feet 1,143 Meters	3,750 Feet 1,143 Meters
	BOX VAN OR WATER/FUEL TRUCK	30,000 Pounds 13,636 Kilos	450 Feet 137 Meters	6,500 Feet 1,982 Meters	6,500 Feet 1,982 Meters
	SEMI-TRAILER	60,000 Pounds 27,273 Kilos	600 Feet 183 Meters	7,000 Feet 2,134 Meters	7,000 Feet 2,134 Meters

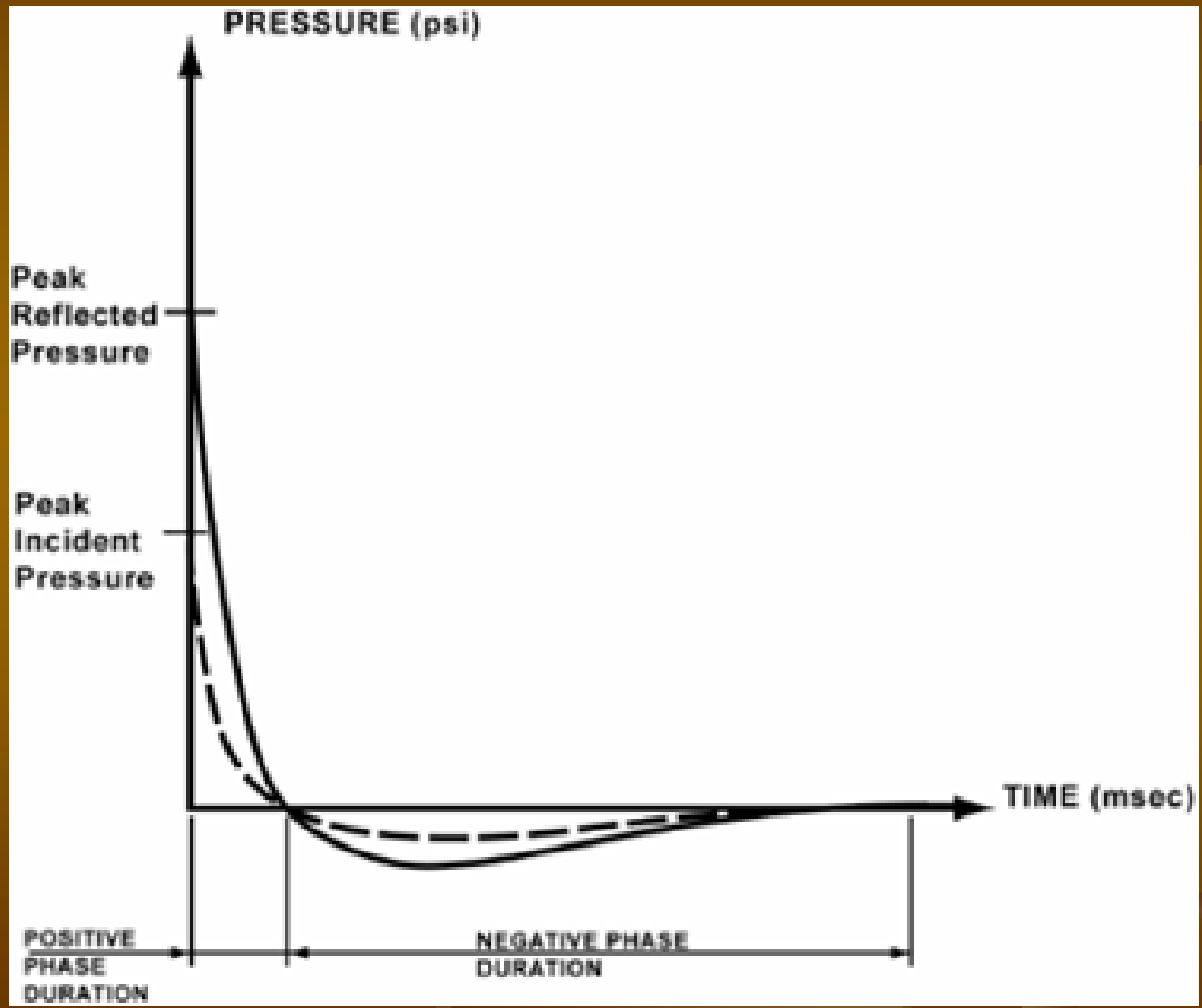
Selection of Design Blast Force

- 25’ standoff distance
- Scaled distance ‘Z’ (TM5-1300):

$$Z = \frac{R}{W^{1/3}} = \frac{25\,feet}{(1000lbs)^{1/3}} = 2.5\,feet$$

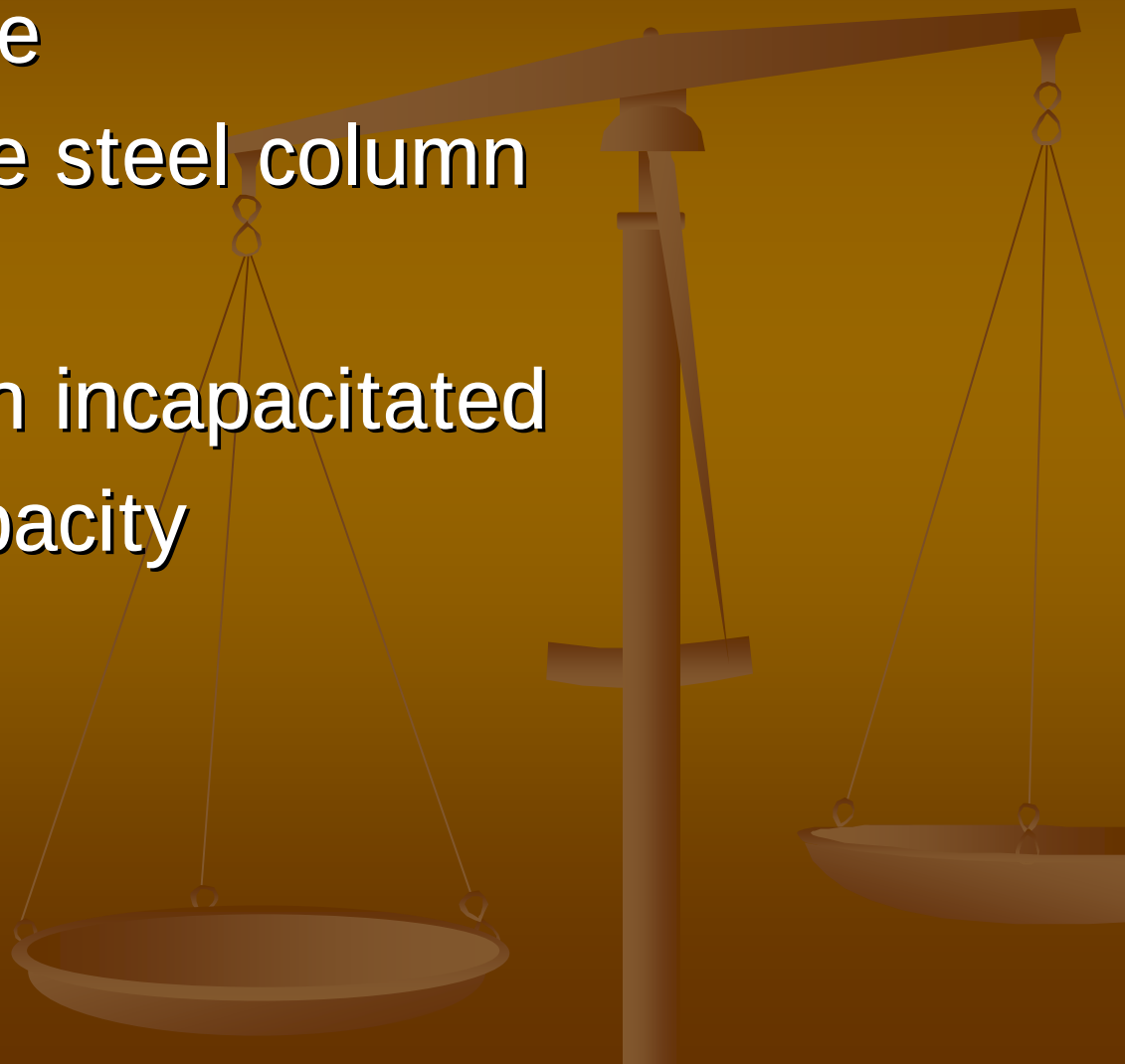
- Pso = 200 psi = 28.8 kips/sq.ft.
- Positive impulse lasts for milliseconds

Charge Pressure-Time Chart

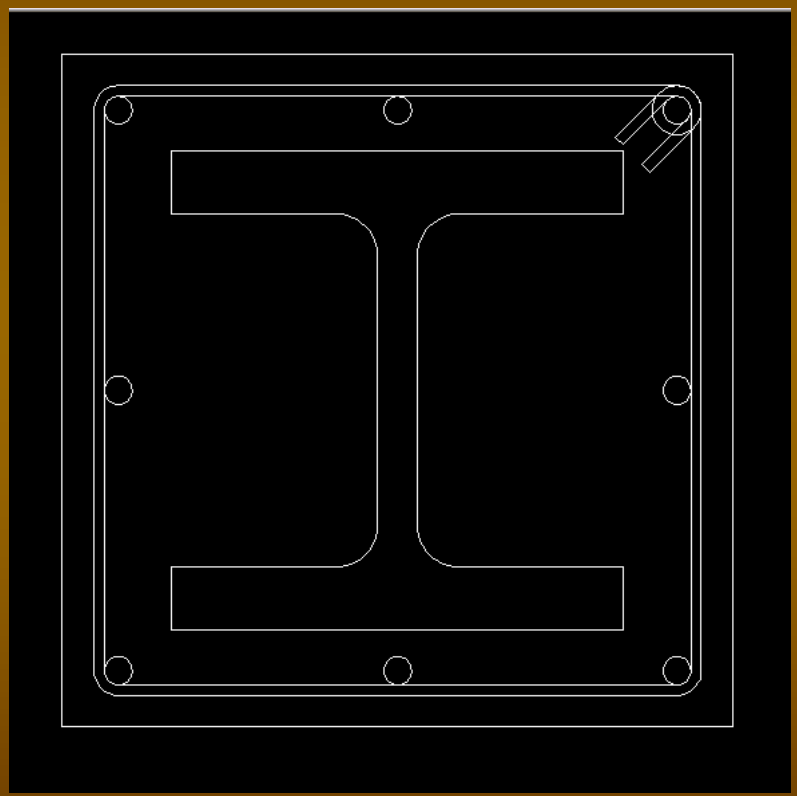


Composite Columns

- Existing concrete
- Protection of the steel column
- Static analysis
- Max of 1 column incapacitated
- Direct shear capacity



Composite Columns



Shape	Min. dim.
no steel	39x39
W12x170	36x36
W12x210	35x35
W12x230	35x35
W14x257	33x33
W14x311	31x31
W14x500	23x23

AISC Blast Test

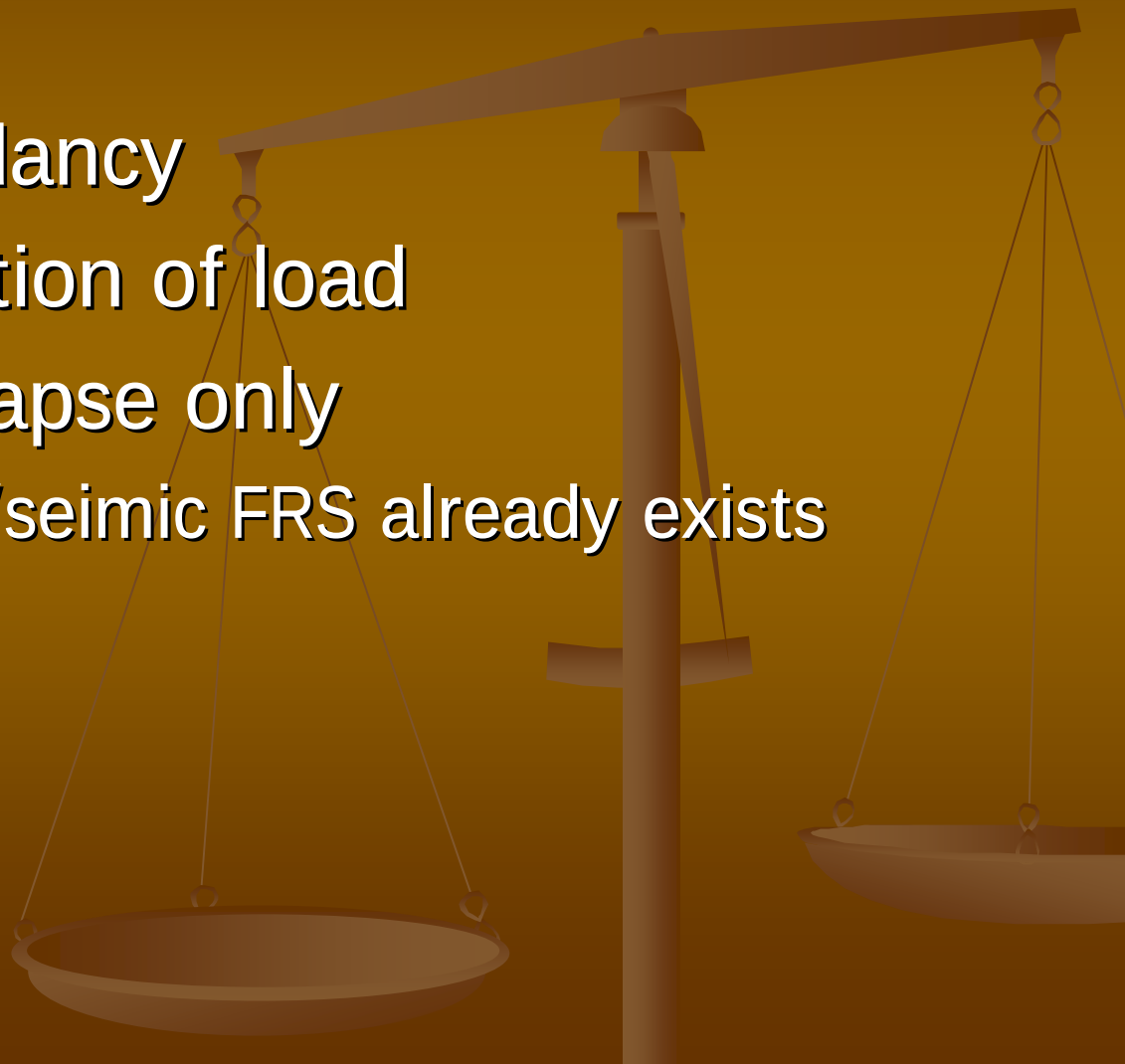
- 4000 lbs @ 12’
- Pso = 1500 psi
- W14x233
- Brick cladding

AISC Blast Test

- δ_x = 4”
- δ_y = 1.5”
- Still usable for prog collapse mitigation

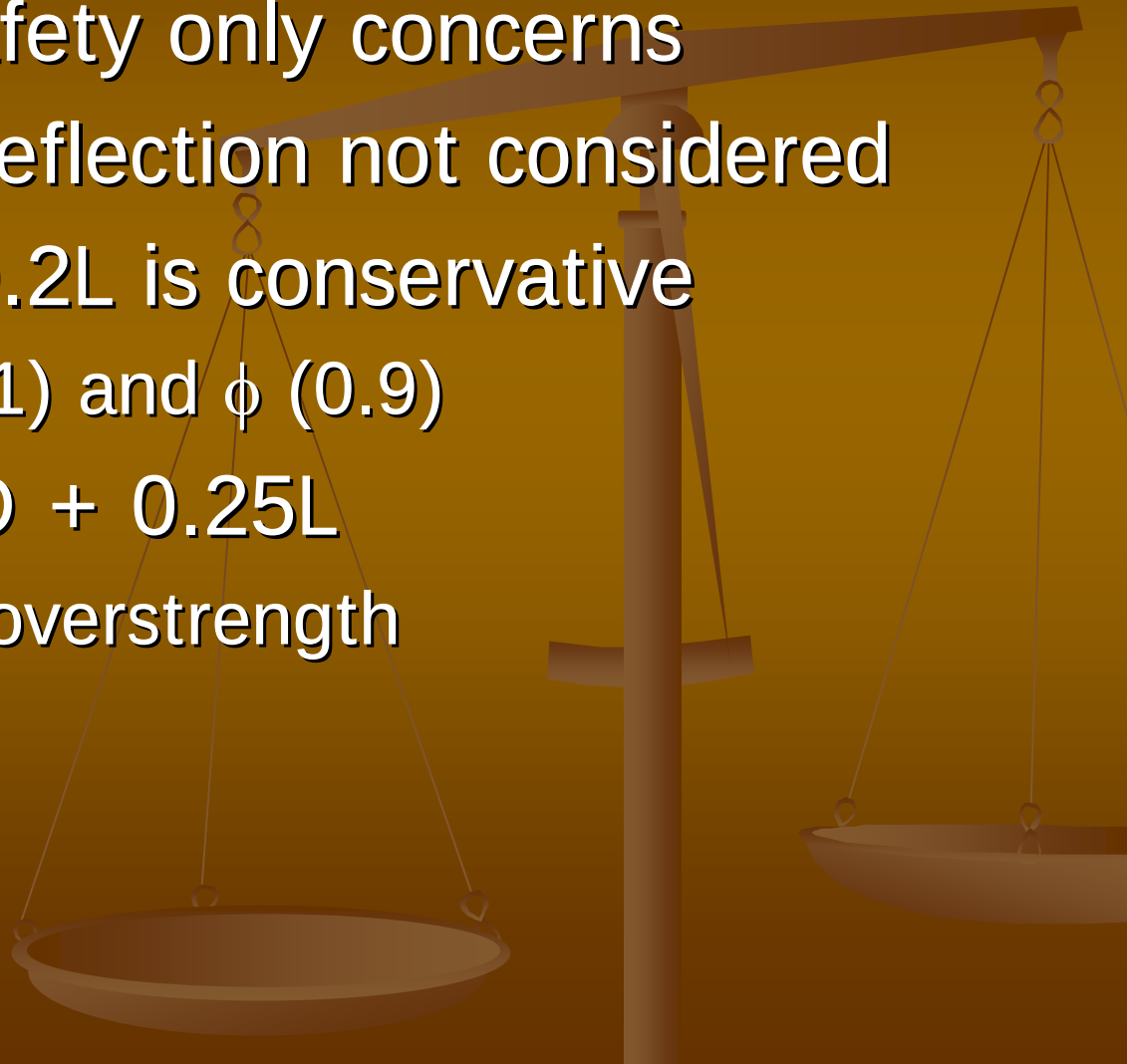
Vierendeel Trusses

- Moment frames
- Improve redundancy
- Allow redistribution of load
- Progressive collapse only
  - Adequate wind/seimic FRS already exists



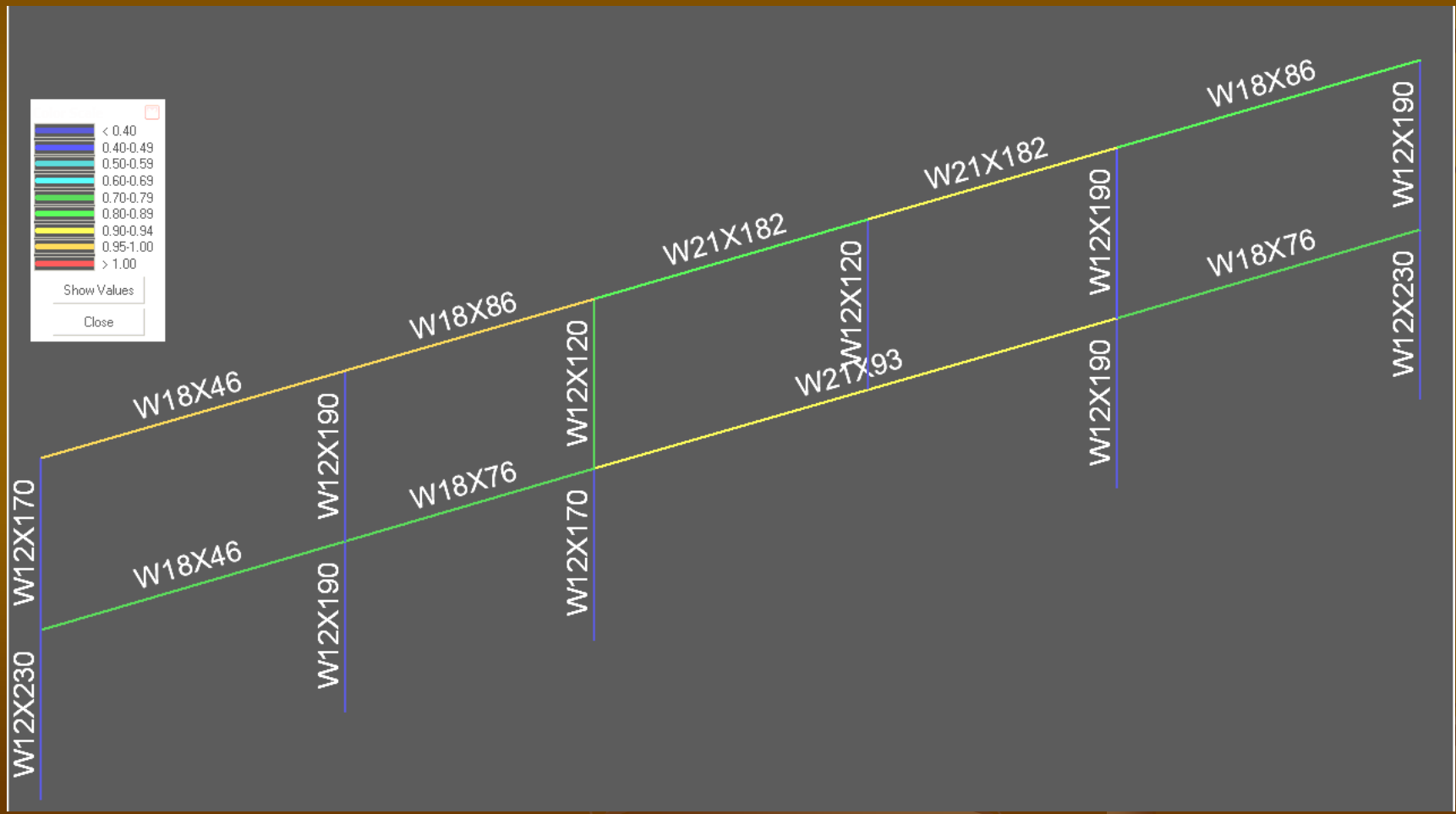
Vierendeel Trusses

- Strength, life safety only concerns
- Serviceability, deflection not considered
- GSA: 0.82D + 0.2L is conservative
  - Includes Ω_o (1.1) and ϕ (0.9)
- My design: 1.0D + 0.25L
  - No reliance on overstrength



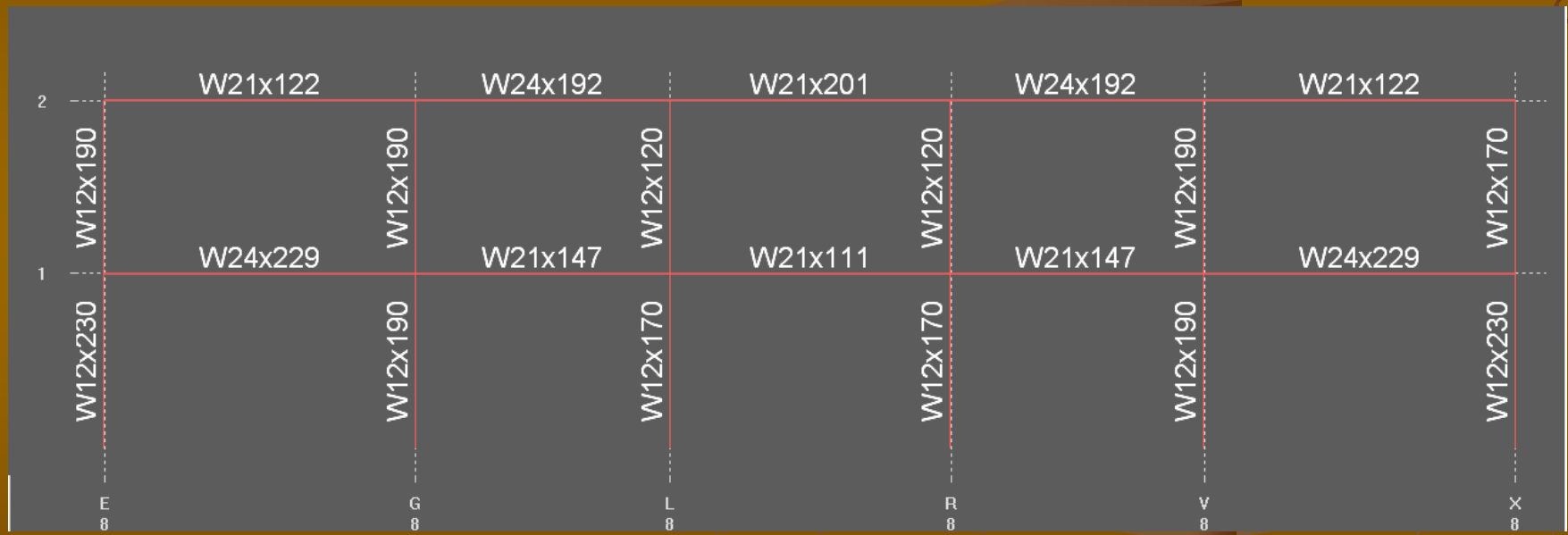
Vierendeel Trusses

Stress Diagram – 0.82D + 0.2L



Vierendeel Trusses

Final Design

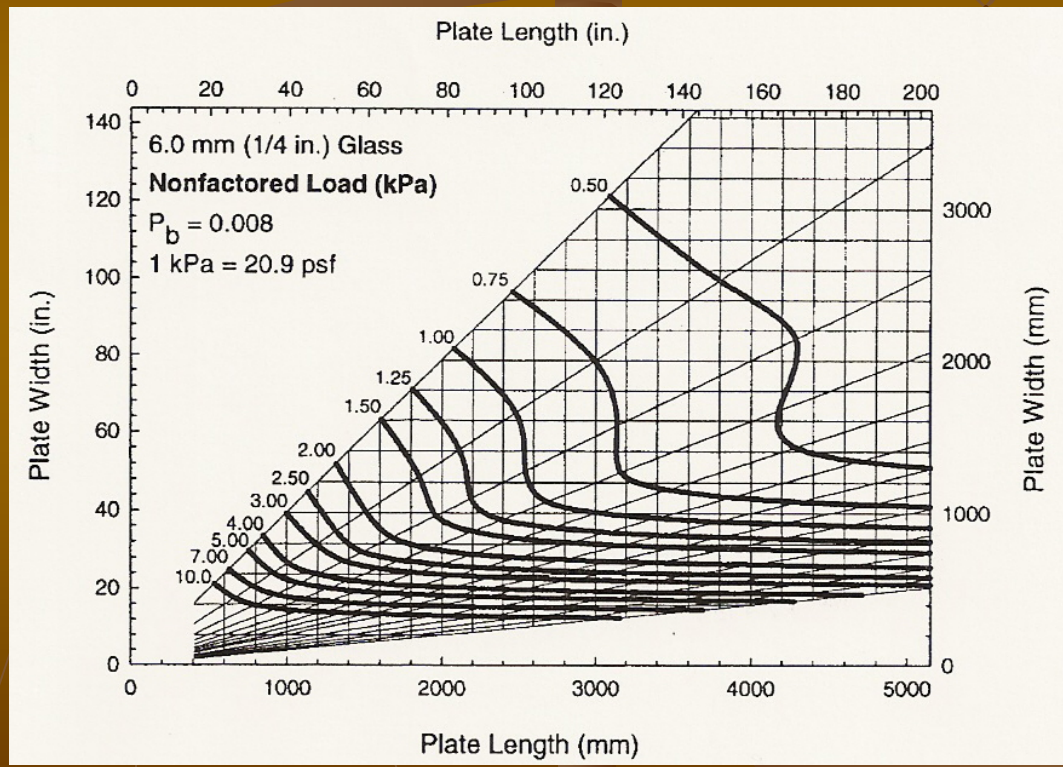


Blast-resistant Glazing

- Glass shards represent serious hazard in blast scenario
- Blasts capable of projecting shards at speeds >70 MPH
- 40% of Ok. City bombing injuries
- 5,000 injured by glass and debris in 1998 U.S. Embassy bombing in Kenya

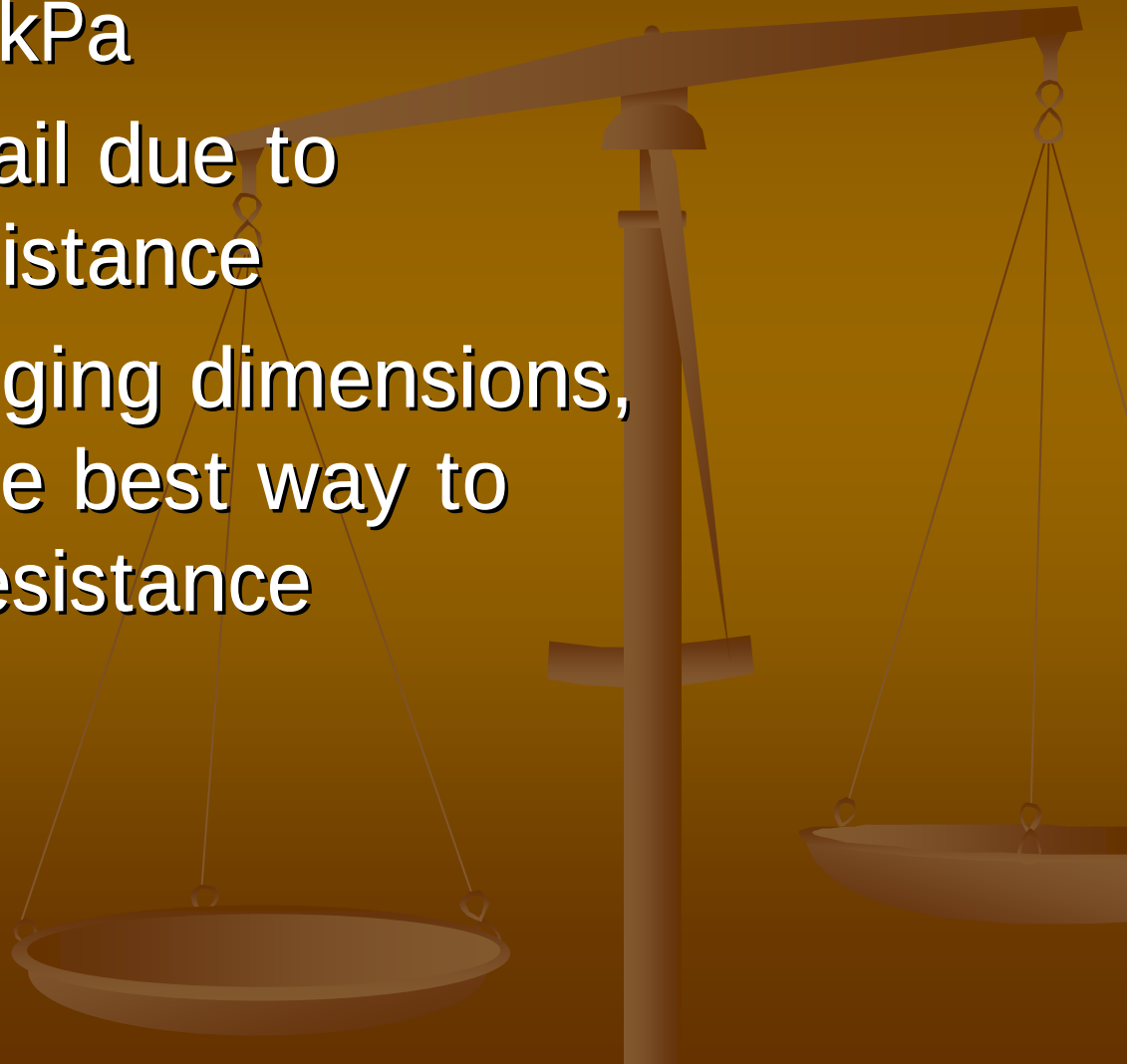
ASTM E1300

- Strength determined by:
  - Glass type
  - Window dimensions
  - Glazing thickness
- For 3 sec loading (conservative for blast)



ASTM E1300

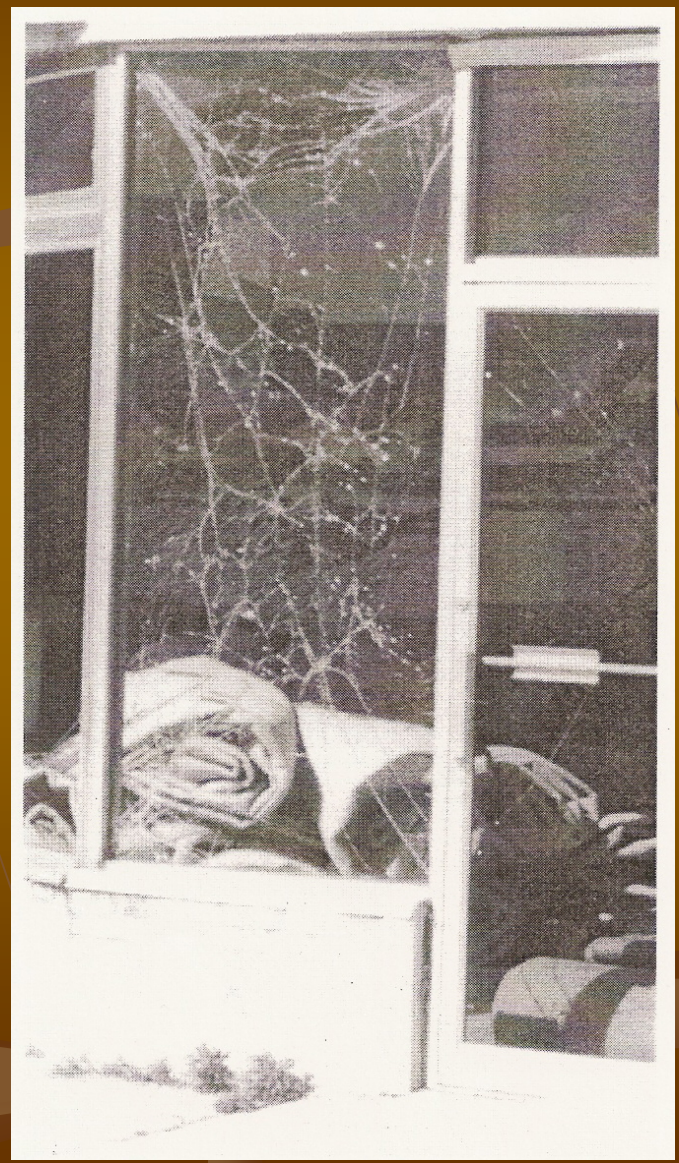
- Limited to 10.0 kPa
- Most windows fail due to short standoff distance
- Therefore, changing dimensions, thickness not the best way to improve blast resistance



Laminated glass

- Keeps glazing in pocket
- Protects life safety
- Does not prevent breakage

- Other option: ASF
  - Usually retrofit
  - More expensive



Cost of new systems

- Vierendeel Trusses
  - Larger members +$62,000
  - Moment connx. + $3,600
- Composite Columns
  - Add'l cost is neglegible
- Blast-resistant glazing
  - Laminated IGU's +$27,400

  +$93,000
- 0.1% increase for $95 million building cost

Mechanical system

- Combat bioterrorism attack
- Automatically flush contaminants from air
- Design for two 3rd floor courtrooms

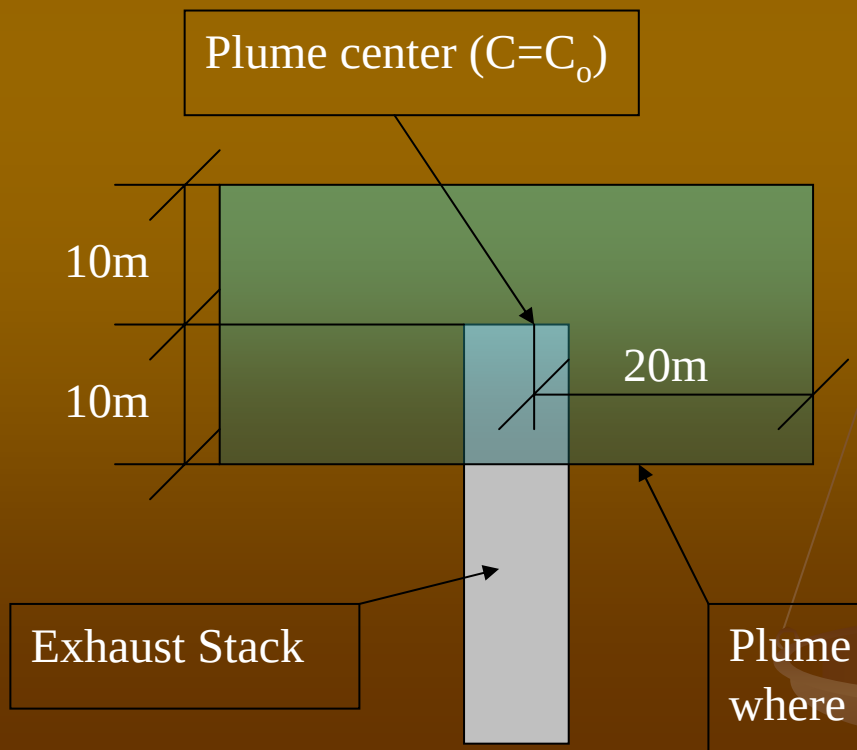
- 6 AC/hour (7560 cfm)
- Negative pressure in room
  - $V_{supply} < V_{exhaust}$

Mechanical System

- Normal Supply Condition: 2930 cfm
- Contamination Condition: 5690 cfm
  - Controlled by supply fan modules
  - 4.5 AC/hour
- Upgrade AHU to McQuay Vision CAH008
  - Min supply: 2200 cfm
  - Max supply: 6000 cfm
- Exhaust Fan: PennBarry Fumex FX18V
  - (3) fans per room @ 3023 cfm = 9069 cfm

Mechanical System

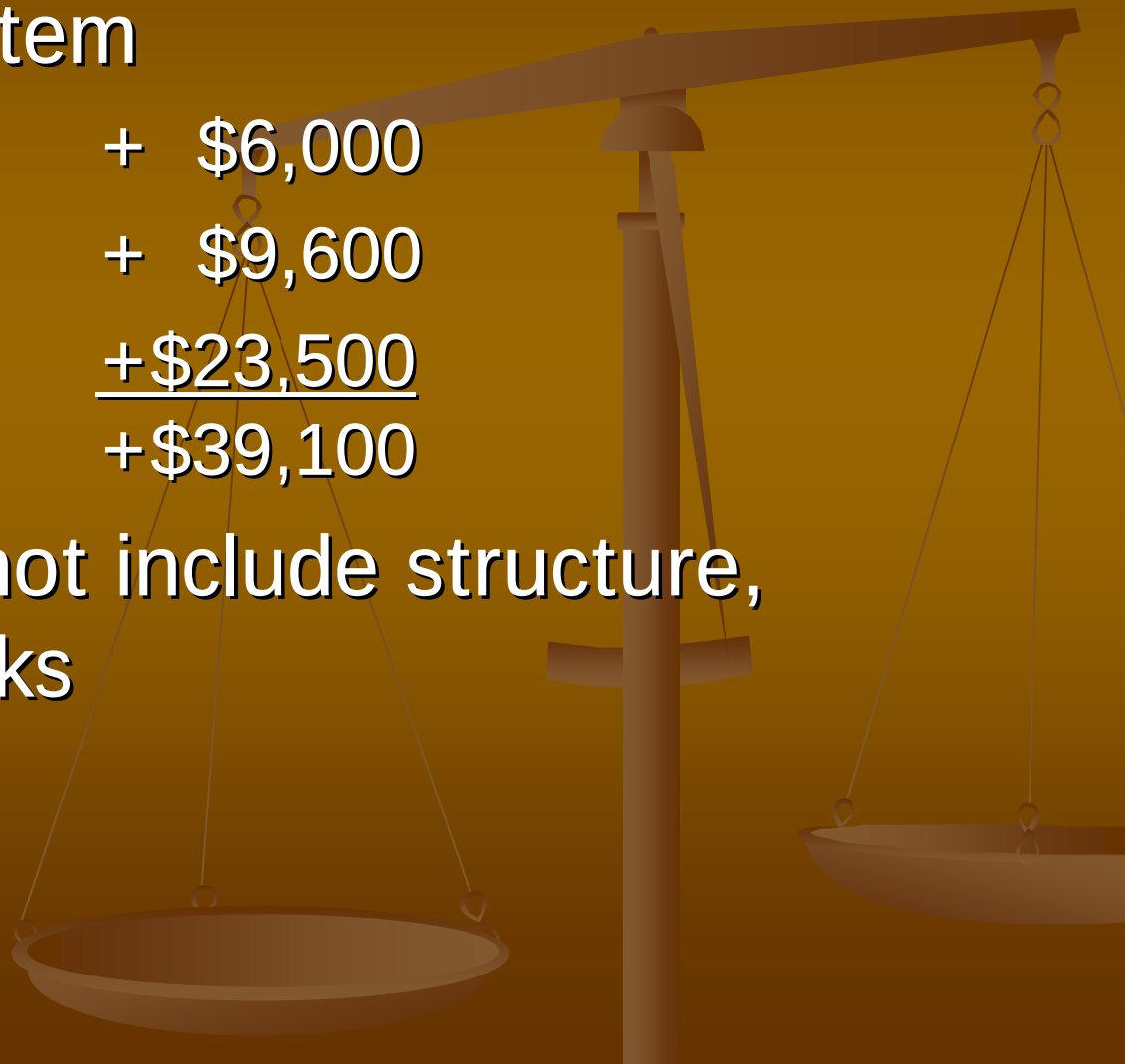
- 12”x16” rectangular ducts
- Separate duct run for each exhaust
- Final exhaust must be 10m from occupancy



Mechanical System

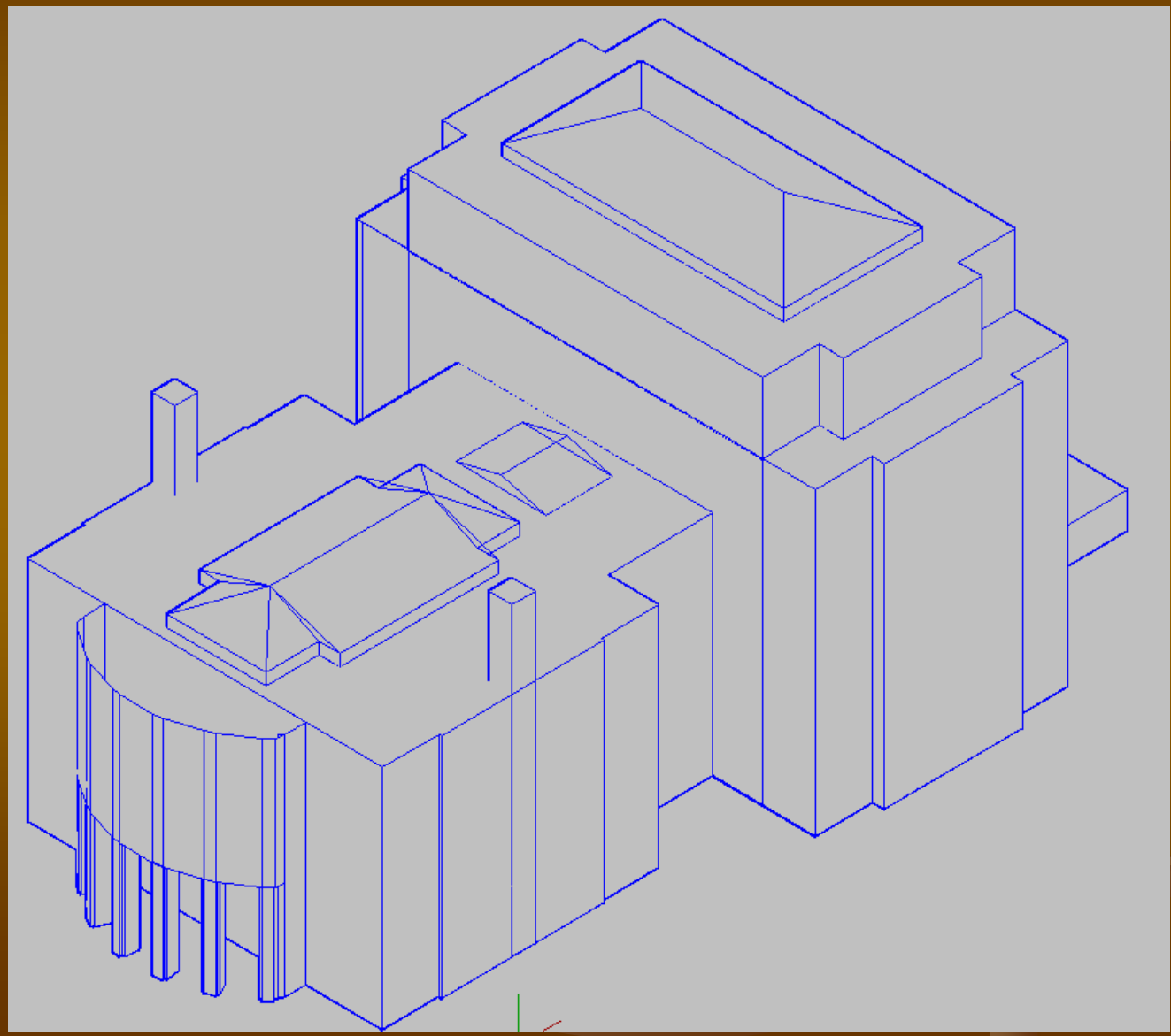
- Cost of new system
  - Larger A.H.U. + $6,000
  - Exhaust fans + $9,600
  - Ductwork +$23,500

    +$39,100
- This cost does not include structure, cladding of stacks



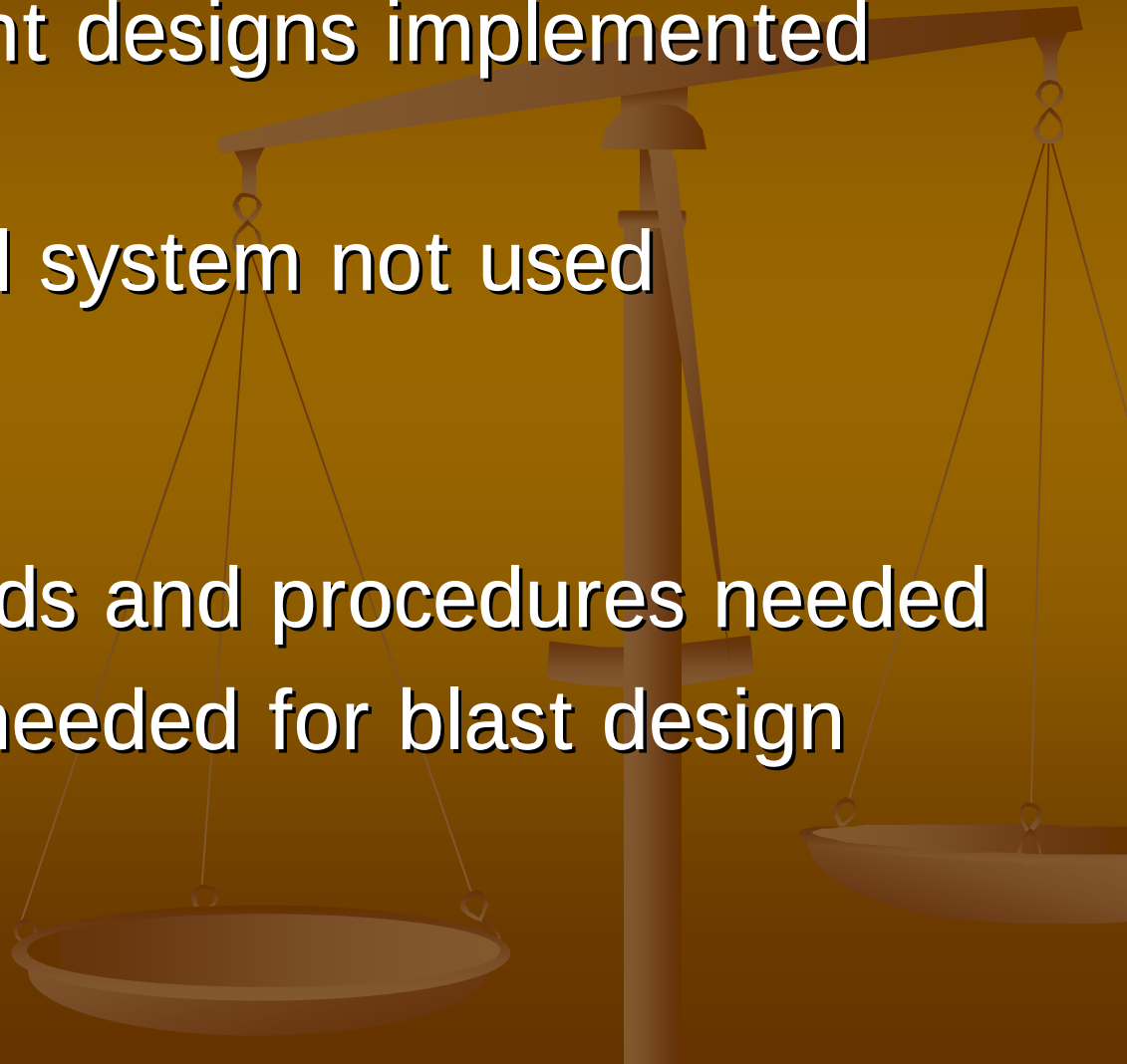
Before

After



Conclusions and Recommendations

- All blast-resistant designs implemented
  - Benefit vs. Cost
- New mechanical system not used
  - Limited use
  - Security
- Better design aids and procedures needed
- More research needed for blast design



Questions?