CASE STUDY

Alfred P. Murrah Federal Building

Oklahoma City

H. S. LEW

National Institute of Standards and Technology

RESOURCE DOCUMENTS

- FEMA 227

  The Oklahoma City Bombing: Improving building performance through multihazard mitigation, 1966

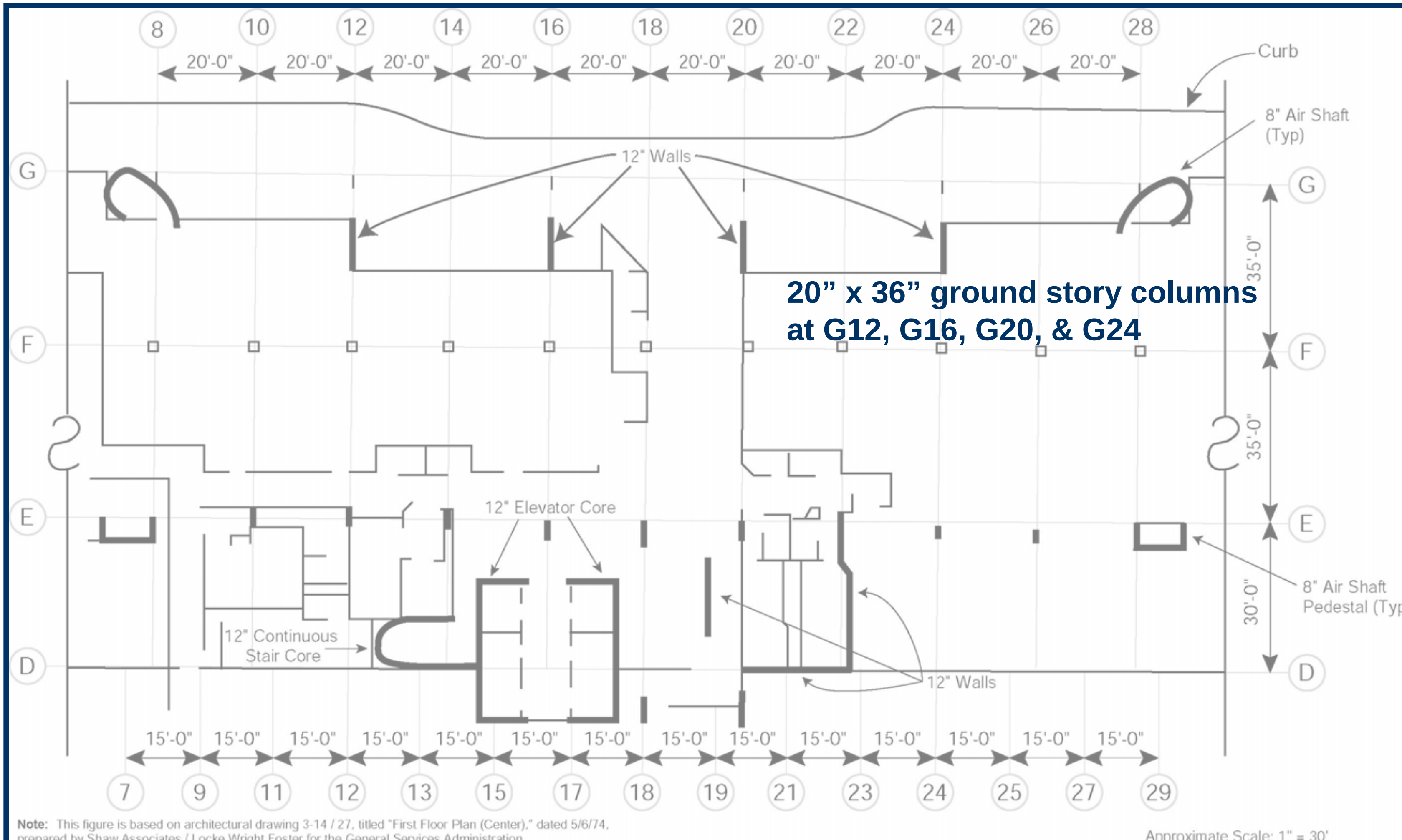
- FEMA 439A

  Blast-Resistance Benefits of Seismic Design, 2005

- Designed in the early 1970s based on ACI 318-71
- Constructed:1974-1976
- Main office building:

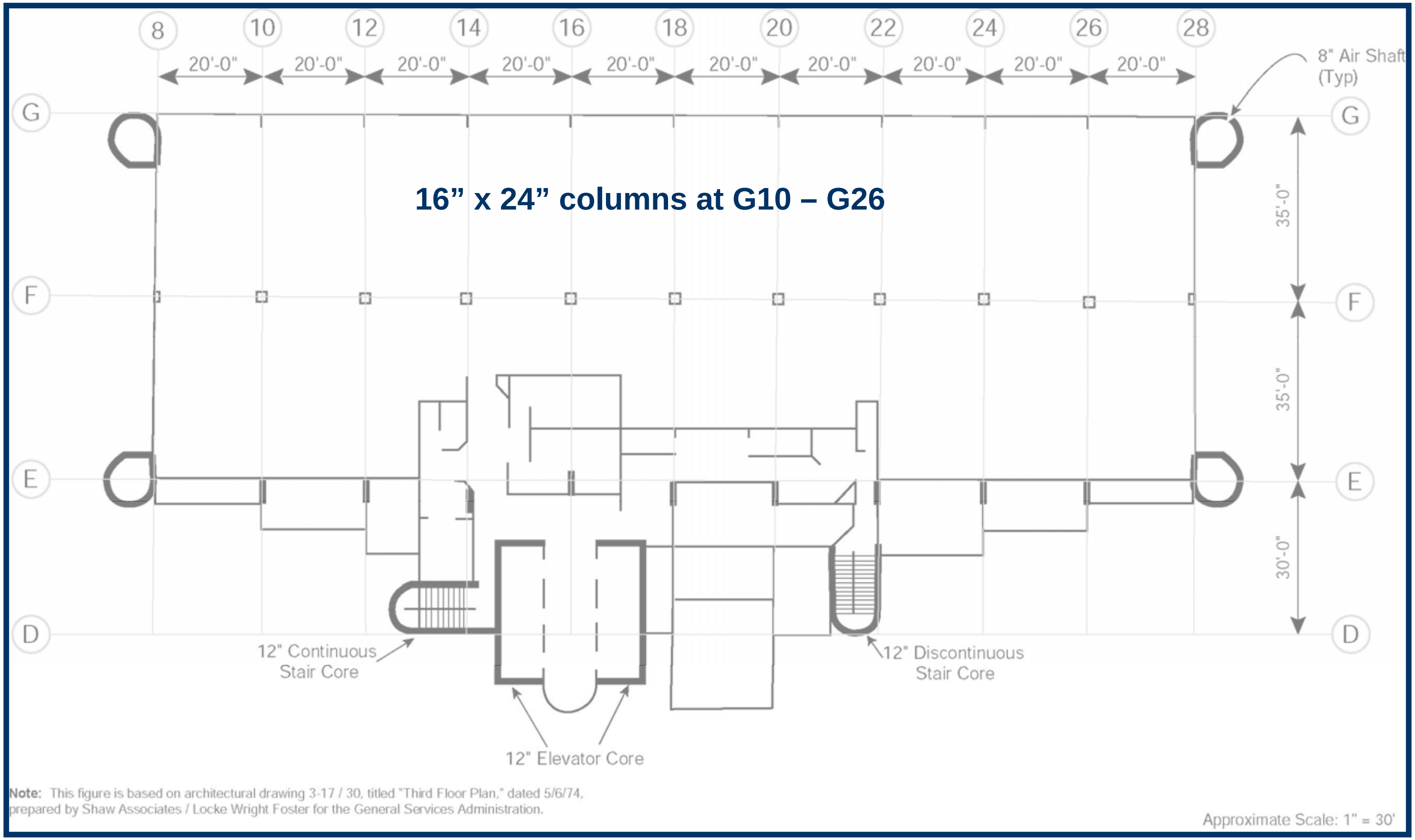
  9-story R/C frame + shear walls
- 3 sides of main building surrounded by 1-story office buildings and parking structure

First Floor Plan

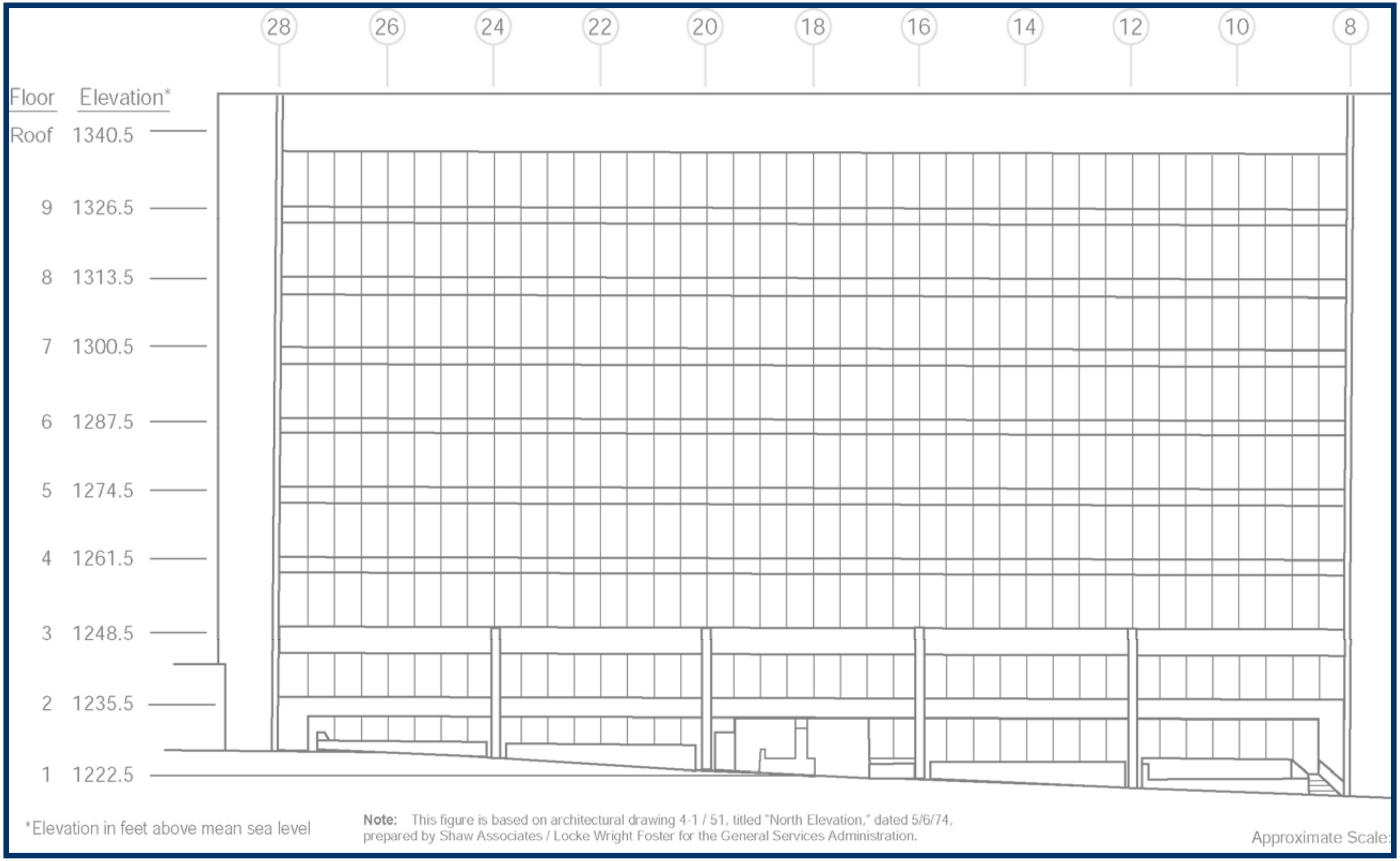


20" x 36" ground story columns at G12, G16, G20, & G24

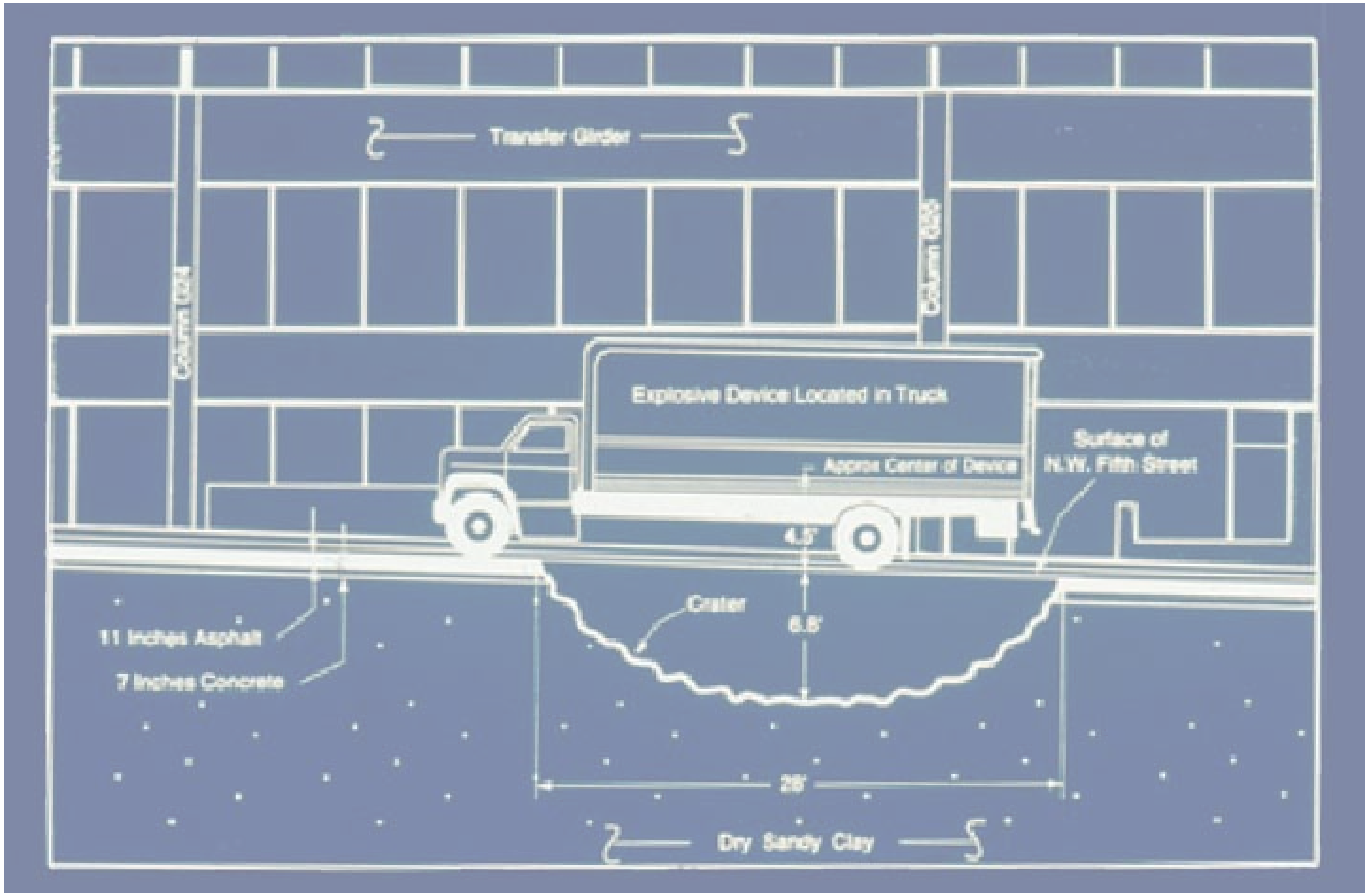
Third Floor Plan



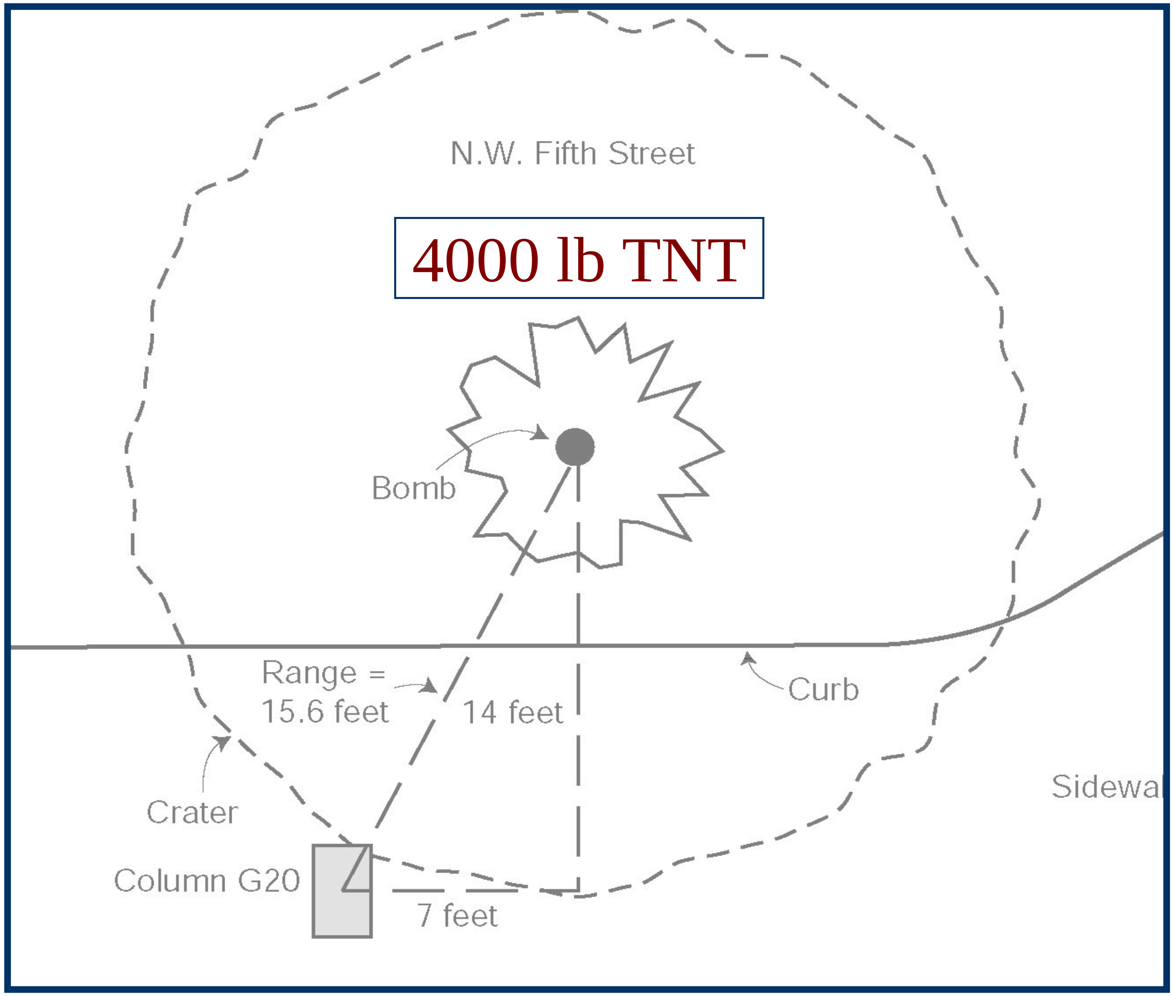
North Face Elevation



Location of Truck Relative to Column G20

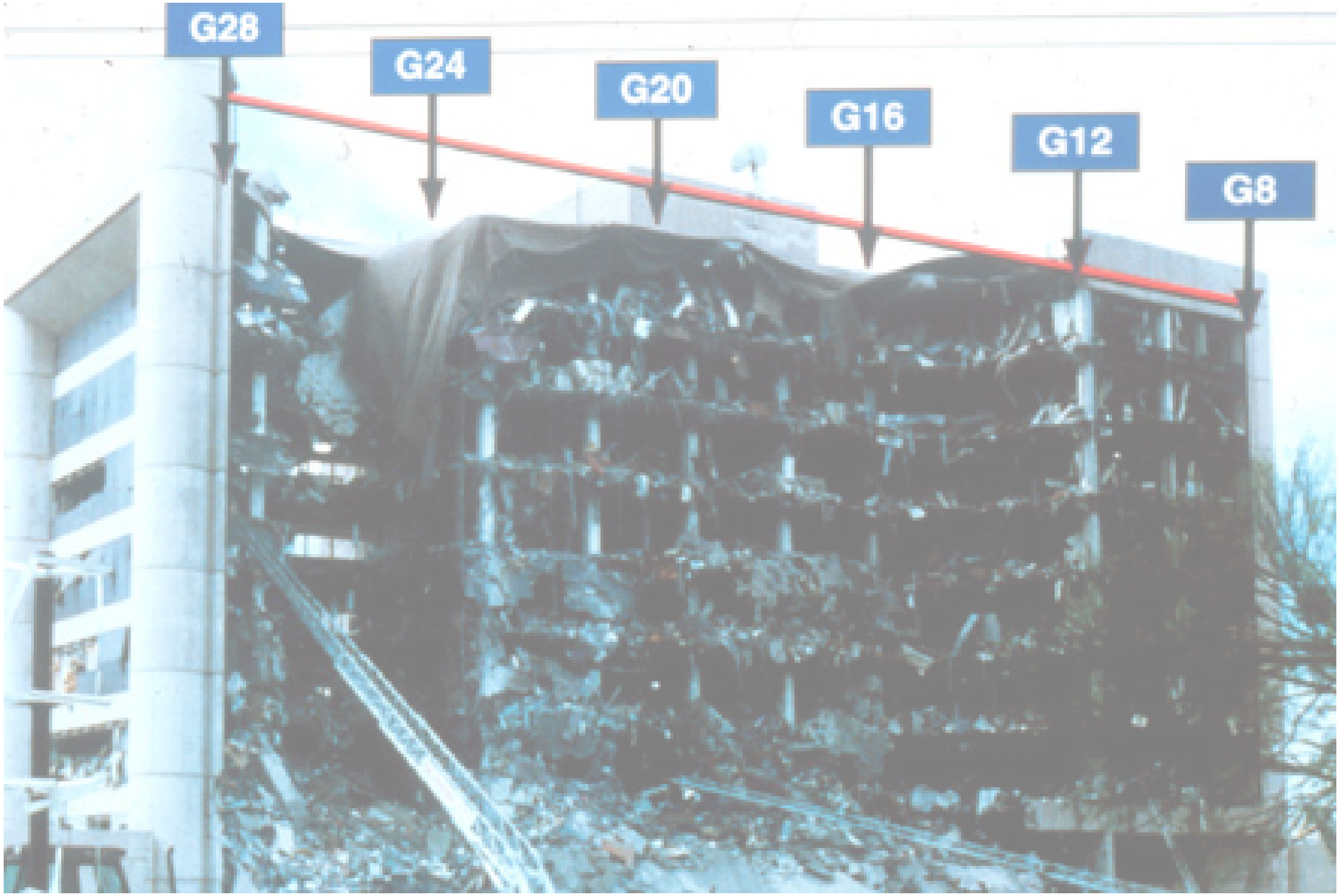


Location of Bomb

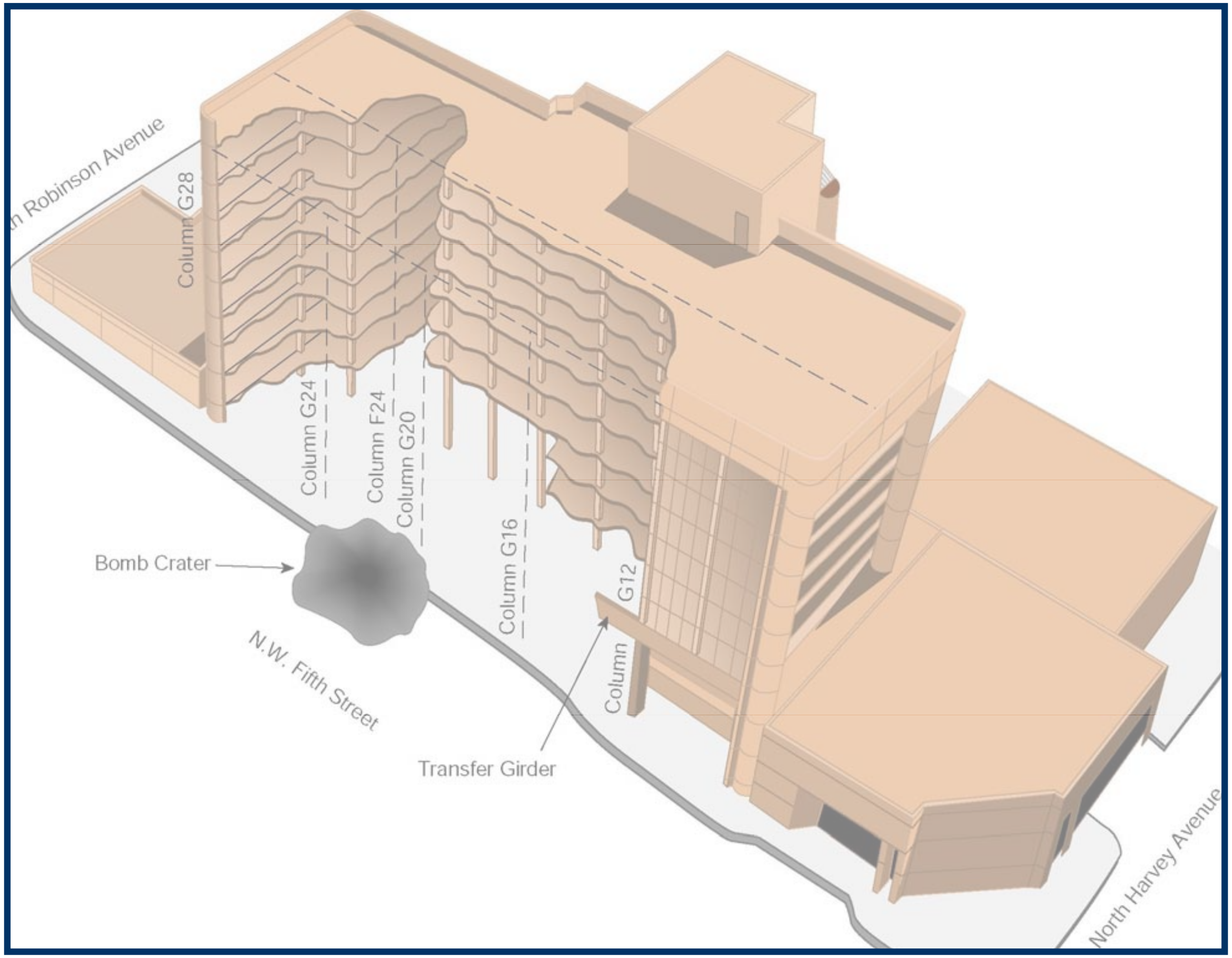


Damage Boundary

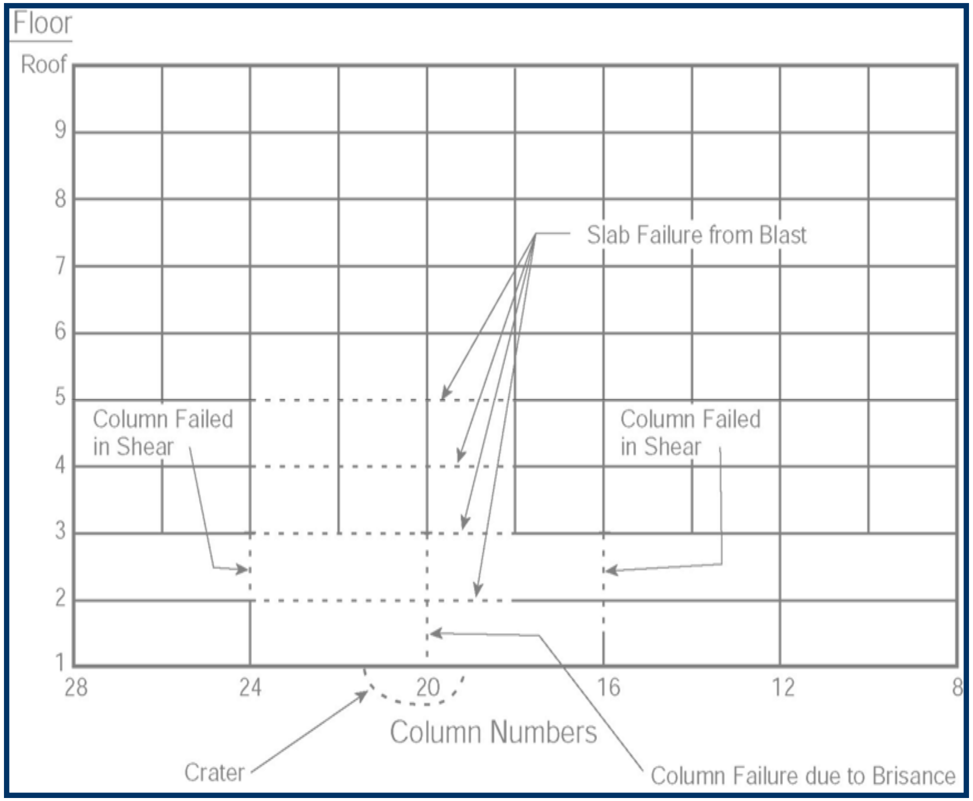
Extent of Collapse



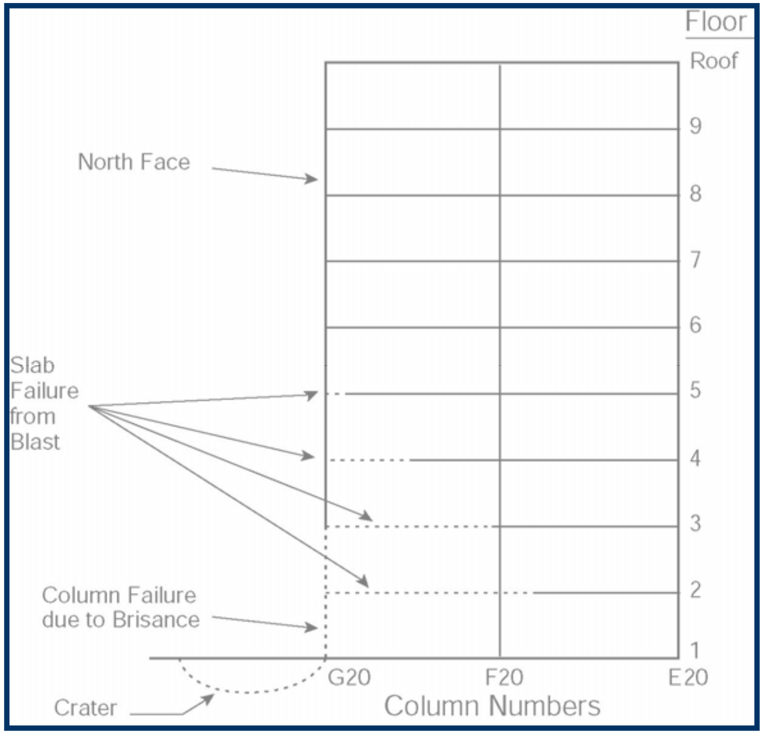
Blast and Progressive Collapse Damage



Schematic Diagrams of Blast Damage



North Face Elevation



North-South Section

Damaged and Destroyed Structural Members

- Destroyed due to blast
  - Columns G16, G20 and G24
- Subsequent collapse due to failed columns
  - Third floor transfer girders between G16 and G26
  - All floors and roof panels bounded by column lines 12, 28, F and G.

Damage Statistics

- **Total Building Floor Area: ~ 137,800 ft ^{2}**
- **4% (~ 5,850 ft ^{2}) destroyed by blast**
- **42% (~ 58,100 ft ^{2}) destroyed by blast + progressive collapse**

FEMA 277 Conclusion

- FEMA 277, The Oklahoma City Bombing: Improving Building Performance Through Multihazard Mitigation

"Many of the techniques used to upgrade the seismic resistance of buildings also improve a building's ability to resist the extreme loads of a blast and reduce the likelihood of progressive collapse following an explosion …"

Post–Murrah Building Damage Study

- Implement ACI 318 provisions
  - 7.13 for R/C structures
- Reinforcing details for Special Moment Frame
- Mechanical splices for continuous load path
- Damage reduced by 80%±

FEMA 439 Study

- "Does seismic strengthening improve blast/progressive collapse resistance?"
- This is *not* the same question as "Is seismic design the same as blast design?"
- Evaluate Murrah Building for High Seismicity location.
- Strengthen building for improved earthquake performance, with no specific consideration for blast resistance.
- Re-detail original frame as Special Moment Frame per ACI 318-02 (no new lateral force analysis).
- Perform blast and progressive collapse response analyses of "new" systems in same manner used for FEMA 277.

FEMA 439 Study

Strengthening Schemes for Improved Earthquake Resistance

- Transverse:

  12” lightly reinforced concrete shear walls between ventilation shafts at east and west ends of building

- Longitudinal:

  Pier-Spandrel System on North Face

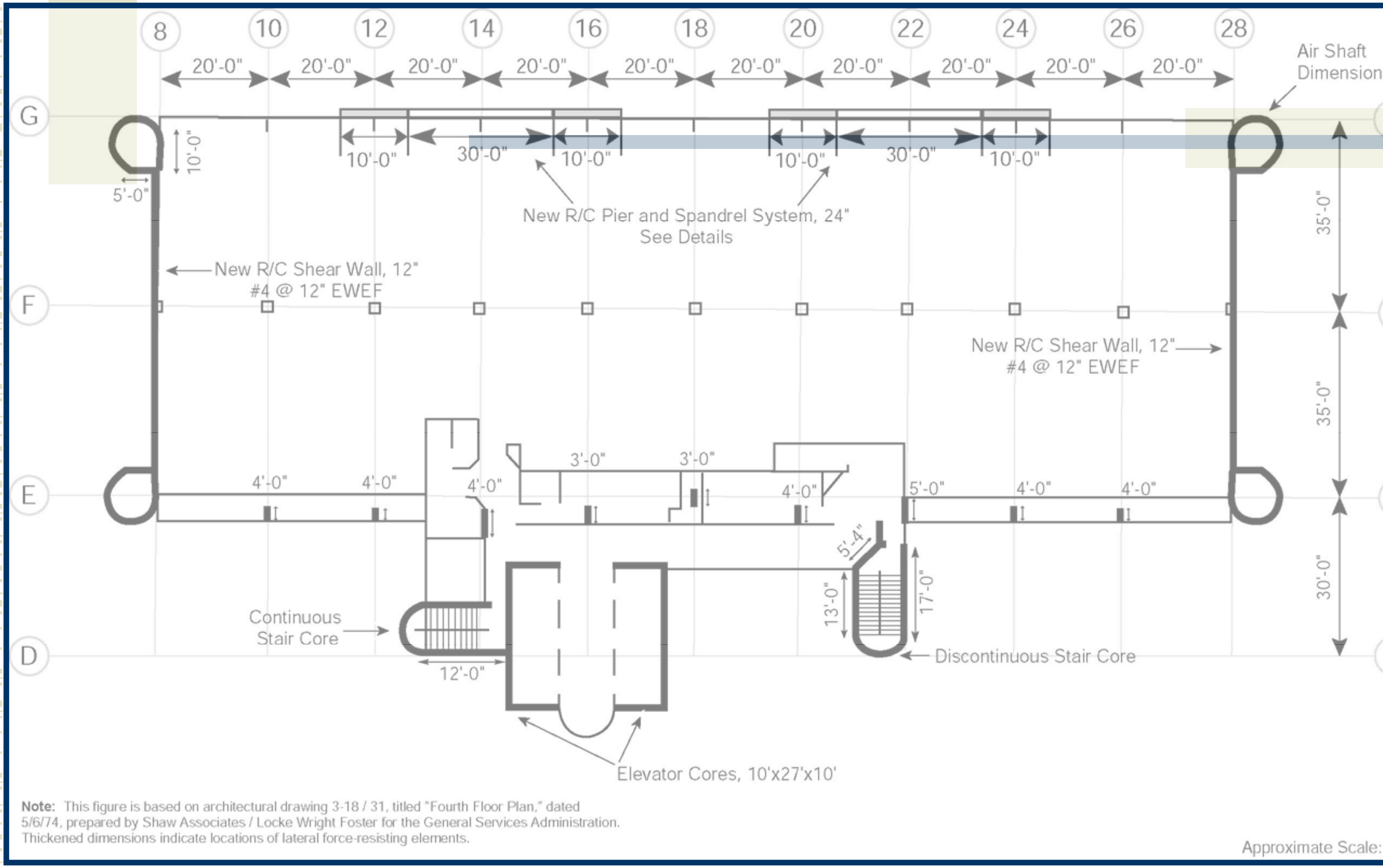
  Special Moment Frame on North Face

  Interior Shear Walls

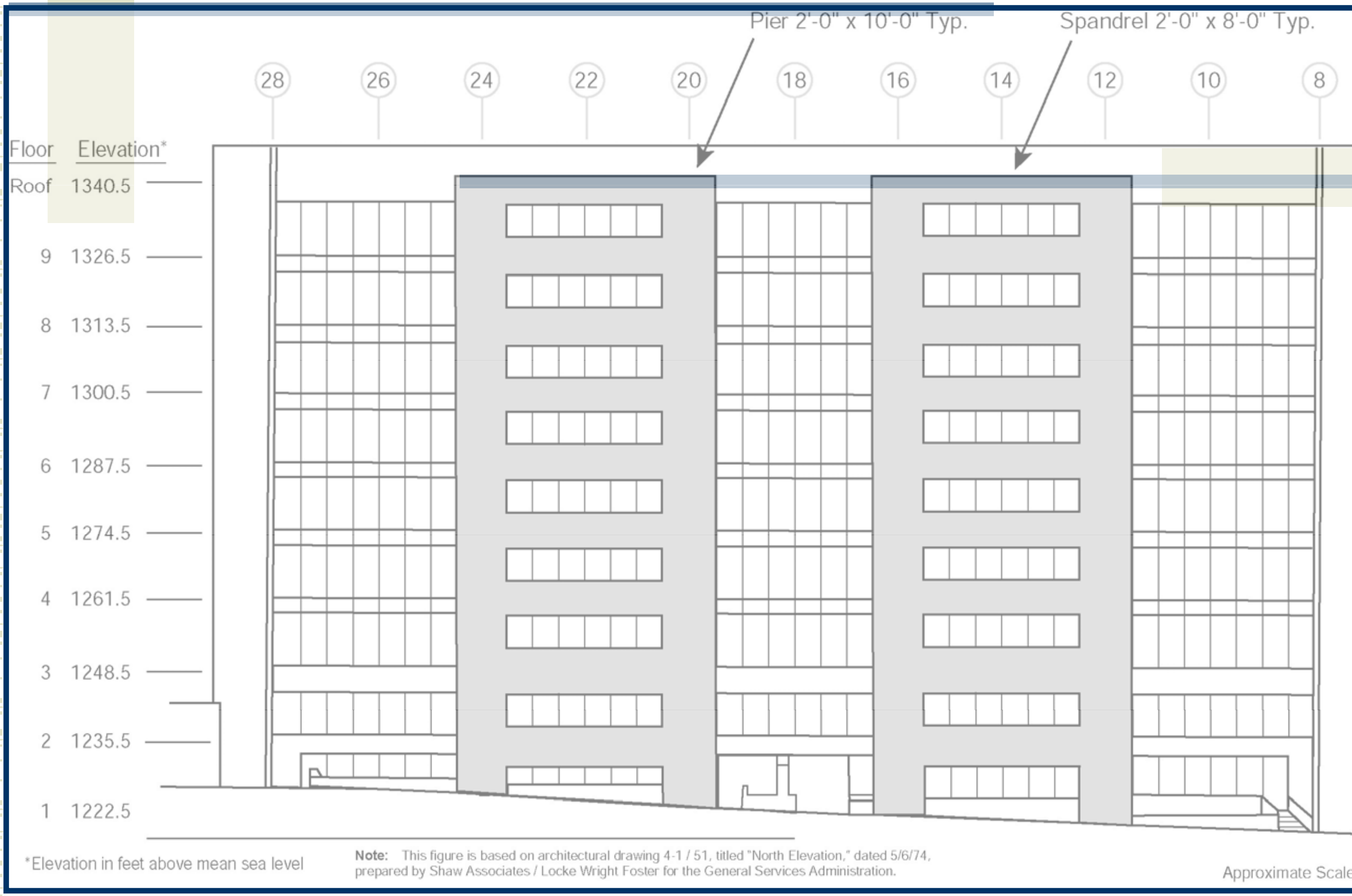
  Re-detailed frame system per ACI 318-02 (no lateral force analysis)

Pier-Spandrel System

- 2 – 24” thick R/C Pier-Spandrel walls on north face
- 10’ wide piers
- 8’ deep spandrels
- Dowel into existing north face frame
- Founded on existing column caissons
- Preserve much of original window openings
- Estimated cost: $2.37M



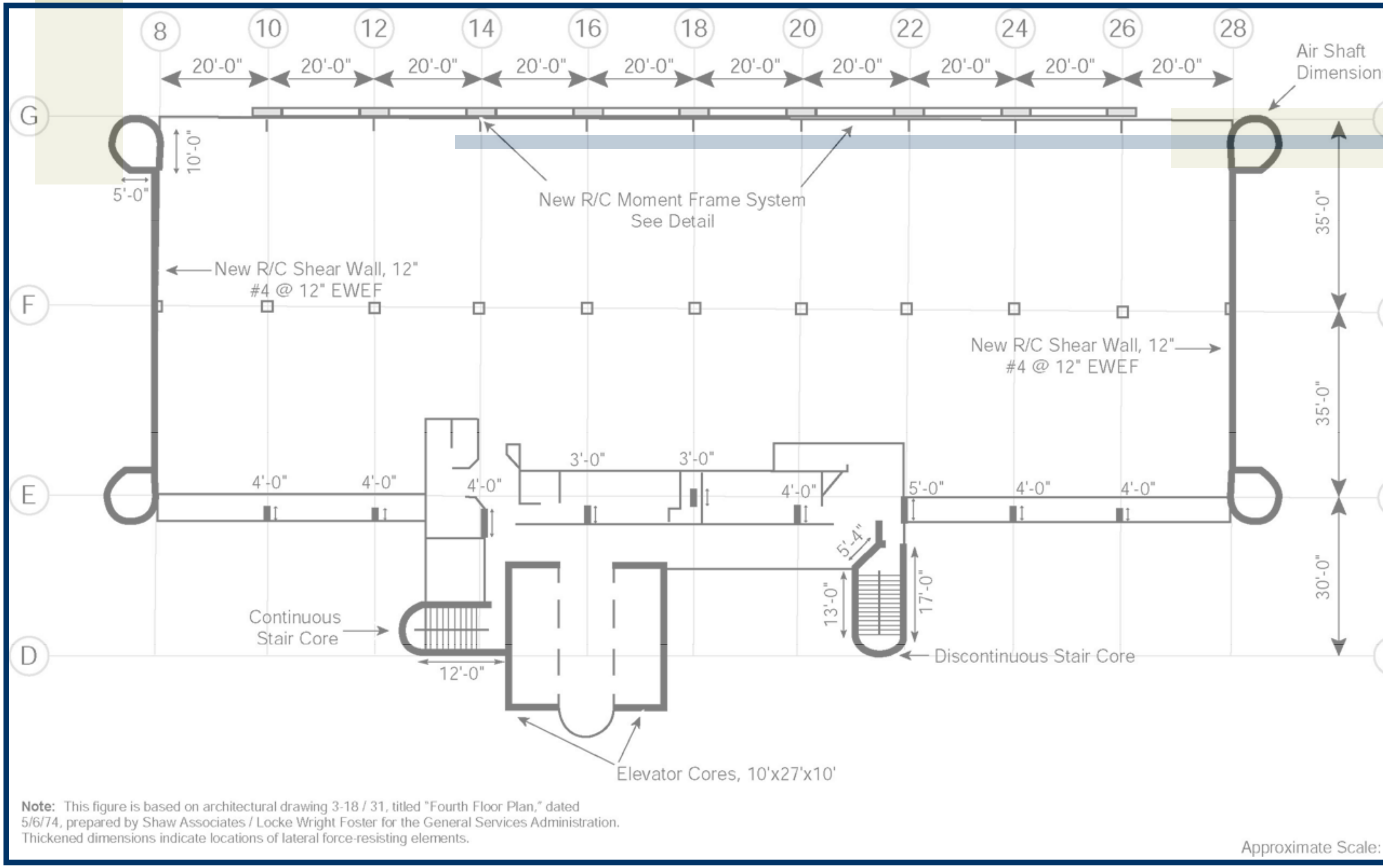
Typical Floor Plan for Pier-Spandrel System



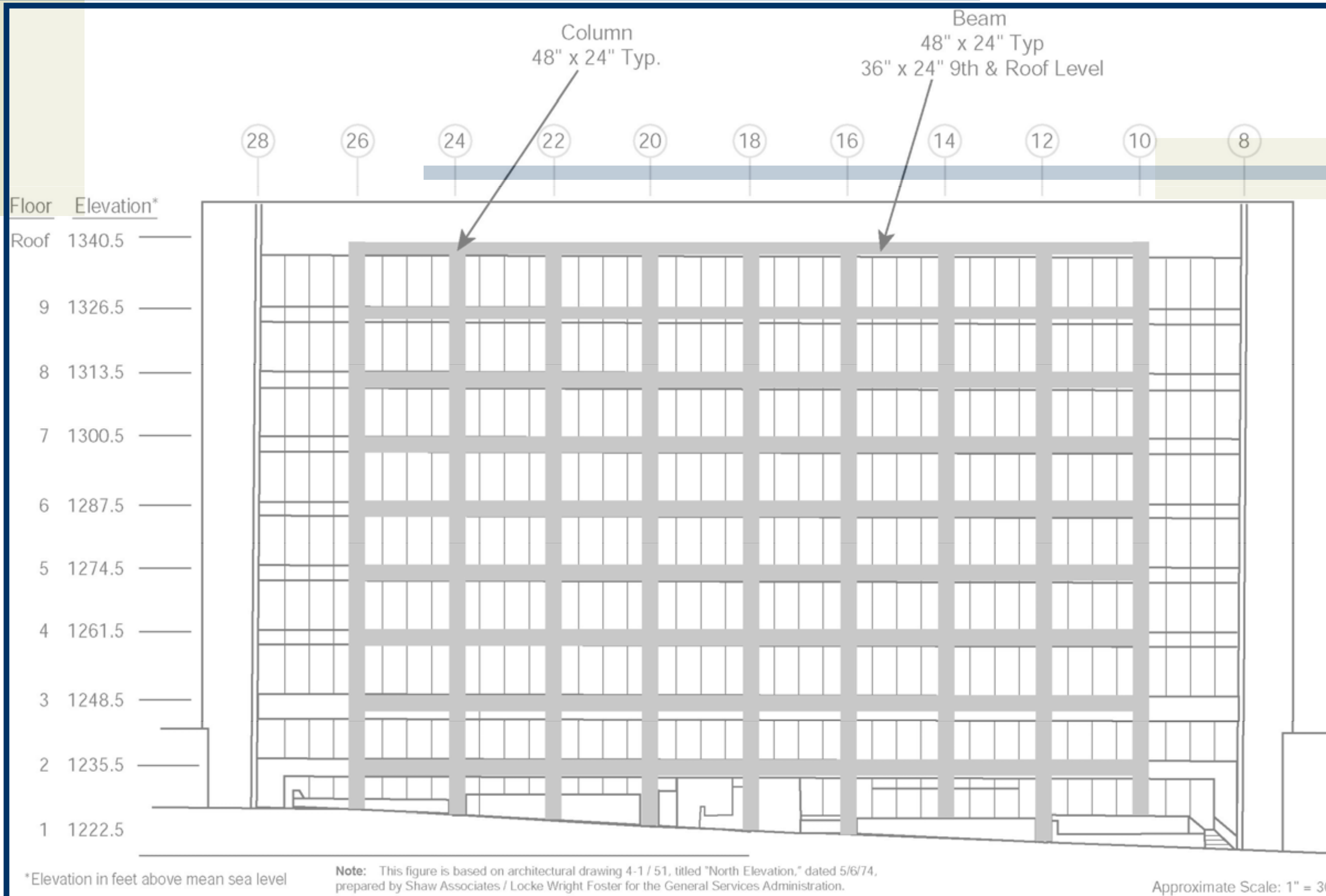
Elevation for Pier-Spandrel System

Special Moment Frame System

- 24” x 48” columns on north face
- 24” x 36” beams on north face (9 Fl, Roof)
- 24” x 48” beams on north face (8 Fl, below)
- Dowel into existing frame
- Founded on existing column caissons
- Estimated cost: $3.64M



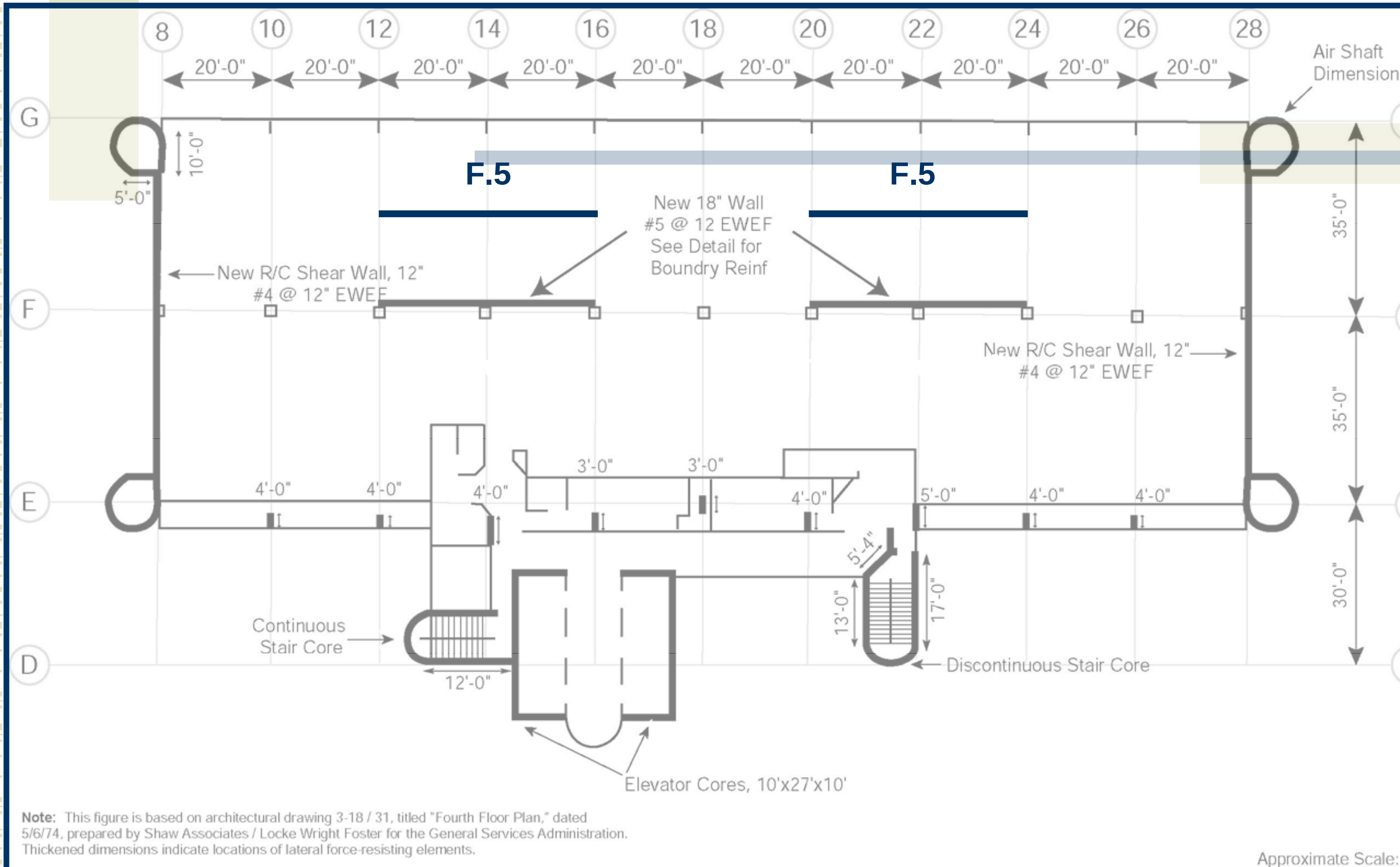
Typical Floor Plan for Special Moment Frame System



Elevation for Special Moment Frame System

Interior Shear Wall System

- 2 full-height walls on Line F
- 2 bays each
- 18” thick, lightly reinforced
- Boundary elements
- Dowel into existing columns
- Founded on existing column caissons
- Estimated cost: $1.95M
- Alternate location: Line “F.5”
  - Estimated cost: $2.30M



Typical Floor Plan for Interior Shear Wall System
(“F.5”Location Shown in Red)

Re-detailed SMF System

- Increased transverse & longitudinal reinforcement
- More continuity in longitudinal reinforcement
- Increased column sizes for strong column – weak beam behavior (e.g. 45” x 36” at ground story)
- No lateral load analysis

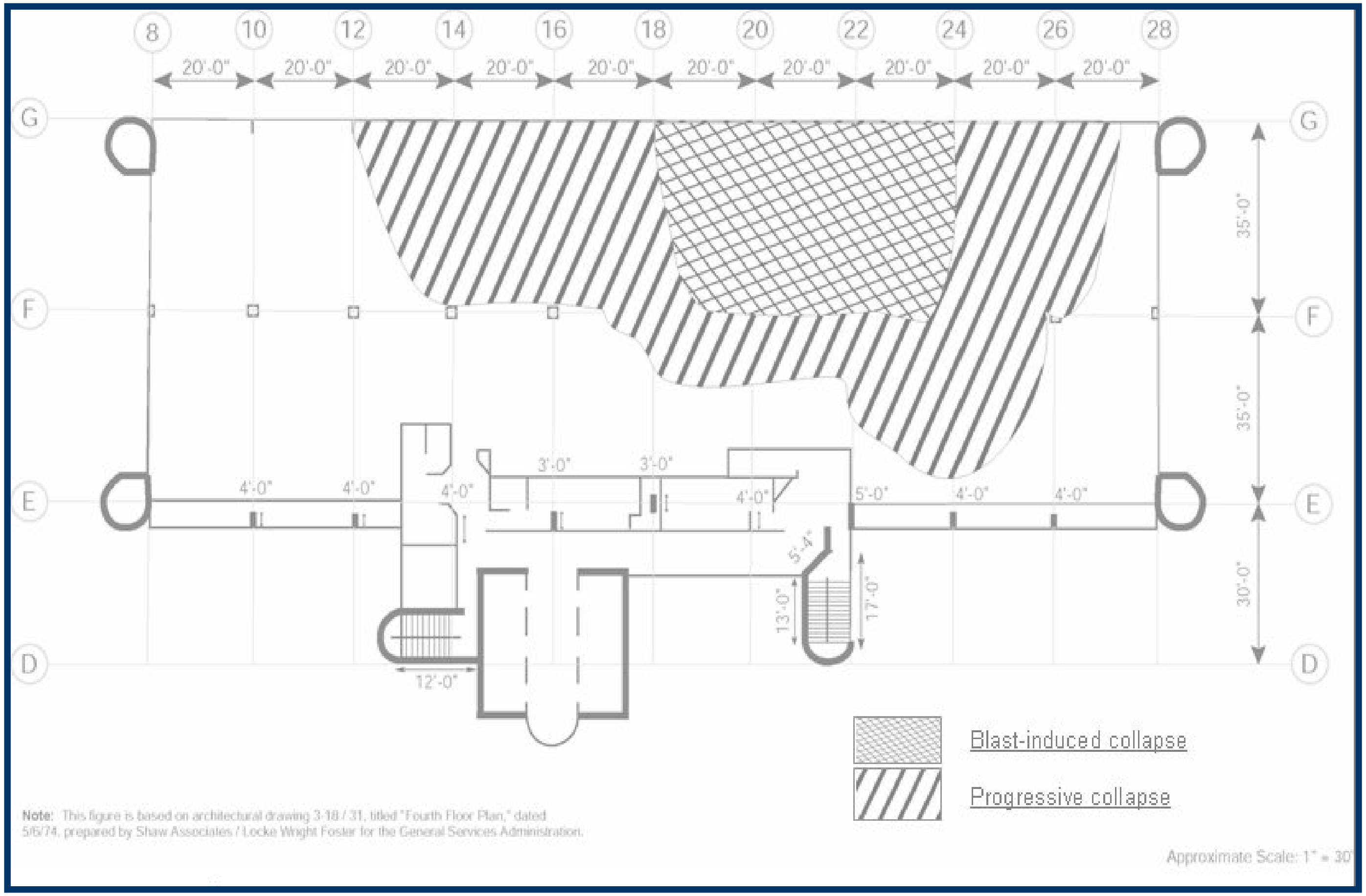
Blast Response Analyses

- *ConWep*: Blast load generation
  - Actual reflected pressure & impulse
  - Idealized uniform reflected pressure & impulse
  - Breaching analysis
- *Span32* and *WAC*: SDOF response
  - Based on uniform pressure loading
  - Based on yield line analysis
  - Provides mid-span deflections

Progressive Collapse Analyses

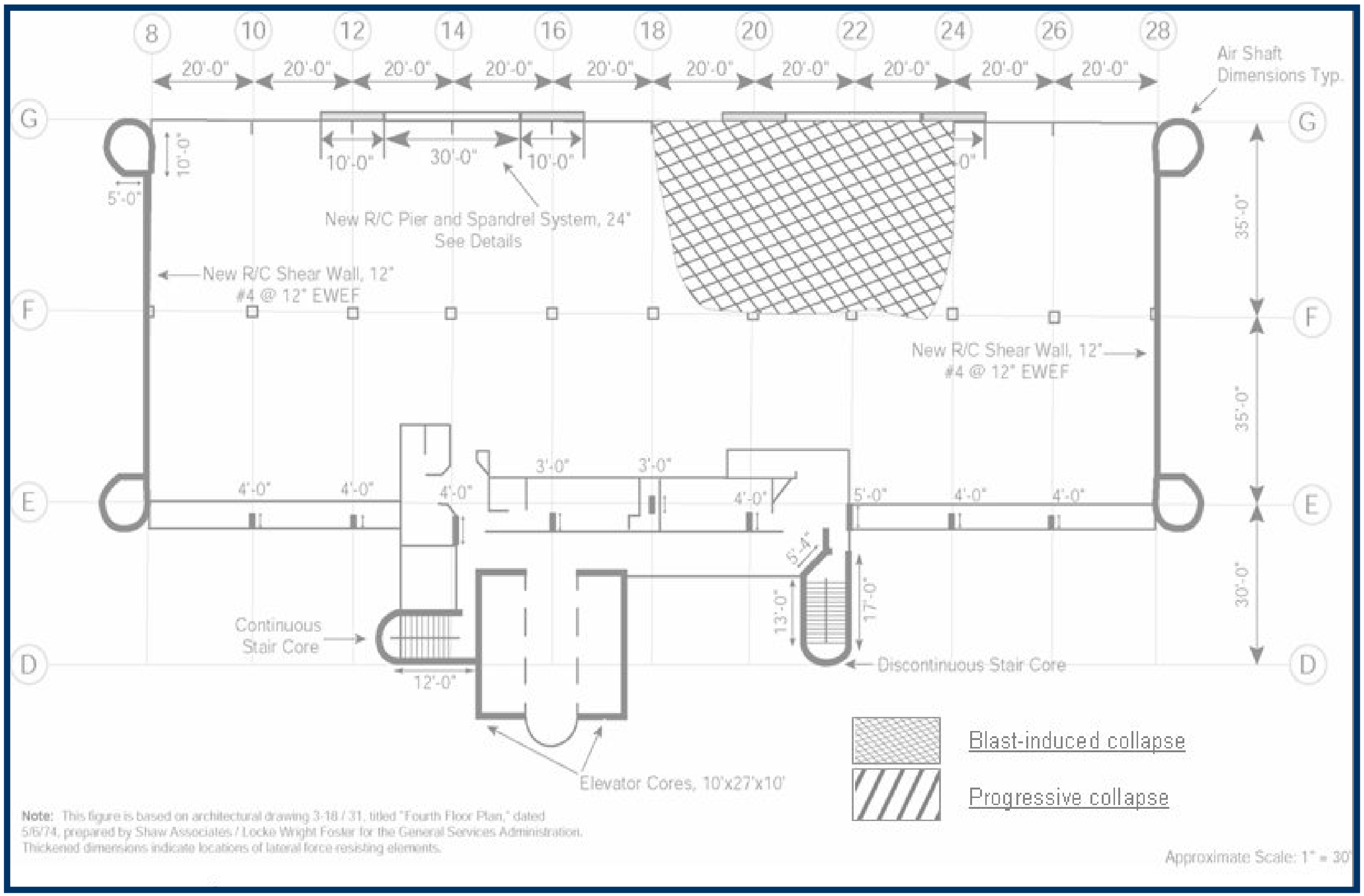
- Floor slabs not strengthened in any scheme
- Blast-damaged members removed before analysis
- Gravity + 25% Live Load
- Elastic analysis followed by plastic mechanism analysis
- Based on assumption that impact loads are twice static loads, examine Capacity/Demand (C/D):
  - If C/D > 2, then no collapse
  - If 1 < C/D < 2, then examine more closely and assess
  - If C/D < 1, then assess as failed

Damage to 3rd Floor Level (Original Building)

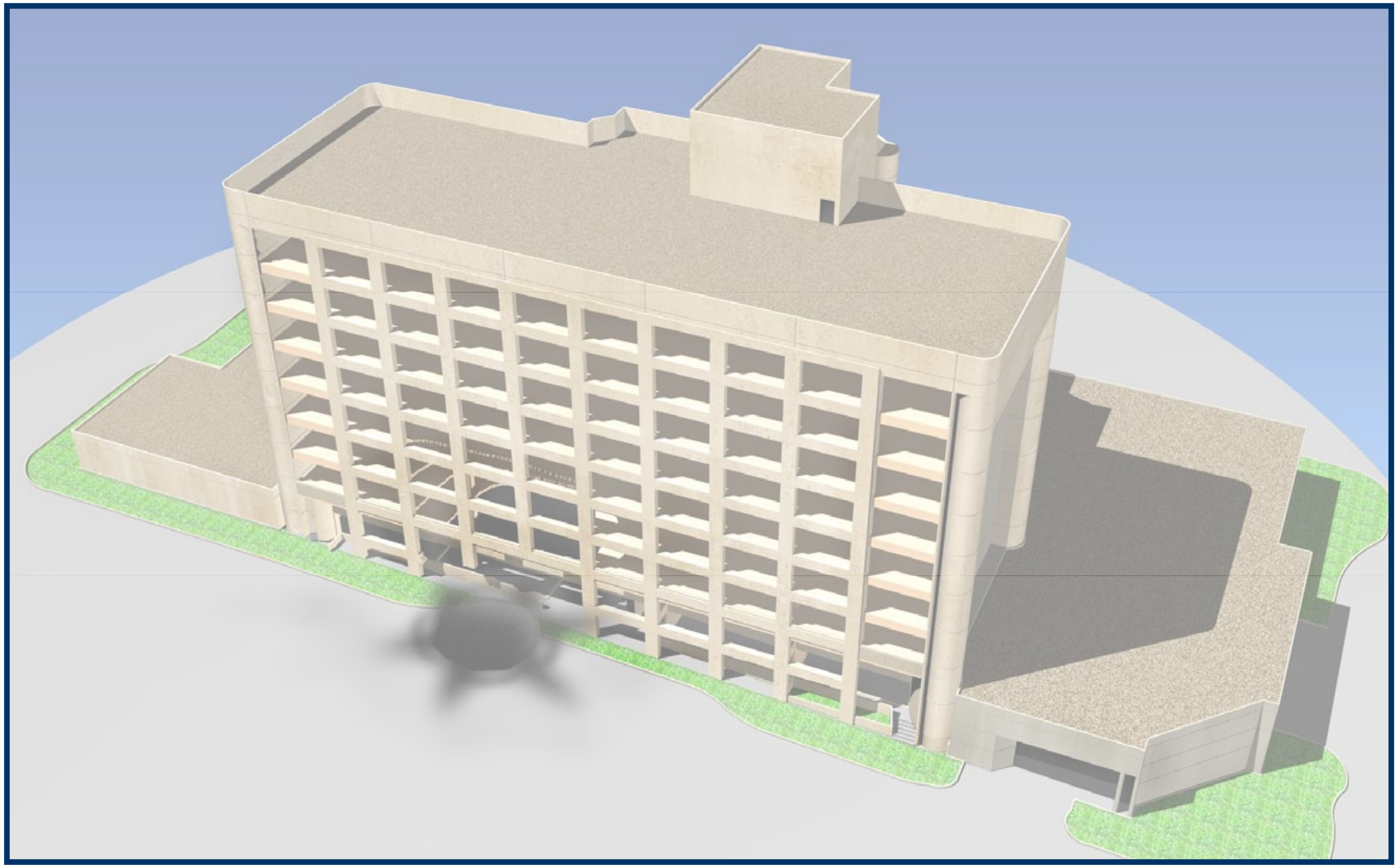


Estimated Damage for Pier-Spandrel System

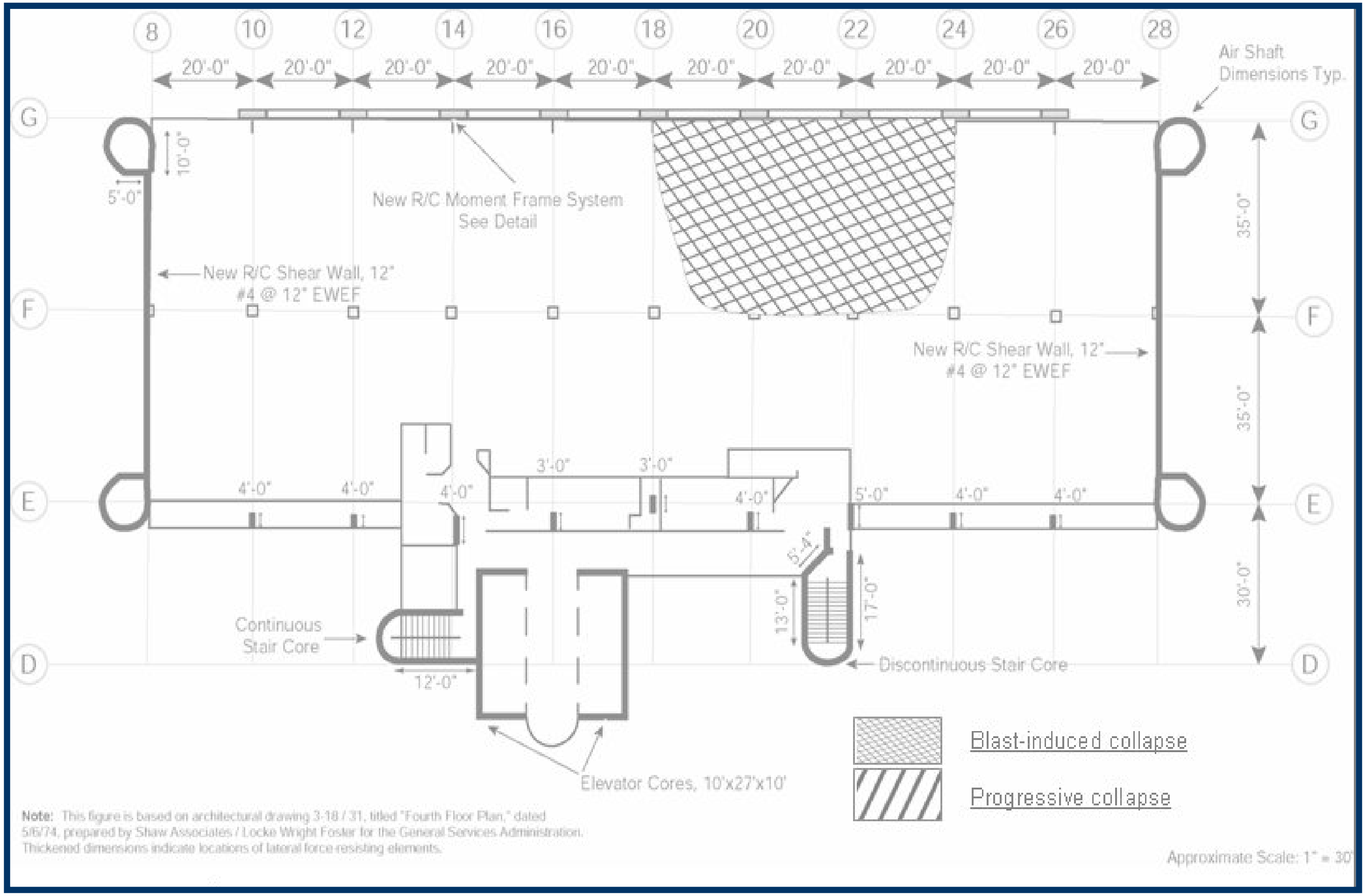
Estimated Damage to 3rd Floor Level (Pier-Spandrel System)



Estimated Damage for SMF System

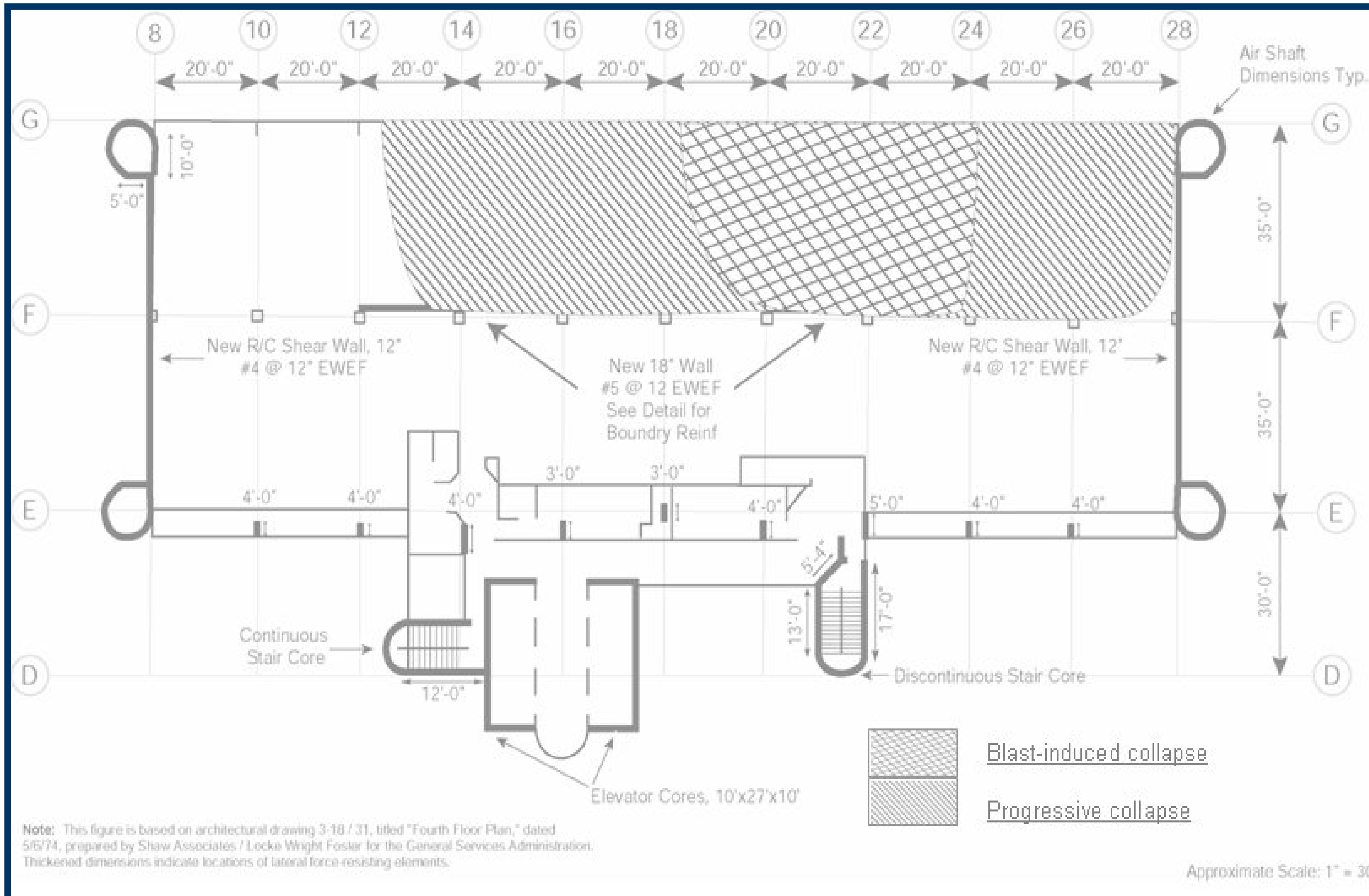


Estimated Damage to 3rd Floor Level (SMF System)

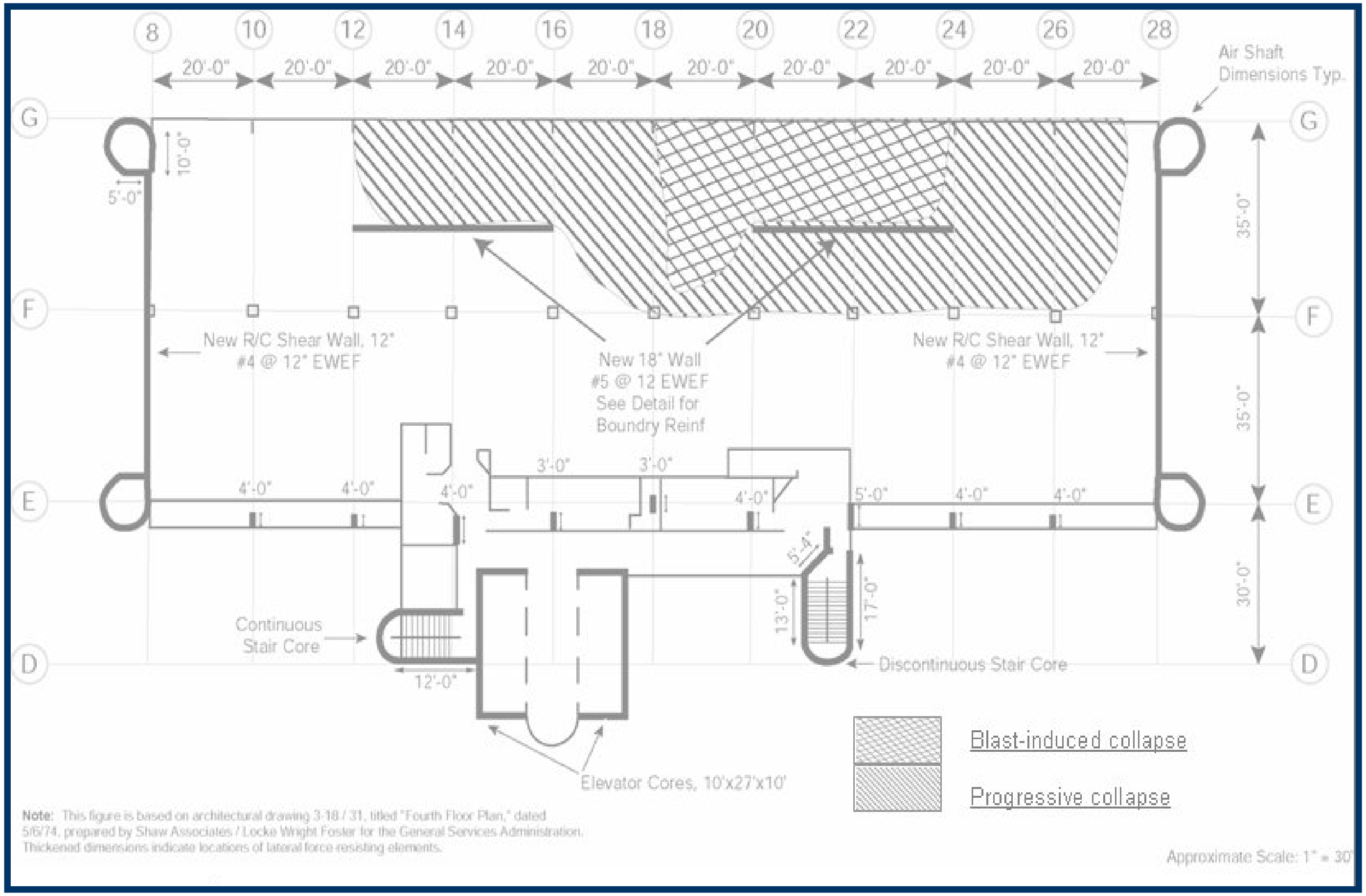


Estimated Damage for Interior Shear Wall System - Line F

Estimated Damage to 3rd Floor Level Interior Shear Wall System – Line F



Estimated Damage to 3rd Floor Level Interior Shear Wall System - Line F.5



Estimated Damage Based on Floor Area

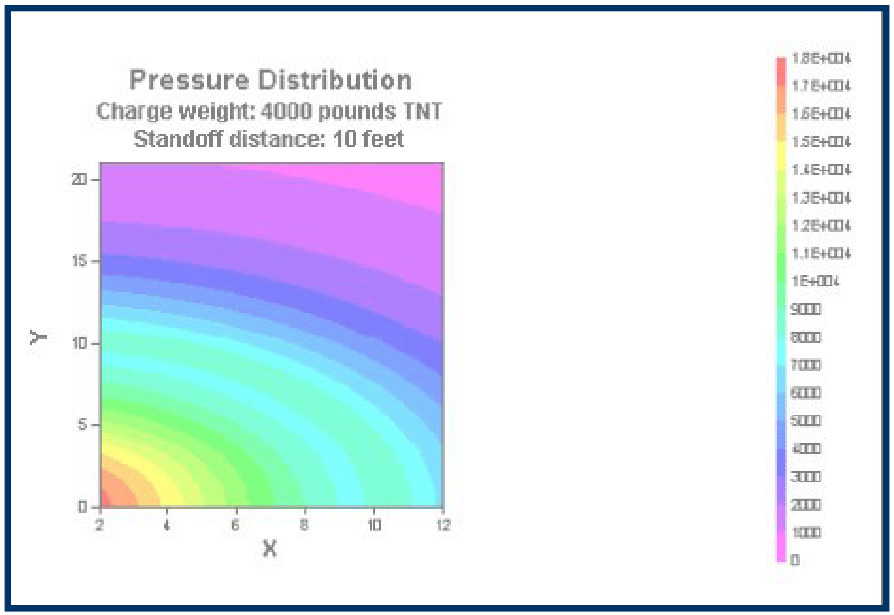
Floor Level	Floor Area (SF)	Blast Damage (SF)	Progressive Collapse Damage				
			Original Building (SF)	Pier-Spandrel Scheme (SF)	SMF Scheme (SF)	Shear Wall Scheme – Line F.5 (SF)	Shear Wall Scheme – Line F (SF)
Roof	15,200	0	6,300	0	0	4,650	5,250
9th	15,200	0	6,300	0	0	4,650	5,250
8th	15,200	0	6,300	0	0	4,650	5,250
7th	15,200	0	6,300	0	0	4,650	5,250
6th	15,200	0	6,300	0	0	4,650	5,250
5th	15,200	300	6,300	300	300	4,650	5,250
4th	15,200	1,050	6,300	1,050	1,050	4,650	5,250
3rd	15,200	2,100	7,000	2,100	2,100	4,650	5,250
2nd	15,200	2,400	7,000	2,400	2,400	6,150	5,250
Total	137,800	5,850	58,100	5,850	5,850	43,350	47,250
% of Total Floor Area Damaged		4%	42%	4%	4%	31%	34%
% of Damaged Area Due to Blast		-	10%	100%	100%	12%	12%
% of Damaged Area Due to Progressive Collapse		-	90%	0%	0%	88%	88%

Conclusions

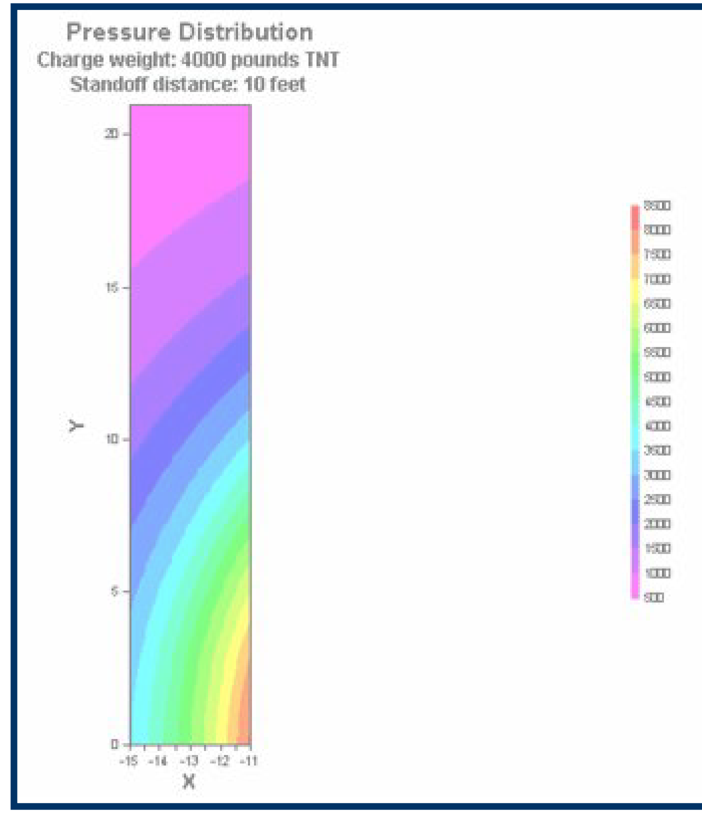
- Pier-Spandrel, Special Moment Frame, and Re-detailed Systems significantly improved blast and progressive collapse resistance.
- Interior Shear Walls modestly improved blast and progressive collapse resistance.

Conclusions

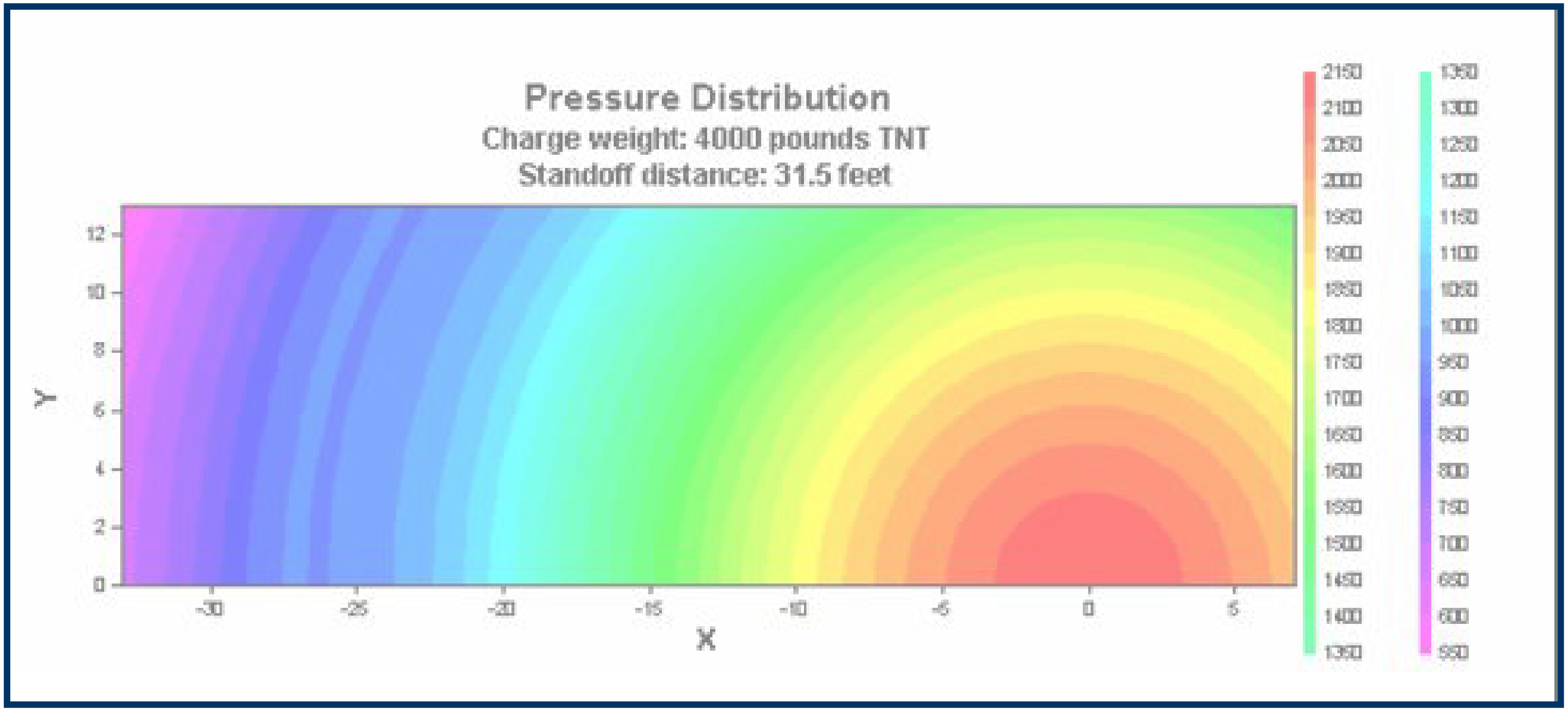
- Strengthening an existing R/C building to meet high seismic demand will improve its blast and progressive collapse resistance.
- Providing high seismic zone detailing for a building will improve its blast and progressive collapse resistance.
- It is more efficient for external blast and impact resistance to place elements proportioned and detailed for seismic forces on the building perimeter.



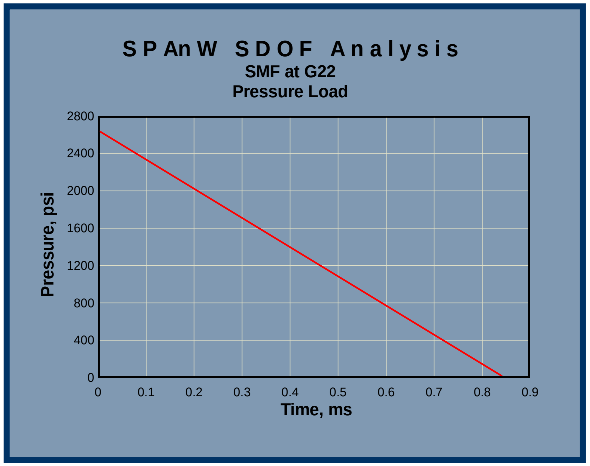
Reflected Pressure Distribution on Pier G20
Pier-Spandrel System



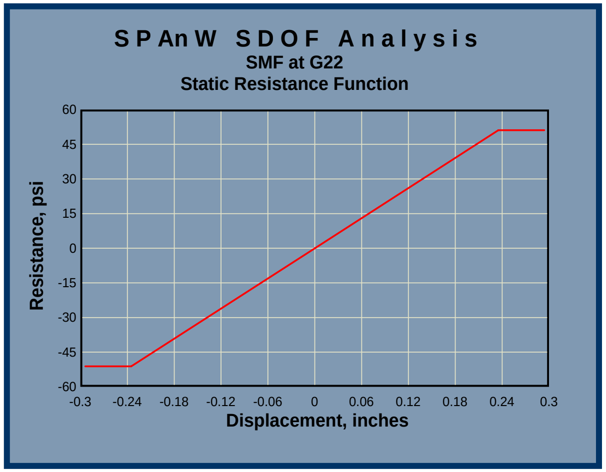
Reflected Pressure Distribution 1st Story Column G22
Special Moment Frame System



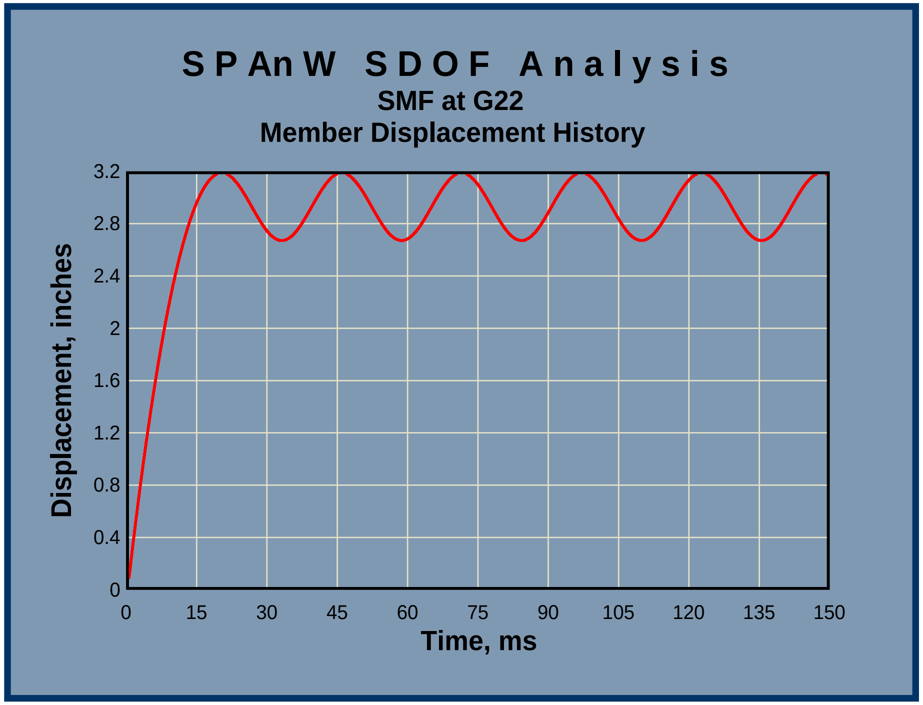
Reflected Pressure Distribution on 1st Story Shear Wall A



Idealized Uniform Reflected Pressure



Element Resistance Function



Predicted Mid-Span Response