MEMORIAL SLOAN-KETTERING CANCER CENTER

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STRUCTURAL OPTION

SENIOR THESIS PRESENTATION

THE PENNSLYVANIA STATE UNIVERSITY

DEPARTMENT OF ARCHITECTURAL ENGINEERING

PRESENTATION OUTLINE

- INTRODUCTION
- BUILDING DESCRIPTION
- EXISTING STRUCTURAL SYSTEM
- PROPOSAL
- SOLUTION OVERVIEW
- STRUCTURAL DESIGN
- CONSTRUCTION MANAGEMENT STUDY
- MECHANICAL STUDY
- CONCLUSIONS

INTRODUCTION

INTRODUCTION

- LOCATED IN SOMERSET COUNTY, NEW JERSEY
- FOUR-STORY HEALTH CARE FACILTY
  - 85,000 SQUARE FEET
  - OPENING SUMMER OF 2006
  - COSTS $41 MILLION
- +80,000 SQ. FT. OUTPATIENT ADDITION (2009)

BUILDING ACCOMODATES:

- 38 EXAM ROOMS
- 27 PRIVATE OFFICES
- 23 CHEMOTHERAPY BAYS
- 3 OPERATING ROOMS
- 2 LINEAR ACCELERATORS
- PHARMACY & LABORATORY

OUTPATIENT ADDITION:

- EDUCATION / PREVENTION CENTER
- PHYSICIAN PRACTICES
- DIAGNOSTIC IMAGING
- ADDITIONAL SURGICAL AREA

BUILDING DESCRIPTION

PROJECT TEAM

OWNER: SLOAN-KETTERING INSTITUTE

STRUCTURAL ENGINEER: EWING COLE

ARCHITECTURE FIRM: EWING COLE

MEP ENGINEER: AKF ENGINEERS

GENERAL CONTRACTOR: BARR & BARR BUILDERS

GEOTECHNICAL ENGINEERS: LANGAN ENGINEERING

ARCHITECTURE

- DESIGNED TO CREATE A SERENE ENVIRONMENT
- 25-ACRE WOODED LOT

EXTERIOR

- SOFT CURVES AND LARGE WINDOWS
- BRICK AND STONE FAÇADE

INTERIOR

- NATURAL LIGHT AND BREATHTAKING VIEWS
- OPEN FLOOR PLAN ALLOWS FOR DYNAMIC LAYOUT

MECHANICAL

- BASEMENT MECHANICAL ROOM
- THREE LARGE ROOFTOP AIR-HANDLING UNITS
- INTERIOR SPACE - VAV SYSTEM

SITE SOIL CONDITIONS

- BUILDING RESTS ON BASALT BEDROCK
  - ALLOWABLE BEARING CAPACITY = 20 KSF
- ADDITION WOULD REST ON DECOMPOSED ROCK
  - ALLOWABLE BEARING CAPACITY = 10 KSF

STRUCTURAL SYSTEM

OVERVIEW

- COMBINATION OF STEEL AND CONCRETE

BELOW GRADE:

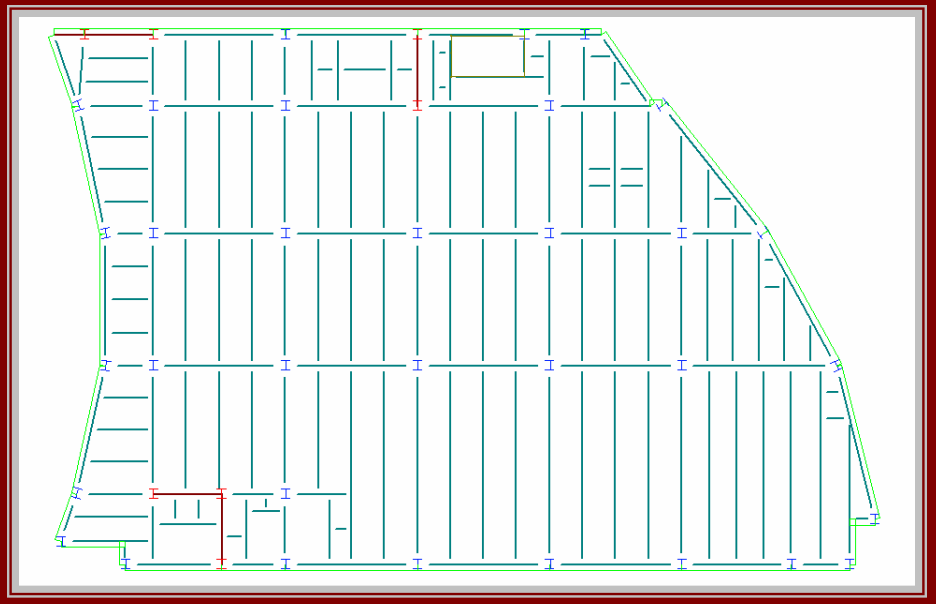
- CONCRETE PIERS ON 30’ x 30’ GRID
- SHEARS WALLS NEAR EXTERIOR

ABOVE GRADE:

- CONVERTS TO STEEL INFASTRUCTURE
- W12 COLUMNS BEAR ON TOP OF PIERS
- CROSS-BRACING RESISTS LATERAL FORCES

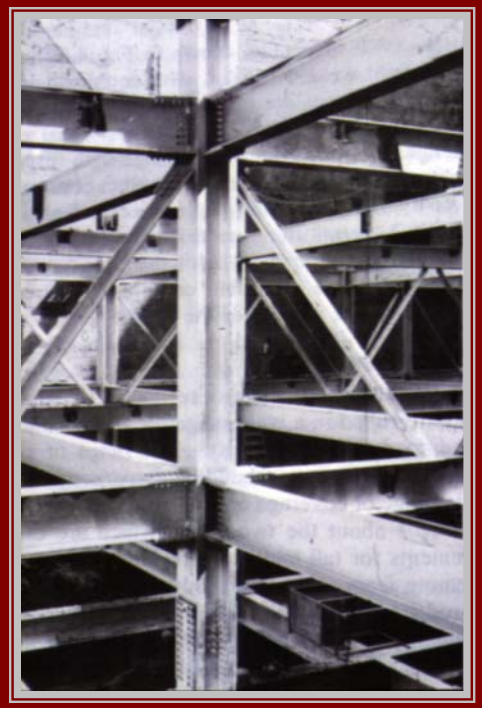
FLOOR FRAMING

- **FLOORS ABOVE GRADE:** COMPOSITE SYSTEM
  - 4 ½" SLAB ON 2" GALVANIZED METAL DECKING
  - 4" LONG SHEAR STUDS
- **TYPICAL BAY:** 30' x 30'
- **SOUTH SIDE BAYS:** 30' x 45'



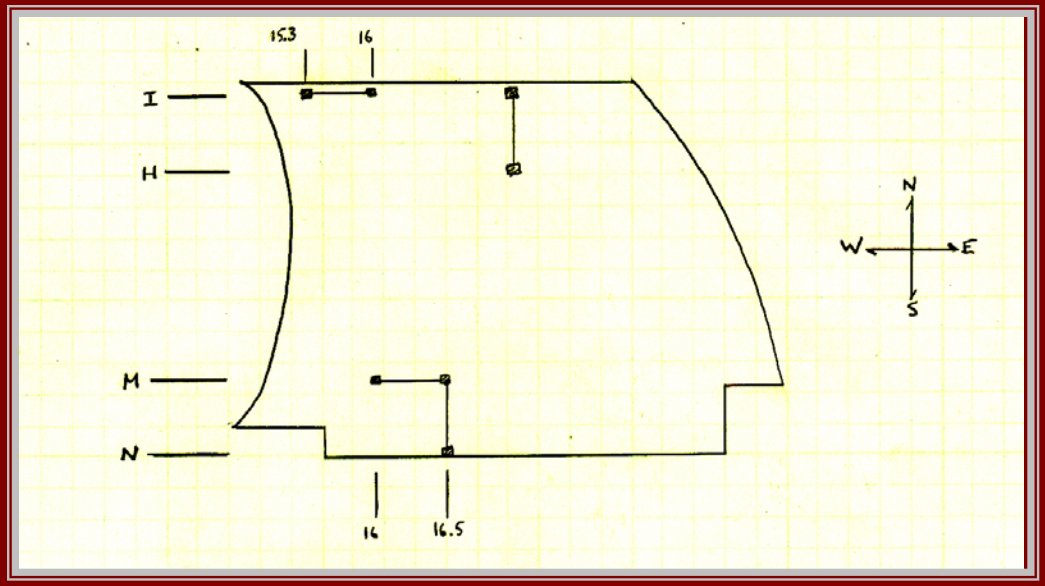
GRAVITY COLUMNS

- SIZE VARIES DEPENDING ON LOCATION
- TYPICAL INTERIOR COLUMN
  - TRIBUTARY AREA = 900 SQ. FT.
  - RANGE BETWEEN W12x87 AND W12x96
- TYPICAL EXTERIOR COLUMN
  - TRIBUTARY AREA = 675 SQ. FT.
  - RANGE BETWEEN W12x45 AND W12x72
- CONCRETE PIERS 24” x 24” IN DIMENSION



LATERAL SYSTEM

- VERTICAL COMBINATION OF SHEAR WALLS AND BRACED FRAMES
- POSITIONED AROUND STAIRWELLS AND ELEVATOR SHAFTS
  - MINIMIZES INTERFERENCE WITH THE FLOOR PLAN
- TWO BRACED FRAMES IN EACH DIRECTION



BRACED FRAMES

- W12x79 COLUMNS AND W18x35 BEAMS
  - BEAMS TYPICALLY SPAN 14'
- HSS DIAGONAL BRACES
  - RANGE FROM 6x6x½ TO 8x8x½
- SUPPORTED BY SHEAR WALLS BELOW GRADE

SHEAR WALLS

- 12" THICK AND 14' LONG
- REINFORCED VERTICALLY WITH #5 BARS AT 12" O.C. BOTH FACES
- LARGE FOOTINGS TO COUNTERACT OVERTURNING MOMENTS

FOUNDATION

- SHALLOW FOUNDATION THAT RESTS ON BEDROCK
- SHEAR WALL FOOTINGS:
  - TYPICALLY 8’ WIDE BY 30’ LONG
  - EXTEND 4’ BELOW BASEMENT FLOOR
- CONCRETE PIER FOOTINGS:
  - TYPICALLY 6’ WIDE BY 6’ LONG
  - ALSO EXTEND 4’ BELOW BASEMENT FLOOR

PROPOSAL

- AFTER ANALYZING STRUCTURAL SYSTEM, DETERMINED:
  - VERY WELL-DESIGNED
    - MEMBERS EFFECTIVELY SIZED AND POSITIONED
    - EFFICIENT FROM A FINANCIAL STANDPOINT
- DECIDED TO INVESTIGATE PLACEMENT PROPOSED OUTPATIENT ADDITION

OUTPATIENT ADDITION REVIEW:

- STILL IN DESIGN STAGE
- BREAK GROUND IN 2009
- CONSTRUCTED TO THE NORTH SIDE
  - EXTEND SIGNATURE CURVED FAÇADE AN ADDITIONAL 120’
  - DOUBLE SIZE OF HEALTHCARE FACILITY

DESIGN DRAWBACKS:

- REPRODUCTION OF ORIGINAL DESIGN
  - SAME FOUNDATION
  - ADDITIONAL EXCAVATION
  - LARGER REQUIRED FOOTINGS
  - WHAT IF ADDITION WAS ERECTED VERTICALLY?

PROPOSED DESIGN:

- INVESTIGATE THE STRUCTURAL EFFECTS FOR VERTICAL EXPANSION
- ADDITION WILL ADD FIVE STORIES TO MSK
  - INCREASE BUILDING HEIGHT FROM 58’ TO 126’
- AMPLIFY LOADS ACTING ON BUILDING
- EFFECT BOTH EXISTING STRUCTURE AND ADDITION

SOLUTION OVERVIEW

- **GRAVITY SYSTEM:**
  - GRAVITY COLUMNS AND CONCRETE PIERS
- **LATERAL SYSTEM:**
  - DETERMINE CONTROLLING FORCES (ASCE 7-02)
  - DESIGN LATERAL SYSTEM
  - RAM STRUCTURAL SYSTEM
- **FOUNDATION:**
  - CHECK ALLOWABLE BEARING STRESSES
  - BASE SHEAR AND OVERTURNING MOMENTS
  - RESIZE FOOTINGS IF NECESSARY

SOLUTION OVERVIEW CONT'D

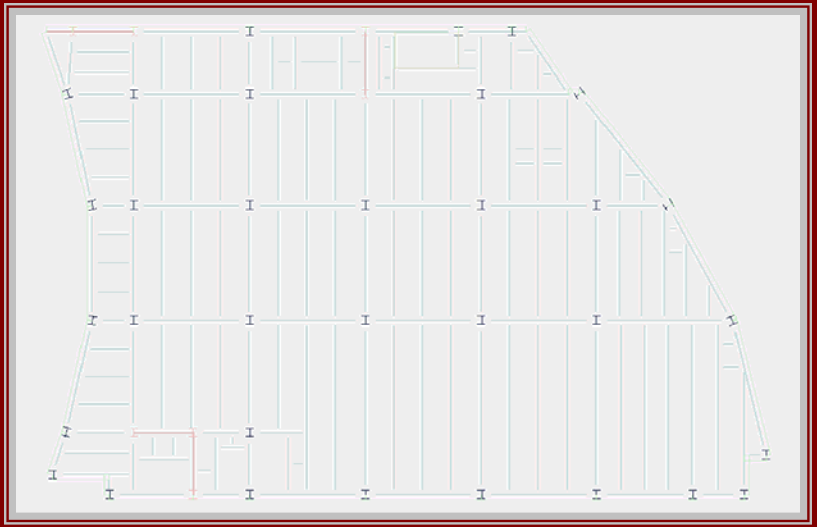
- **CONSTRUCTION MANAGEMENT STUDY:**
  - COST ANALYSIS AND COMPARISON
- **MECHANICAL STUDY:**
  - AIR-HANDLING UNIT ISSUES
    - MECHANICAL FLOOR
    - LOUVERS

STRUCTURAL DESIGN

GRAVITY COLUMN DESIGN

- FIVE ADDITIONAL FLOORS
  - INCREASED AXIAL LOAD ON LOWER COLUMNS
- **HAND CALCULATIONS**
  - TRIBUTARY AREAS AND LLR VALUES DETERMINED
  - AXIAL LOADS FOUND – W12 SIZES ASSIGNED
- **RAM MODEL** CREATED FOR COMPARISON
  - APPROPRIATE LOADINGS ASSIGNED
  - COLUMNS DESIGNED THROUGH PROGRAM
- RESULTS COMPARED - PRODUCED SIMILAR SIZES

GRAVITY COLUMN RESULTS



Gravity Column Redesign Comparison				
Hand Calcuations vs. RAM Design				
	Column Location	Hand Calculations		RAM
		Force (kips)	Size	Size Given
Design A	Typical Interior Column	1455.74	W12x152	W12x152
Design B	Atypical Interior Column (South Side)	1778.96	W12x190	W12x190
Design C	Typical Exterior Column (South Side)	1326.75	W12x136	W12x136
Design D	Typical Exterior Column (North Side)	712.36	W12x72	W12x79
Design E	Atypical Interior Column (North Side)	1120.48	W12x120	W12x120

LATERAL SYSTEM DESIGN

- LATERAL DESIGN CRITERIA – ASCE 7-02
  - **WIND LOADS** – ANALYTICAL APPROACH
    - CASE 1 CONTROLLED
      - **N-S** – BASE SHEAR = 646 KIPS ; OVERTURNING = 45,000 FT-KIPS
      - **E-W** – BASE SHEAR = 394 KIPS ; OVERTURNING = 27,500 FT-KIPS
  - **SEISMIC LOADS** – EQUIVALENT LATERAL FORCE METHOD
    - BOTH DIRECTIONS EXPERIENCED SAME LOADS
      - BASE SHEAR = 442 KIPS ; OVERTURNING = 39,000 FT-KIPS
- **CONTROLLING FORCES:**
  - **N-S** – WIND
  - **E-W** – SEISMIC

LIMITING FACTORS AND DESIGN GOALS:

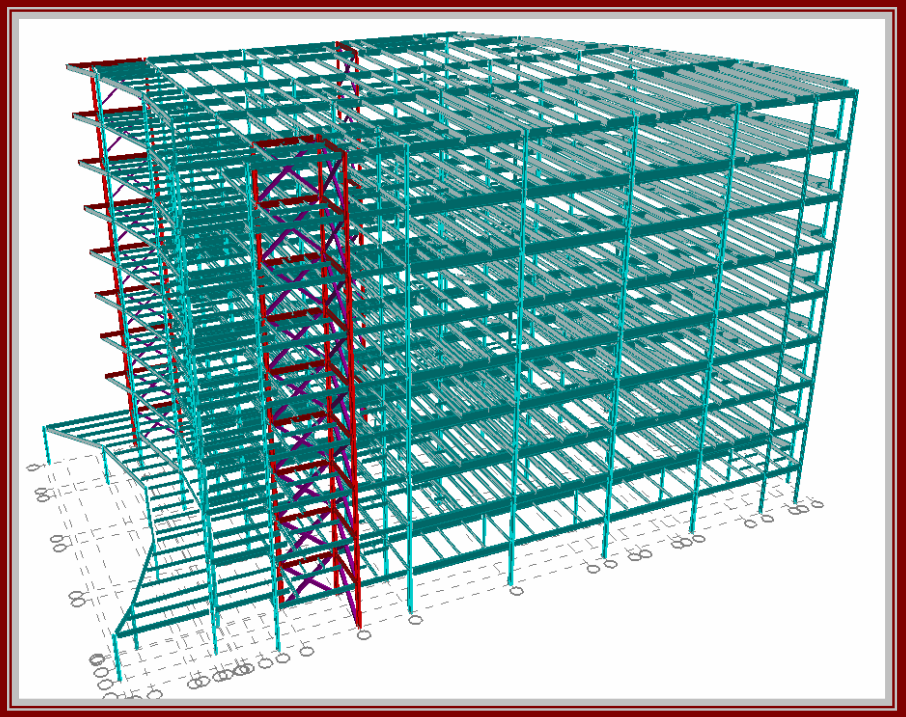
- LIMITING FACTORS:
  - WIND CONTROLS N-S DESIGN
  - SEISMIC CONTROLS E-W DESIGN
  - MAINTAIN W12 COLUMNS
- DESIGN GOALS:
  - KEEP BRACES, COLUMNS AS LIGHT AS POSSIBLE
  - REDUCE DRIFT TO L/480 DESIGN CRITERIA
  - MINIMIZE IMPACT ON INTERIOR SPACES AND EXTERIOR FAÇADE
  - AVOID MOMENT CONNECTIONS IF POSSIBLE

PROPOSED DESIGN ONE:

- EXTENDED EXISTING FRAMES TO ROOF
- INCREASED COLUMN AND BRACE SIZES

BENFITS OF PROPOSAL:

- KEEP EXISTING LAYOUT
- ONLY USED BRACED FRAMES

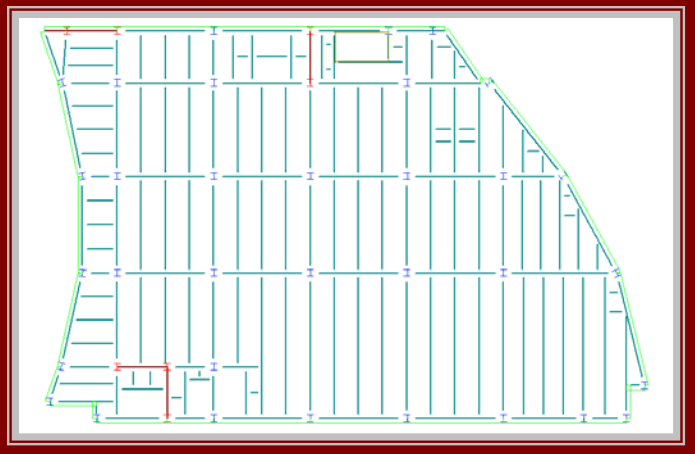


PROPOSED DESIGN ONE RESULTS:

- SIGNIFICANTLY INCREASED COLUMN SIZES
  - UP TO W12x336
- BUILDING DRIFT EXCEEDED LIMIT
  - DRIFT AT CENTER OF RIGIDITY = 7.11”
  - SOUTHEAST CORNER DRIFTED 14.71”
    - LACK OF STIFFNESS IN EAST SIDE

NECESSARY MODIFICATIONS:

- MORE FRAMES IN EACH DIRECTION
- INCREASE STIFFNESS OF SOUTHEAST CORNER

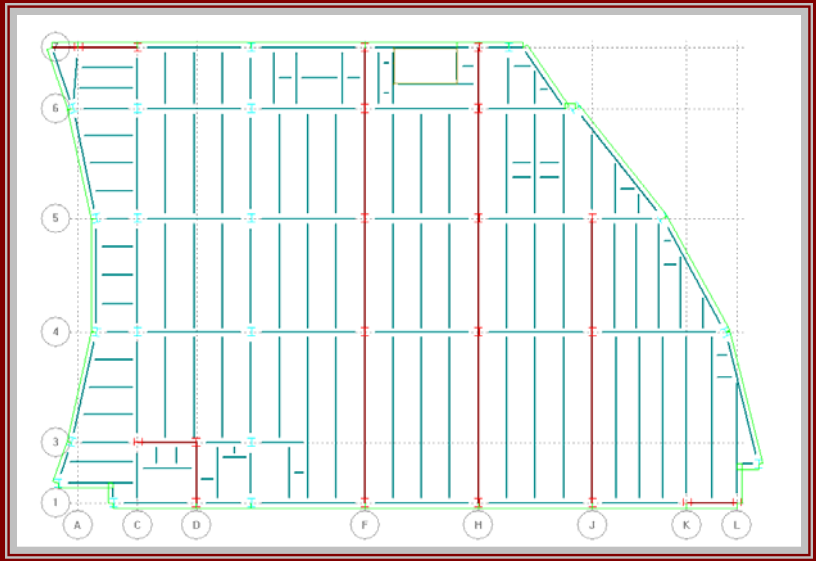


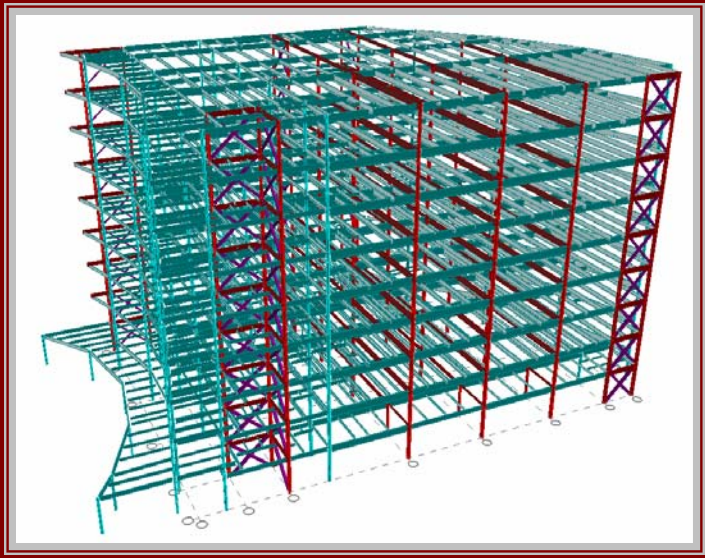
PROPOSED DESIGN TWO:

- ADDED BRACED FRAME IN EACH DIRECTION
- MOMENT FRAMES INTRODUCED

BENFITS OF PROPOSAL:

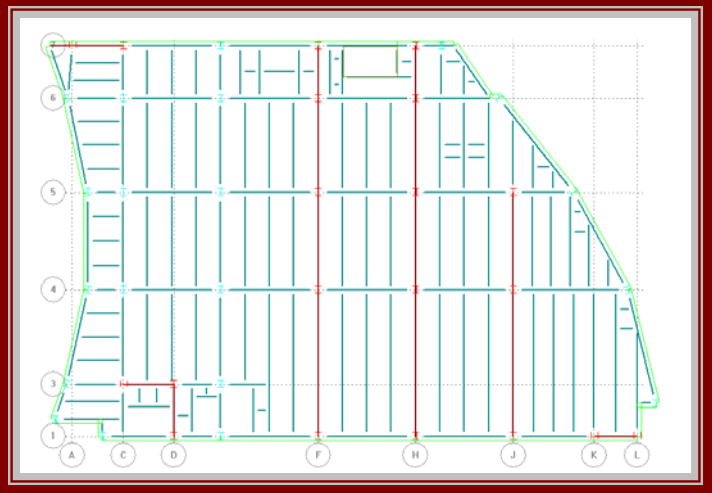
- REDUCE AMOUNT OF FORCE ON EACH BRACE
- PROVIDES STIFFNESS IN THE EAST HALF OF MSK





PROPOSED DESIGN TWO RESULTS:

- COLUMN SIZES REDUCED
  - UP TO W12x210
- DRIFT REDUCED – STILL EXCEEDS DRIFT LIMIT
  - CENTER OF RIGIDITY DRIFTED 5.82”
  - EAST EXTERIOR WALL DRIFTED 7.8”
- MOMENT CONNECTION ISSUES
  - REQUIRES LARGE COLUMNS
  - PROVIDE INADEQUATE STIFFNESS



FURTHER MODIFICATIONS:

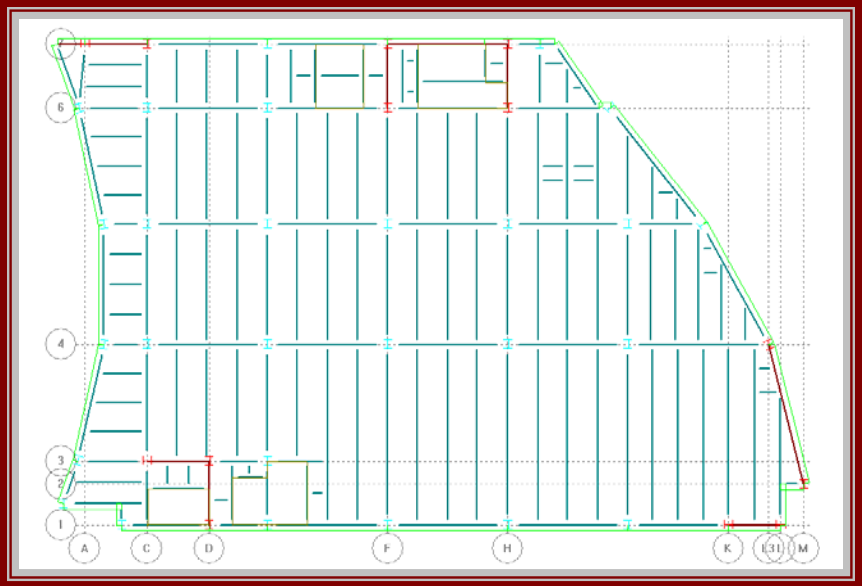
- ADDITIONAL BRACED FRAMES
- MORE STIFFNESS IN SOUTH-EAST CORNER

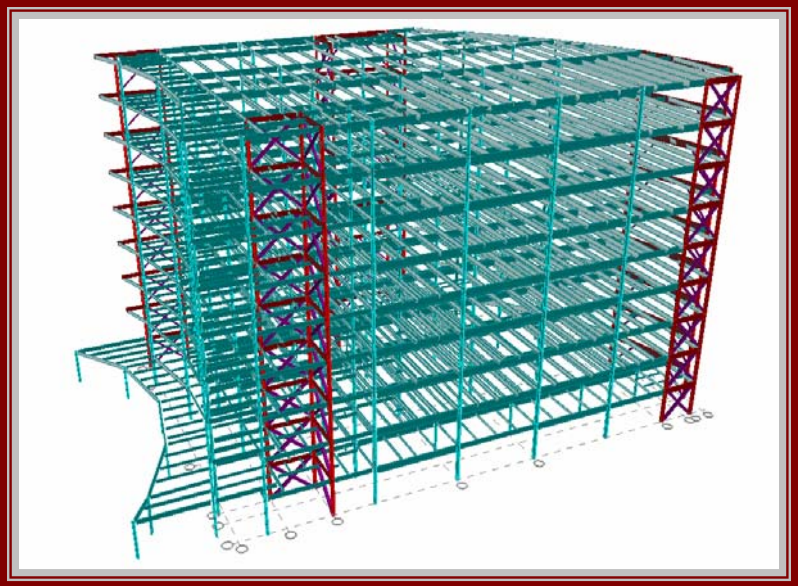
PROPOSED DESIGN THREE:

- ADDS BRACED FRAME IN EACH DIRECTION
- INCORPORATES BRACED FRAME IN SE CORNER

BENFITS OF PROPOSAL:

- ADDITIONAL FRAMES HELP CONTROL DRIFT
- ELIMINATES MOMENT CONNECTIONS IN DESIGN



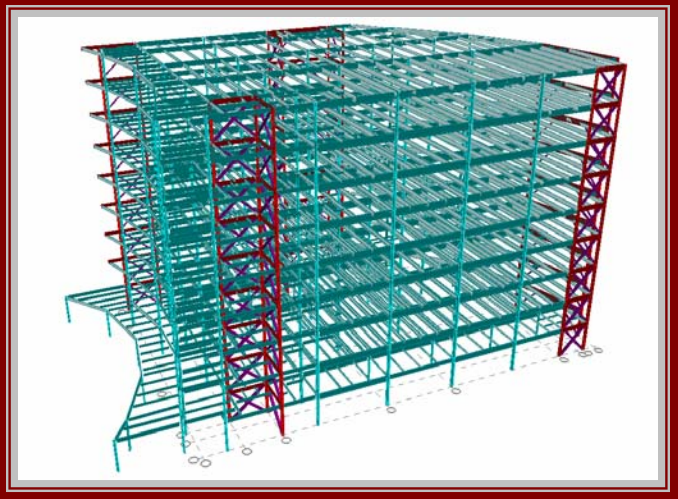


PROPOSED DESIGN THREE RESULTS:

- COLUMN SIZES REMAINED SAME SIZE
  - BETWEEN W12x136 AND W12x210
- BUILDING DRIFT REACHED ACCEPTABLE LIMIT
  - CENTER OF RIGIDITY DRIFT: N-S: 2.66”; E-W: 2.77”
  - EAST EXTERIOR WALL DRIFT REDUCED TO 2.38”

FINAL DESIGN:

- FOUR BRACED FRAMES IN EACH DIRECTION
- NEW FRAMES ADDED IN EAST SIDE
- MINIMAL INTERFERENCE WITH FLOOR LAYOUT AND BUILDING FAÇADE



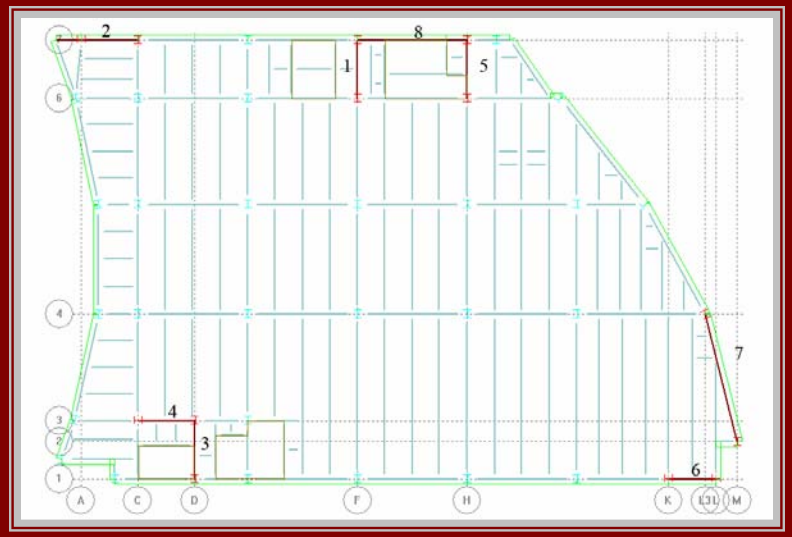
FOUNDATION DESIGN

CONCRETE PIERS:

- REQUIRED (12) #11 BARS
- FOOTINGS INCREASED TO 10’ x 10’

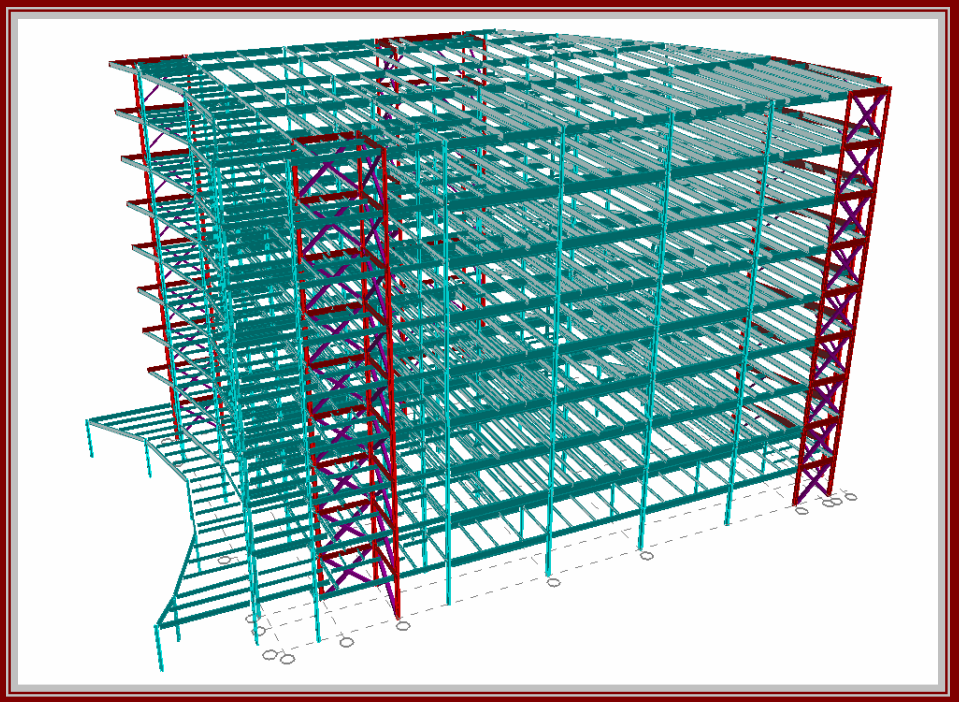
SHEAR WALLS:

- CHECKED BASE SHEAR AND OVERTURNING MOMENTS



DESIGN CONCLUSIONS

- DETERMINED THAT A VERTICAL EXPANSION IS FEASIBLE
- REQUIRES:
  - LARGER COLUMNS
  - MORE BRACED FRAMES
  - ADDITIONAL REINFORCEMENT
  - LARGER FOOTINGS



CONSTRUCTION MANAGEMENT STUDY

ADDITION COST ANALYSIS

- ASSUMPTIONS MADE:
  - EXISTING STUCTURE AND ADJACENT ADDITION SAME PRICE
  - COMPARE COST OF STEEL AND CONCRETE
  - VERTICAL EXPANSION COST INCLUDES INCREASED MEMBER SIZE
- R.S. MEANS USED TO ESTIMATE COST OF VERTICAL ADDITON

Phase One Price	
Structural Components	**Price**
Structural Steel	$1,839,199
Structural Concrete	$375,000
Total	**$2,214,199**

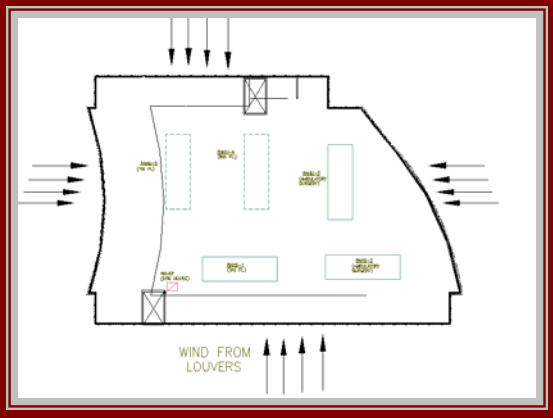
Total Addition Price	
Stuctural Components	**Price**
Structural Steel	$2,121,136
Structural Concrete	$473,939
Phase 2 Total	**$2,595,076**
Phase1 Total	**$2,214,199**
Difference	**$380,877**

- BUILDING ADDTION VERTICALLY WOULD BE 17% MORE EXPENSIVE

MECHANICAL STUDY

ROOFTOP AIR-HANDLING UNITS:

- UNITS SUPPLY AIR TO THE 3RD AND 4TH FLOORS
- MAKE 5TH FLOOR A MECHANICAL SPACE
  - ADD AHU'S FOR ADDITION
  - SUPPLY FLOOR WITH OUTDOOR AIR
  - LOUVERS INSTALLED ON EXTERIOR WALLS



Air Handling Units on 5th Floor		
Unit	**Handles**	**Dimension**
RAHU-1	3rd Floor	12' x 27'
RAHU-2	Ambulatory Surgery	12' x 27'
RAHU-3	Ambulatory Surgery	12' x 27'
RAHU-4	6th Floor	12' x 27'
RAHU-5	7th Floor	12' x 27'

TABLE E-1		
ASHRAE Standard 62.1 (Ventilation for Acceptable Indoor Air Quality)		
Application	**Max Occupancy Density**	**Outdoor Air Requirement**
	#/1000 ft²	**cmf/person**
Medical Procedure	20	15
Operating Rooms	20	30

LOUVER CALCULATIONS:

Required CFM Calculations

Medical Procedure Floors

= (20 people/1000 ft^2)(20,000 ft^2) = 400 people
= (400 people)(15 cfm/person) = 6000 cfm
= (6000 cfm per floor)(3 floors) = **18,000 cfm**

Operating Room Floor

= (20 people/1000 ft^2)(20,000 ft^2) = 400 people
= (400 people)(30 cfm/person) = **12000 cfm**

Total Floor Required =30,000 cfm

Convert Values to Area of Louver needed (ft^2)

Wind Velocity = 4.9 mph ----> convert to ft/min = **431.2 ft/min**

cfm/(ft/min) = ft^2 -----> gives area

= (30,000 cfm)/(431.2 ft/min) = **69.57 ft^2**

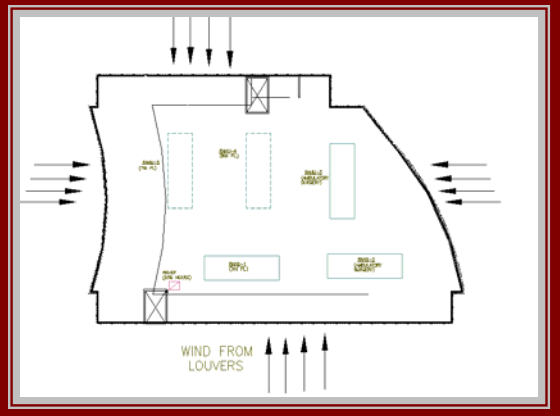
- Multiply Area by 1.43, assume that louver only provides 70% free area

(1.43)*(69.57 ft^2) = **100 ft^2** per wall

- Also take into account louver size needed for maintanance/ repair

- Increase louver size to 15' x 10' , therefore **150 ft^2** per wall

- 5 AIR-HANDLING UNITS ON THE FLOOR
  - 3 SUPPLY EXISTING STRUCTURE
  - 2 SUPPLY ADDITION
- LOUVERS ON EXTERIOR WALLS
  - 10’ x 15’ IN DIMENSION



CONCLUSIONS

- VERTICAL ADDITON STRUCTURAL FEASIBLE
  - FOUR ADDITIONAL BRACED FRAMES
  - BUILDING LAYOUT NOT EFFECTED
- LESS ECONOMIC SOLUTION – 17% MORE EXPENSIVE
- COMPLICATES OTHER SYSTEMS

RECOMMONDATION

- UNDER GIVEN CONDITIONS, NO REASON TO BUILD VERTICALLY
  - 25 ACRE LOT – PLENTY OF ROOM
  - SPECIALIZED FACILITY NEEDS TO WORK TOGETHER
    - HORIZONTAL ADDITION CREATES INTERNAL FLOW
  - ORIGINAL DESIGN FOR OUTPATIENT ADDITION BE USED

ACKNOWLEDGEMENTS

- AE FACULTY AND STAFF
- SPECIAL THANKS TO PROFFESOR PARFITT
- OSCAR GOMES AND BRENT ELLMANN; EWING COLE
- MY FAMILY AND FRIENDS

QUESTIONS