# 1100 BROADWAY, OAKLAND, CA

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Structural Option
Integrated BAE/MAE Program
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Senior Thesis Final Presentation
April 14, 2008

# PRESENTATION OUTLINE

- Introduction
- Existing Conditions
- Proposal
- Project Goals
- Structural System Redesign
  - Gravity System
  - Lateral System
  - Impact on Foundations
- Lateral Analysis
  - Wind
  - Seismic
- Breadth Studies
- Overall Summary and Conclusions

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# INTRODUCTION TO 1100 BROADWAY

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# INTRODUCTION

- Owner: SKS Investments, San Francisco, CA
- Architect: Kaplan McLaughlin Diaz Architects, San Francisco, CA
- Structural Engineer: Simpson Gumpertz & Heger, Inc., San Francisco, CA

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# INTRODUCTION


**Architecture**

- New high-rise tower combined with the adaptive reuse of the Key System building facade

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# INTRODUCTION

**Architecture**

- LEED Gold rating
- Transit Oriented Development (TOD)
- Photovoltaic solar panels, green roof, and a rainwater collection, filtration and reuse system


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# EXISTING CONDITIONS

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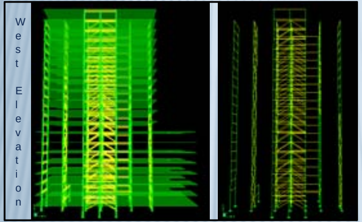


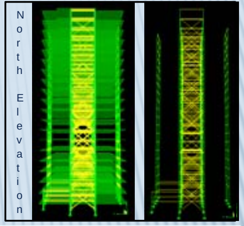


**Existing Structural System**

- Gravity system: 3¼” light weight concrete fill on a 3” composite steel deck supported by composite steel beams
- Lateral system: Dual system composed of steel special concentric braced frames and special moment resisting frames
- Foundations:
  - Prestressed, precast concrete piles beneath a 5’-9” thick reinforced concrete mat foundation
  - Remaining portion of the foundation is a 9” thick reinforced concrete slab

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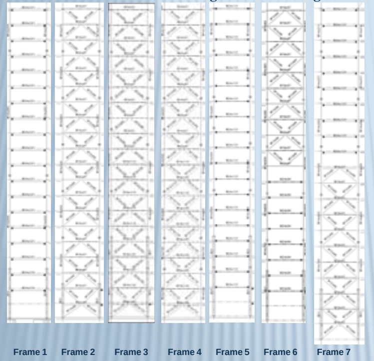
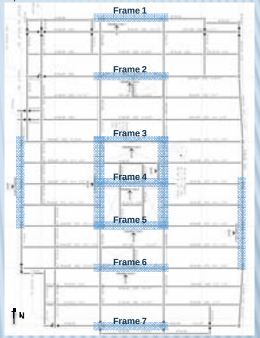
# EXISTING CONDITIONS

Existing frames resisting forces in E/W direction



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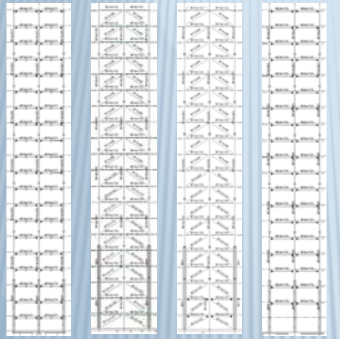
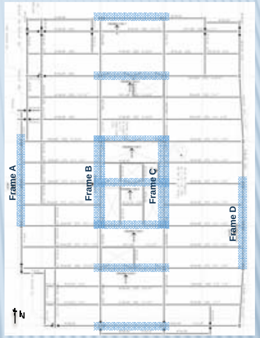
# EXISTING CONDITIONS

Existing frames resisting forces in N/S direction



Frame A | Frame B | Frame C | Frame D



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# PROPOSAL

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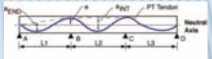
# PROPOSAL

Drawbacks of existing system:
- Deflections
- Depth

**Proposed Design**

Gravity System: One way mild-steel reinforced concrete slab with post-tensioned concrete beams




Why:
- Bays exhibit one-way behavior
- Limited Deflections
- Location of openings not critical

Lateral System: Concrete shear walls

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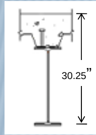
# PROJECT GOALS




- Reduce total floor system depth

- Become more familiar with the design of post-tensioned systems
  - Building Relocation

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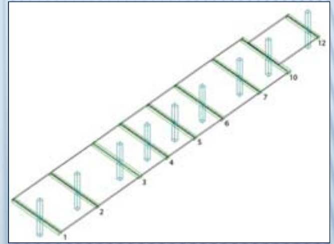
# STRUCTURAL SYSTEM REDESIGN

## One-way slab design

Minimum slab thickness (h) according to ACI

| Span | Length (ft) | h min | h min (in) |
|---|---|---|---|
| 1-2 | 27.33 | l/24 | 13.7 |
| 2-3 | 31 | l/28 | 13.3 |
| 3-4 | 20 | l/28 | 8.6 |
| 4-5 | 20 | l/28 | 8.6 |
| 5-6 | 20 | l/28 | 8.6 |
| 6-7 | 27.33 | l/28 | 11.8 |
| 7-10 | 20.95 | l/38 | 9.0 |
| 10-12 | 28.7 | l/24 | 14.4 |



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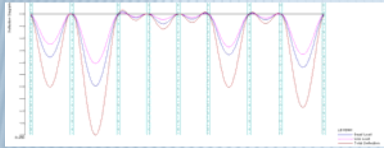
# STRUCTURAL SYSTEM REDESIGN

**One-way slab design**

Slab deflections from PCA Slab



Long-term deflection Check

| | | Deflections from PCA Slab | | Long-term deflection | Allowable Δ |
|---|---|---|---|---|---|
| Span | Length (ft) | LL Δ (in) | DL Δ (in) | LL Δ + 3DL Δ (in) | l/240 |
| 1-2 | 27.33 | 0.062 | 0.088 | 0.326 | 1.4 |
| 2-3 | 31 | 0.102 | 0.149 | 0.549 | 1.6 |
| 3-4 | 20 | - | - | - | - |
| 4-5 | 20 | - | - | - | - |
| 5-6 | 20 | - | - | - | - |
| 6-7 | 27.33 | 0.067 | 0.084 | 0.319 | 1.4 |
| 7-10 | 20.95 | - | - | - | - |
| 10-12 | 28.7 | 0.083 | 0.11 | 0.413 | 1.5 |

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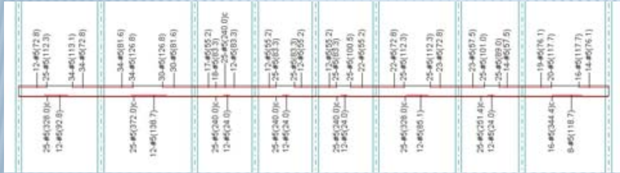
# STRUCTURAL SYSTEM REDESIGN

**One-way slab design**

Final Slab Design:

f'c=5000 psi
Reinforcing steel: 60 ksi, #5 bars top and bottom



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# STRUCTURAL SYSTEM REDESIGN

**Post-tensioned beam design**

Preliminary Design:

Trial beam size of l/22 : Using 37' span amounted to a depth of **20"**

½" diameter unbonded tendons

f'c=5000psi

Precompression limits (P/A): ACI minimum of 125 psi, 200-400 psi typical for beams

Targeted load balance of 70-80% of the dead load

Class T

Analyzed as T sections for interior beams and L sections for perimeter beams

Mild steel: #4 shear and #8 for top and bottom

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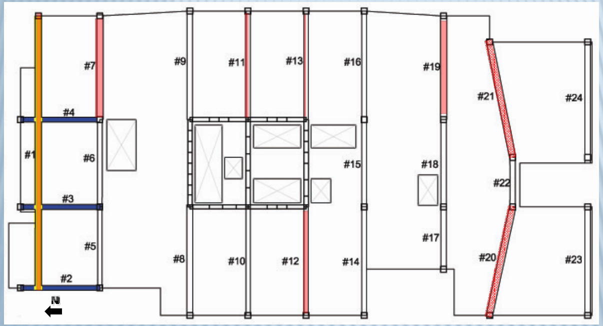
**Post-tensioned beam design**

**Beam layout**



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# STRUCTURAL SYSTEM REDESIGN

## Post-tensioned beam design

**Tendon layout**

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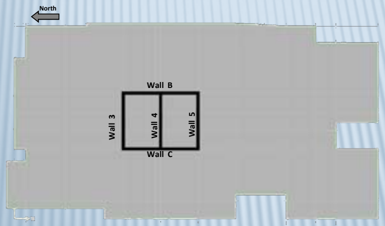
# STRUCTURAL SYSTEM REDESIGN

## Shear Wall Design

Shear wall layout

Preliminary thickness = 18”

Reinforcing: 2 rows of #5 bars at 10” O.C



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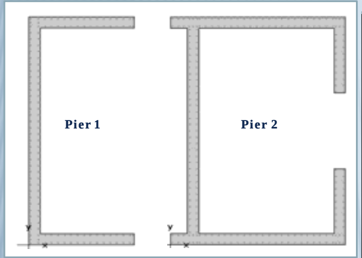


| Pier 1 | |
|---|---|
| Mu (y-axis) ft-k | Mu (x-axis) ft-k |
| 23809 | 49211 |
| **Pier 2** | |
| Mu (y-axis) ft-k | Mu (x-axis) ft-k |
| 23809 | 85367 |

**For a typical floor: Level 10-Roof**

| 1.4D | | | 1.2D+1.6L+0.5Lr | | |
|---|---|---|---|---|---|
| | PIER 1 | PIER 2 | | PIER 1 | PIER 2 |
| Wall | axial load (k) | axial load (k) | Wall | axial load (k) | axial load (k) |
| 3 | 226 | | 3 | 324 | |
| 4 | | 30 | 4 | | 14.8 |
| 5 | | 129 | 5 | | 190 |
| B | 59 | 164 | B | 92.5 | 250.5 |
| C | 58.5 | 167.5 | C | 89.5 | 254.5 |
| total | 343.5 | 490.5 | total | 506 | 709.8 |

**For a typical floor: Level 4-9**

| 1.4D | | | 1.2D+1.6L+0.5Lr | | |
|---|---|---|---|---|---|
| | PIER 1 | PIER 2 | | PIER 1 | PIER 2 |
| Wall | axial load (k) | axial load (k) | Wall | axial load (k) | axial load (k) |
| 3 | 199 | | 3 | 277 | |
| 4 | | 86.8 | 4 | | 110 |
| 5 | | 115 | 5 | | 165 |
| B | 70.5 | 211.5 | B | 82.75 | 248.25 |
| C | 52.25 | 156.75 | C | 80.75 | 242.25 |
| total | 321.75 | 570.05 | total | 440.5 | 765.5 |

Shear walls supporting Level 4 support 18 floors:

| | | | | | |
|---|---|---|---|---|---|
| **total axial (k)** | 6053 | 9306 | | **8715** | **13111** |

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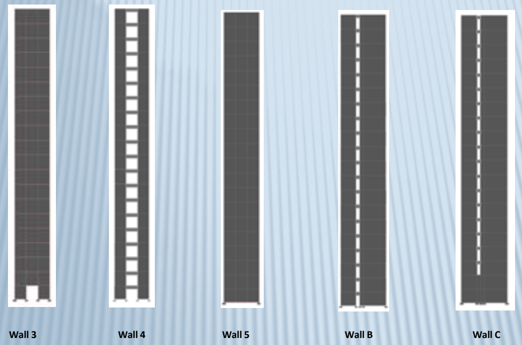

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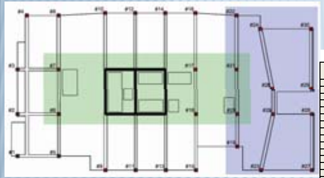
## Impact on Foundations



| Column # | Ultimate load per floor to each column (k): Level 2 | Levels 3-8 | Level 9 | Levels 10-Roof | Total load on each column (k) | Shear wall | Weight (k) |
|---|---|---|---|---|---|---|---|
| 6 | 57.4 | 249 | 242 | 245 | 4733.4 | 3 | 1744.88 |
| 7 | 186 | 265 | 266 | 264 | 5210 | 4 | 1744.88 |
| 16 | | 228 | 230 | 233 | 4394 | 5 | 1744.88 |
| 17 | 137 | 224 | 223 | 233 | 4500 | B | 2326.50 |
| 20 | 14.5 | 184 | 197 | 118 | 2731.5 | C | 2326.50 |
| 21 | 124 | 269 | 285 | 185 | 4243 | | |

Total load to be supported by mat foundation (k) 35700

# Piles required under mat foundation for concrete system 145

# Piles supporting mat foundation for original design 121

**Increase in # of piles required to support mat foundation= 19.8%**

| Column # | Ultimate load per floor to each column (k): Level 2 | Levels 3-8 | Level 9 | Levels 10-Roof | Total load on each column (k) | # of piles required to support column for concrete system | # of piles in original design | % Increase in piles required |
|---|---|---|---|---|---|---|---|---|
| 1 | | 88.1 | 66.6 | 68.2 | 1413.6 | 6 | 6 | 0.0% |
| 2 | | 161 | 151 | 133 | 2713 | 12 | 8 | 50.0% |
| 3 | 91 | 158 | 158 | 156 | 3069 | 13 | 8 | 62.5% |
| 4 | 112 | 84.9 | 84.2 | 79.3 | 1657.2 | 7 | 8 | -12.5% |
| 5 | | 127 | 130 | 192 | 3196 | 13 | 8 | 62.5% |
| 8 | 143 | 151 | 152 | 152 | 3025 | 13 | 14 | -7.1% |
| 9 | | 134 | 136 | 137 | 2584 | 11 | 8 | 37.5% |
| 10 | 118 | 148 | 150 | 148 | 2932 | 12 | 8 | 50.0% |
| 11 | | 116 | 115 | 115 | 2191 | 9 | 6 | 50.0% |
| 12 | 107 | 113 | 111 | 114 | 2264 | 10 | 8 | 25.0% |
| 13 | | 111 | 111 | 113 | 2133 | 9 | 8 | 12.5% |
| 14 | 102 | 115 | 114 | 115 | 2286 | 10 | 6 | 66.7% |
| 15 | | 87.4 | 87.4 | 109 | 1919.8 | 8 | 6 | 33.3% |
| 18 | 111 | 131 | 131 | 133 | 2624 | 11 | 8 | 37.5% |
| 19 | | 111 | 120 | 88.5 | 1848 | 8 | Columns 19-30 support the Key System portion of the structure and not enough information is available from the original design to compare with the new concrete system | |
| 22 | 81.4 | 118 | 115 | 91.4 | 2001.2 | 9 | | |
| 23 | | 156 | 188 | | 1124 | 5 | | |
| 24 | | 198 | 236 | | 1424 | 6 | | |
| 25 | | 217 | 252 | | 1554 | 7 | | |
| 26 | | 193 | 191 | | 1349 | 6 | | |
| 27 | | 107 | 123 | | 765 | 4 | | |
| 28 | | 93.1 | 106 | | 664.6 | 3 | | |
| 29 | | 109 | 122 | | 776 | 4 | | |
| 30 | | 114 | 135 | | 819 | 4 | | |

**Average increase in # of piles required to support each column= 33.4%**

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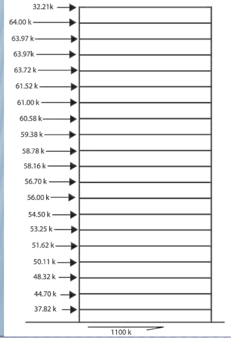
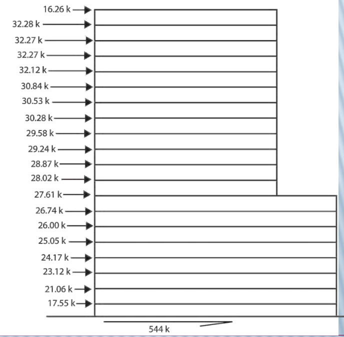
## Wind

Story forces x-direction (E/W)




Story forces y-direction (N/S)



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# LATERAL ANALYSIS

| | | | Wind | | |
|---|---|---|---|---|---|
| Level | Height (ft) | Floor to Floor H (ft) | **Allow. drift (in)** | disp. WX (in) | disp. WY (in) |
| Roof | 258.50 | 13.00 | **7.755** | 1.416 | 4.916 |
| 20 | 245.50 | 13.00 | **7.365** | 1.336 | 4.695 |
| 19 | 232.50 | 13.00 | **6.975** | 1.255 | 4.470 |
| 18 | 219.50 | 13.00 | **6.585** | 1.173 | 4.240 |
| 17 | 206.50 | 13.00 | **6.195** | 1.091 | 4.004 |
| 16 | 193.50 | 13.00 | **5.805** | 1.007 | 3.761 |
| 15 | 180.50 | 13.00 | **5.415** | 0.922 | 3.512 |
| 14 | 167.50 | 13.00 | **5.025** | 0.837 | 3.257 |
| 13 | 154.50 | 13.00 | **4.635** | 0.752 | 2.997 |
| 12 | 141.50 | 13.00 | **4.245** | 0.667 | 2.733 |
| 11 | 128.50 | 13.00 | **3.855** | 0.584 | 2.465 |
| 10 | 115.50 | 13.00 | **3.465** | 0.502 | 2.196 |
| 9 | 102.50 | 13.00 | **3.075** | 0.421 | 1.931 |
| 8 | 89.50 | 13.00 | **2.685** | 0.345 | 1.601 |
| 7 | 76.50 | 13.00 | **2.295** | 0.272 | 1.268 |
| 6 | 63.50 | 13.00 | **1.905** | 0.203 | 0.942 |
| 5 | 50.50 | 13.00 | **1.515** | 0.141 | 0.631 |
| 4 | 37.50 | 13.00 | **1.125** | 0.087 | 0.350 |
| 3 | 24.50 | 12.50 | **0.735** | 0.041 | 0.117 |
| 2 | 12.00 | 12.00 | **0.360** | 0.014 | 0.039 |

Allowable Drift:
h/400

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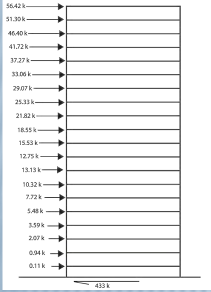
## Seismic

Allowable Story Drift= $0.02h_{sx}$

Actual Story Drift=Cd*Δ/I

Seismic forces at each level




| | | | Seismic | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Level | Height (ft) | Floor to Floor H (ft) | all. Story drift (in) | x-disp. (in) | x-story drift (in) | $\delta_x$ (in) | y-disp. (in) | y-story drift (in) | $\delta_y$ (in) |
| Roof | 258.50 | 13.00 | 3.12 | 1.694 | 0.104 | 0.466 | 2.029 | 0.130 | 0.585 |
| 20 | 245.50 | 13.00 | 3.12 | 1.590 | 0.105 | 0.473 | 1.899 | 0.130 | 0.586 |
| 19 | 232.50 | 13.00 | 3.12 | 1.485 | 0.106 | 0.478 | 1.769 | 0.131 | 0.590 |
| 18 | 219.50 | 13.00 | 3.12 | 1.379 | 0.107 | 0.482 | 1.638 | 0.132 | 0.592 |
| 17 | 206.50 | 13.00 | 3.12 | 1.272 | 0.108 | 0.486 | 1.506 | 0.132 | 0.593 |
| 16 | 193.50 | 13.00 | 3.12 | 1.164 | 0.108 | 0.486 | 1.374 | 0.131 | 0.590 |
| 15 | 180.50 | 13.00 | 3.12 | 1.056 | 0.108 | 0.484 | 1.243 | 0.130 | 0.585 |
| 14 | 167.50 | 13.00 | 3.12 | 0.948 | 0.106 | 0.479 | 1.113 | 0.128 | 0.576 |
| 13 | 154.50 | 13.00 | 3.12 | 0.842 | 0.105 | 0.470 | 0.985 | 0.125 | 0.563 |
| 12 | 141.50 | 13.00 | 3.12 | 0.737 | 0.102 | 0.458 | 0.860 | 0.121 | 0.546 |
| 11 | 128.50 | 13.00 | 3.12 | 0.636 | 0.098 | 0.441 | 0.738 | 0.117 | 0.524 |
| 10 | 115.50 | 13.00 | 3.12 | 0.538 | 0.097 | 0.438 | 0.622 | -0.017 | -0.076 |
| 9 | 102.50 | 13.00 | 3.12 | 0.440 | 0.087 | 0.393 | 0.639 | 0.125 | 0.564 |
| 8 | 89.50 | 13.00 | 3.12 | 0.353 | 0.081 | 0.365 | 0.513 | 0.116 | 0.524 |
| 7 | 76.50 | 13.00 | 3.12 | 0.272 | 0.073 | 0.330 | 0.397 | 0.106 | 0.478 |
| 6 | 63.50 | 13.00 | 3.12 | 0.198 | 0.065 | 0.290 | 0.291 | 0.094 | 0.422 |
| 5 | 50.50 | 13.00 | 3.12 | 0.134 | 0.054 | 0.244 | 0.197 | 0.079 | 0.355 |
| 4 | 37.50 | 13.00 | 3.12 | 0.080 | 0.042 | 0.189 | 0.118 | 0.061 | 0.276 |
| 3 | 24.50 | 12.50 | 3 | 0.038 | 0.021 | 0.095 | 0.057 | 0.043 | 0.195 |
| 2 | 12.00 | 12.00 | 2.88 | 0.016 | 0.016 | 0.074 | 0.013 | 0.013 | 0.059 |

Displacement values taken from ETABS

| | |
|---|---|
| Cd | 4.5 |
| I | 1.0 |

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- Overall Summary and Conclusions

# BREADTH STUDIES

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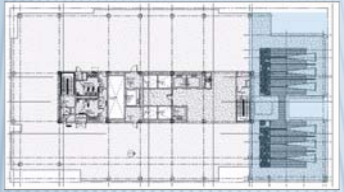
Complete Green Roof Design



- Architectural Breadth

- Building Enclosure Breadth

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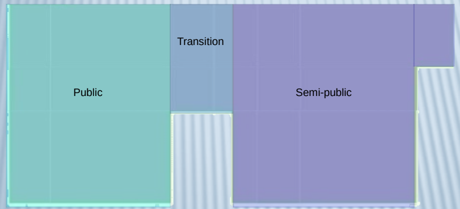
# BREADTH STUDIES

**Architectural Breadth**

- Goals
- Impact on structure
- Zones



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# BREADTH STUDIES

Final Plan

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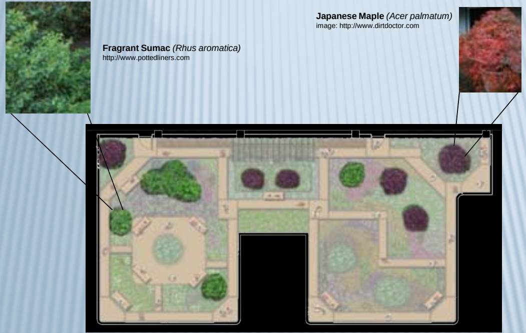
# BREADTH STUDIES

Planting Plans



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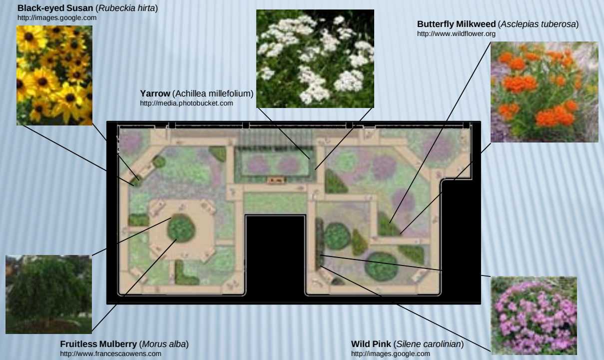

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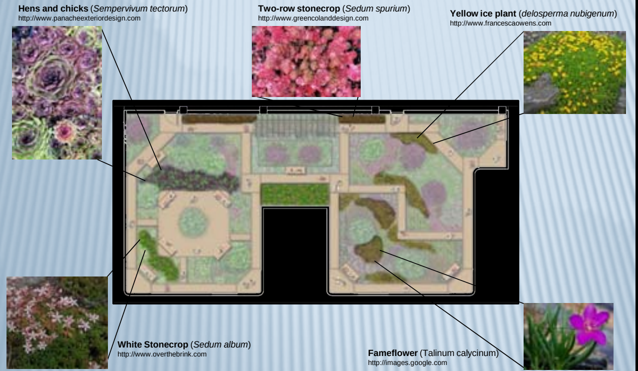

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# OVERALL SUMMARY & CONCLUSIONS

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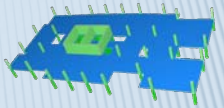
# OVERALL SUMMARY & CONCLUSIONS

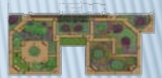
Goals:

- ✓ Reduced floor system depth by 8.25”
- ✓ Developed a greater understanding for PT design
- ✓ Created a roof garden for building occupants



Conclusions:

- Floor system depth reduced, for the 20 story height could add another 13’ story
- Foundations increased on average by 19-33% due to increased building weight
- Redesigned for lower loads than existing system
- Structure supporting green roof needs designed for significantly higher loads



- Unless limits are placed on depth of the floor system the cost of PT and increased building weight will most likely outweigh advantages of design

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# ACKNOWLEDGEMENTS

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| | |
|---|---|
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| The Pennsylvania State University: | Dr. Linda Hanagan<br>Robert Holland<br>Kevin Parfitt |