# Analysis 3

Alternate structural systems to replace the large steel I-beams in the gymnasium

**Problem**

Structural steel members in the Columbia Heights Community Center gymnasium are extremely large. They span a distance of 60'-0" and receive loading from the open-plan office above as well as roof loads through transfer columns. The gymnasium is a two-story space and the average steel beam in this area is a W40x215x60'. These large members are very costly in terms of material and also require a larger crane to set them in place.

**Goal**

The goal of this analysis is to see if this system can be replaced with an alternate system that can save costs through use of less material. The current system will be modeled in RAM Steel v 10.0 to determine if it can be reduced or even changed to an open-web steel joist system.

**Methodology**

1. Determine the building loads that the current steel members support.
2. Design alternate systems using these loads in RAM Steel v10.0 modeling software.
3. Analyze the systems' impacts to cost and schedule.
4. Perform comparison between the proposed systems.
5. Select best viable solution.

**Tools**

1. RAM Steel v10.0 modeling software
2. R.S. Means 2006 Edition
3. AISC - LRFD Manual of Steel Construction 3rd Edition
4. ASCE7 2005 Minimum Design Loads for Buildings
5. Canam Steel Corporation Joist Catalog
6. Penn State Architectural Engineering faculty

**Outcome**

Upon completion of the analysis and a tabulation of the results generated from the Ram Steel modeling software, it was determined that an open-web steel joist system will be less in price and save material (tonnage). In terms of erection speeds, the open-web joist system barely impacts the schedule, saving only a few minutes. Please see the following pages for the complete analysis including tables, loading diagrams, and layouts.

**Building Load Determination**

In order to enter the steel structure into the RAM modeling software, the buildings existing loading must be determined. Using a combination of the structural specifications for Columbia Heights Community Center and the ASCE7 2005 Minimum Design Loads for Buildings manual, the worst case scenario loadings were determined. On a few occasions, the structural specifications called for higher loads than the ASCE7 manual. When this occurred, the heavier load was used. Please see "*Table 1 – Building Loads*" on the following page for all the loads that were considered when redesigning the steel structure in the gymnasium.

# TABLE 1 - BUILDING LOADS

## Snow

(roof slope 1/4" / 12")

| | $C_e$ | $C_t$ | I | $p_g$ (psf) | $p_f$ (psf) |
|---|---|---|---|---|---|
| 0.7 | 0.9 | 1.0 | 1.1 | 25.0 | **17.33** |
| | **Fully Exposed* | | **Category III* | | |
| | ***Category B* | | | | |

**Quantities and calculation method taken from ASCE7-05(Ch.7)*

*** Use 30psf per drawing S 1.00*

## Dead Loads

| ***Component*** | ***Load (psf)*** |
|---|---|
| **Roof** | |
| PVC Roofing Membrane (single ply) | 0.7 |
| Polyisocyanurate Board Insulation (glass-fiber) | 1.1 |
| Skylight Metal Frame | 8.0 |
| Steel Deck (20 gage) | 2.5 |
| Concrete slab on deck (lightweight 3" thick) | 50.0 |
| Green Roof* | 50.0 |
| Miscellaneous | 0.7 |
| | |
| **Ceiling System (4th Floor)** | |
| Acoustical Fiberboard | 1.0 |
| Mechanical Allowance | 4.0 |
| **Total:** | **118.0** |
| | |
| **Floor System (4th Floor)** | |
| Carpet Tile | 2.0 |
| Steel Deck (18 gage) | 3.0 |
| Concrete slab on deck (lightweight 3" thick) | 50.0 |
| | |
| **Ceiling System (Gymnasium)** | |
| Mechanical Allowance | 4.0 |
| **Total:** | **57.0** |

** Per drawing S 1.00*

**Quantities and calculation method taken from ASCE7-05(Ch.3)*

## Live Loads

| ***Component*** | ***Load (psf)*** |
|---|---|
| **Fourth Floor** | |
| Open Office / corridor | **80.0** |

**Quantities and calculation method taken from ASCE7-05(Ch.4)*

**System Design**

Once these building loads were identified, they were then entered into the RAM Steel v10.0 Modeling Software. Only the gymnasium ceiling ($4^{th}$ floor system) and the roof system were entered into the modeling software, along with their loadings, since these are the only systems that will affect the area of redesign. Initially, the existing members at their spacing of 6'-6" were looked at. Surprisingly, the RAM modeling software yielded results that show the existing large members, W40x215x60', reduced to W30x90x60'. This was unexpected considering the loadings determined in the previous section encompassed all known loads, both in the structural specifications and in the ASCE7 manual. Ultimately, the RAM software produced a system that was almost 50% lighter and would save around $86,000.

After this analysis, a test was then run to determine if open-web steel joists could be used. In order for this type of system to work, the typical spacing had to be adjusted from the original 6'-6" to 4'-0" on center. Having done this, the RAM software was able to design a system with a standard joist of 44LH09 and a special joist of 44LH15 to handle the transfer columns. All joists are to have diagonal bridging, with a minimum angle size of 1-1/4, r=.25" (per *Table 2.5.2 Maximum Joist Spacing for Diagonal Bridging* in the *Canam Steel Corporation Joist Catalog*). This resulting open-web joist system was found to weigh approximately 10% less than the original system and cost about $35,000 less.

On the following page, you will see "*Table 2 – System Comparison Sheet*", which gives a complete breakdown of each system and a summary comparison. On the pages following this table, you will find a floor plan for the original system, reduced steel system, and the open-web joist system. Also, you will find all calculations and loading models used to design the open-web joist system.

## Table 2 - System Comparison Sheet

### Original Steel System

| Item | Number | Total Length (ft.) | Tons | Material $ / Ton | Total Material $ | Labor $ / Ton | Total Labor $ | Equipment $ / Ton | Total Equipment $ | Total Cost | Daily Output (L.F. / day) | Total Work Days |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beams | | | **Tons** | | | | | | | | | |
| W 12x30 | 5 | 60.00 | 0.90 | 2550.00 | $2,295 | 360.00 | $324 | 169.00 | $152 | $2,771 | 810 | 0.074 |
| W 14x22 | 20 | 144.00 | 1.58 | 2550.00 | $4,039 | 360.00 | $570 | 169.00 | $268 | $4,877 | 990 | 0.145 |
| W 24x55 | 3 | 30.00 | 0.83 | 2550.00 | $2,104 | 360.00 | $297 | 169.00 | $139 | $2,540 | 1100 | 0.027 |
| W 24x62 | 19 | 760.00 | 23.56 | 2550.00 | $60,078 | 360.00 | $8,482 | 169.00 | $3,982 | $72,541 | 1100 | 0.691 |
| W 36x182 | 1 | 60.00 | 5.46 | 2550.00 | $13,923 | 360.00 | $1,966 | 169.00 | $923 | $16,811 | 1125 | 0.053 |
| W 40x183 | 1 | 60.00 | 5.49 | 2550.00 | $14,000 | 360.00 | $1,976 | 169.00 | $928 | $16,904 | 1025 | 0.059 |
| W 40x199 | 2 | 120.00 | 11.94 | 2550.00 | $30,447 | 360.00 | $4,298 | 169.00 | $2,018 | $36,763 | 1025 | 0.117 |
| W 40x215 | 2 | 120.00 | 12.90 | 2550.00 | $32,895 | 360.00 | $4,644 | 169.00 | $2,180 | $39,719 | 1025 | 0.117 |
| **Total** | **53** | **1354.00** | **62.66** | | **$159,780** | | **$22,557** | | **$10,589** | **$192,927** | | **1.284** |

### Reduced Steel System

| Item | Number | Total Length (ft.) | Tons | Material $ / Ton | Total Material $ | Labor $ / Ton | Total Labor $ | Equipment $ / Ton | Total Equipment $ | Total Cost | Daily Output (L.F. / day) | Total Work Days |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Beams | | | **Tons** | | | | | | | | | |
| W 8x10 | 25 | 184.00 | 0.92 | 2550.00 | $2,346 | 360.00 | $331 | 169.00 | $155 | $2,833 | 810 | 0.227 |
| W 10x12 | 2 | 20.00 | 0.12 | 2550.00 | $306 | 360.00 | $43 | 169.00 | $20 | $369 | 810 | 0.025 |
| W 12x16 | 1 | 10.00 | 0.08 | 2550.00 | $204 | 360.00 | $29 | 169.00 | $14 | $246 | 810 | 0.012 |
| W 16x26 | 4 | 80.00 | 1.04 | 2550.00 | $2,652 | 360.00 | $374 | 169.00 | $176 | $3,202 | 810 | 0.099 |
| W 16x31 | 1 | 20.00 | 0.31 | 2550.00 | $791 | 360.00 | $112 | 169.00 | $52 | $954 | 810 | 0.025 |
| W 18x35 | 3 | 60.00 | 1.05 | 2550.00 | $2,678 | 360.00 | $378 | 169.00 | $177 | $3,233 | 990 | 0.061 |
| W 21x44 | 2 | 80.00 | 1.76 | 2550.00 | $4,488 | 360.00 | $634 | 169.00 | $297 | $5,419 | 990 | 0.081 |
| W 21x50 | 1 | 60.00 | 1.50 | 2550.00 | $3,825 | 360.00 | $540 | 169.00 | $254 | $4,619 | 990 | 0.061 |
| W 24x55 | 8 | 480.00 | 13.20 | 2550.00 | $33,660 | 360.00 | $4,752 | 169.00 | $2,231 | $40,643 | 1100 | 0.436 |
| W 27x84 | 4 | 240.00 | 10.08 | 2550.00 | $25,704 | 360.00 | $3,629 | 169.00 | $1,704 | $31,036 | 1125 | 0.213 |
| W 30x90 | 2 | 120.00 | 5.40 | 2550.00 | $13,770 | 360.00 | $1,944 | 169.00 | $913 | $16,627 | 1025 | 0.117 |
| **Total** | **53** | **1354.00** | **34.54** | | **$88,077** | | **$12,434** | | **$5,837** | **$106,349** | | **1.129** |

### Proposed Steel Joist System

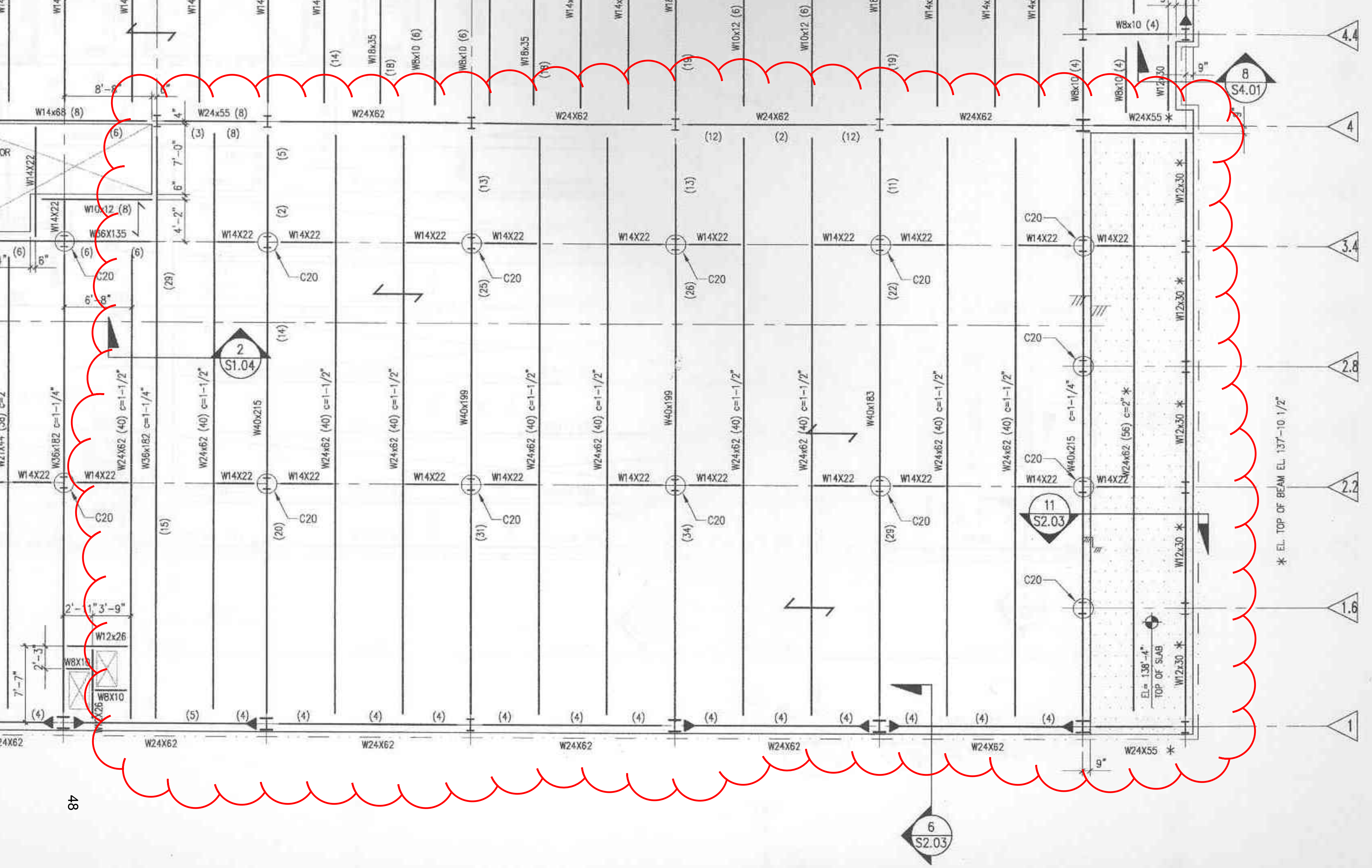
| Item | Number | Total Length (ft.) | Tons | Material $ / L.F. | Total Material $ | Labor $ / L.F. | Total Labor $ | Equipment $ / L.F. | Total Equipment $ | Total Cost | Daily Output | Total Work Days |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Steel Joists | | | | | | | | | | | | |
| 44LH15 | 6 | 358.50 | 6.45 | 28.50 | $10,217.25 | 1.36 | $487.56 | 0.68 | $243.78 | $10,948.59 | 2200 | 0.163 |
| 44LH09 | 18 | 1075.50 | 10.22 | 14.85 | $15,971.18 | 1.36 | $1,462.68 | 0.68 | $731.34 | $18,165.20 | 2200 | 0.489 |
| Beams | | | | **Material $ / Ton** | | **Labor $ / Ton** | | | | | | |
| W 8x10 | 10 | 100.00 | 3.80 | 2550.00 | $9,690 | 360.00 | $1,368 | 169.00 | $642 | $11,700 | 600 | 0.167 |
| W 12x19 | 4 | 80.00 | 0.61 | 2550.00 | $1,556 | 360.00 | $220 | 169.00 | $103 | $1,878 | 880 | 0.091 |
| W 14x22 | 1 | 20.00 | 16.61 | 2550.00 | $42,356 | 360.00 | $5,980 | 169.00 | $2,807 | $51,142 | 990 | 0.020 |
| W 16x26 | 3 | 60.00 | 2.50 | 2550.00 | $6,375 | 360.00 | $900 | 169.00 | $423 | $7,698 | 1000 | 0.060 |
| W 16x31 | 1 | 20.00 | 1.43 | 2550.00 | $3,647 | 360.00 | $515 | 169.00 | $242 | $4,403 | 900 | 0.022 |
| W 18x35 | 1 | 60.00 | 17.15 | 2550.00 | $43,733 | 360.00 | $6,174 | 169.00 | $2,898 | $52,805 | 960 | 0.063 |
| **Total** | **44** | **1774.00** | **58.77** | | **$133,543.43** | | **$17,106.24** | | **$8,090.02** | **$158,739.69** | | **1.074** |

### System Comparison Summary

| Item | Number | Total Length (ft.) | Tons | Total Material $ | Total Labor $ | Total Equipment $ | Total Cost | Total Work Days |
|---|---|---|---|---|---|---|---|---|
| Original Steel System | 53 | 1354.00 | 62.66 | $159,780.45 | $22,557.24 | $10,589.37 | $192,927.06 | 1.284 |
| Reduced Steel System | 53 | 1354.00 | 34.54 | $88,077.00 | $12,434.40 | $5,837.26 | $106,348.66 | 1.129 |
| Proposed Steel Joist System | 44 | 1774.00 | 58.77 | $133,543.43 | $17,106.24 | $8,090.02 | $158,739.69 | 1.074 |

** Costs and daily output taken from R.S. Means 2006*

*** Systems only include the area of redesign, the gymnasium ceiling structure, Columns 1-4 and E.5 - M.*




1 S1.04 FOURTH FLOOR FRAMING PLAN
SCALE: 1/8"=1'-0"

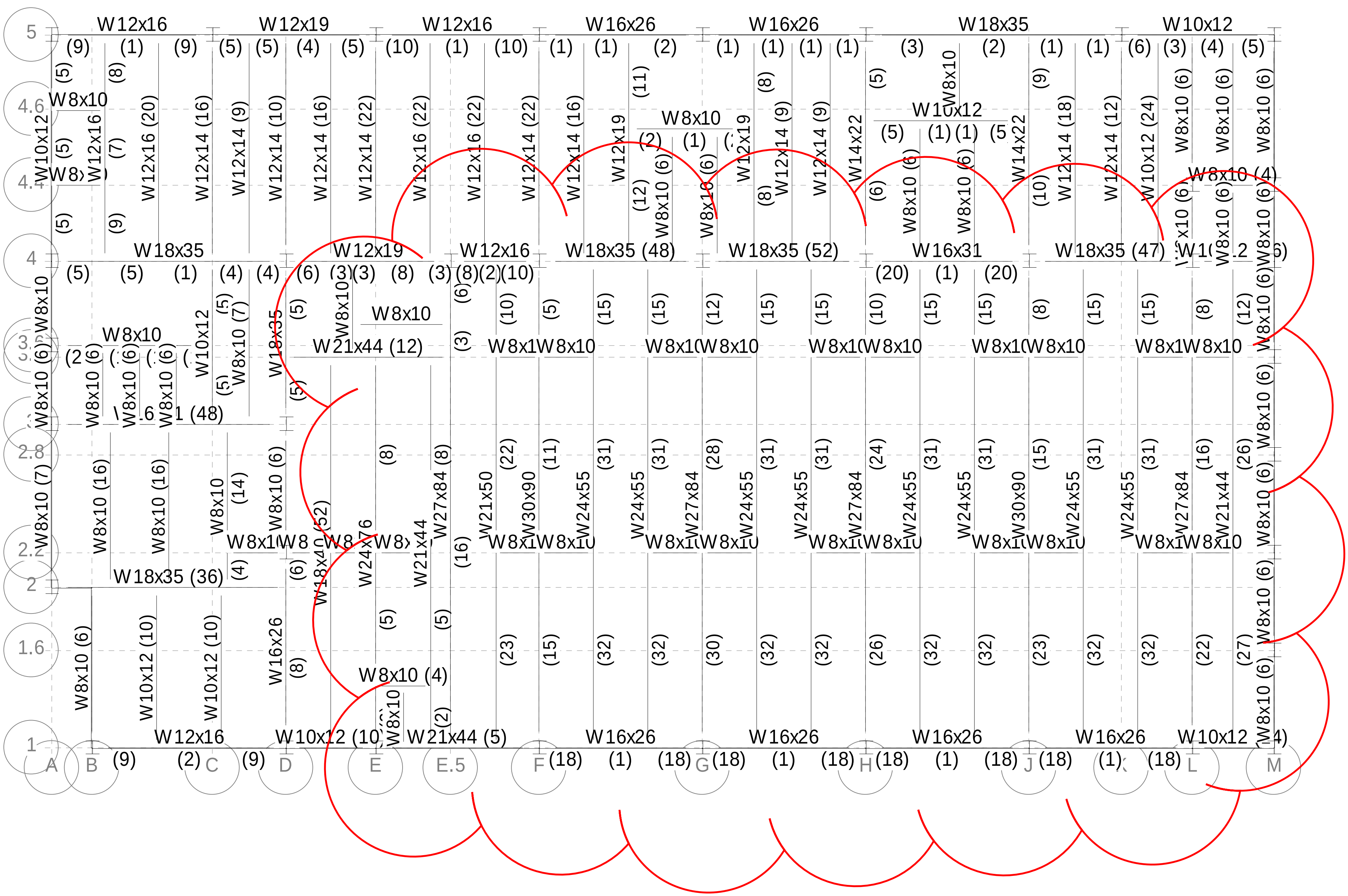
48

# Reduced Steel Floor Map

RAM Steel v10.0
DataBase: glinski thesis existing
Building Code: IBC

03/22/06 21:27:43
Steel Code: ASD 9th Ed.

**Floor Type: FOURTH**

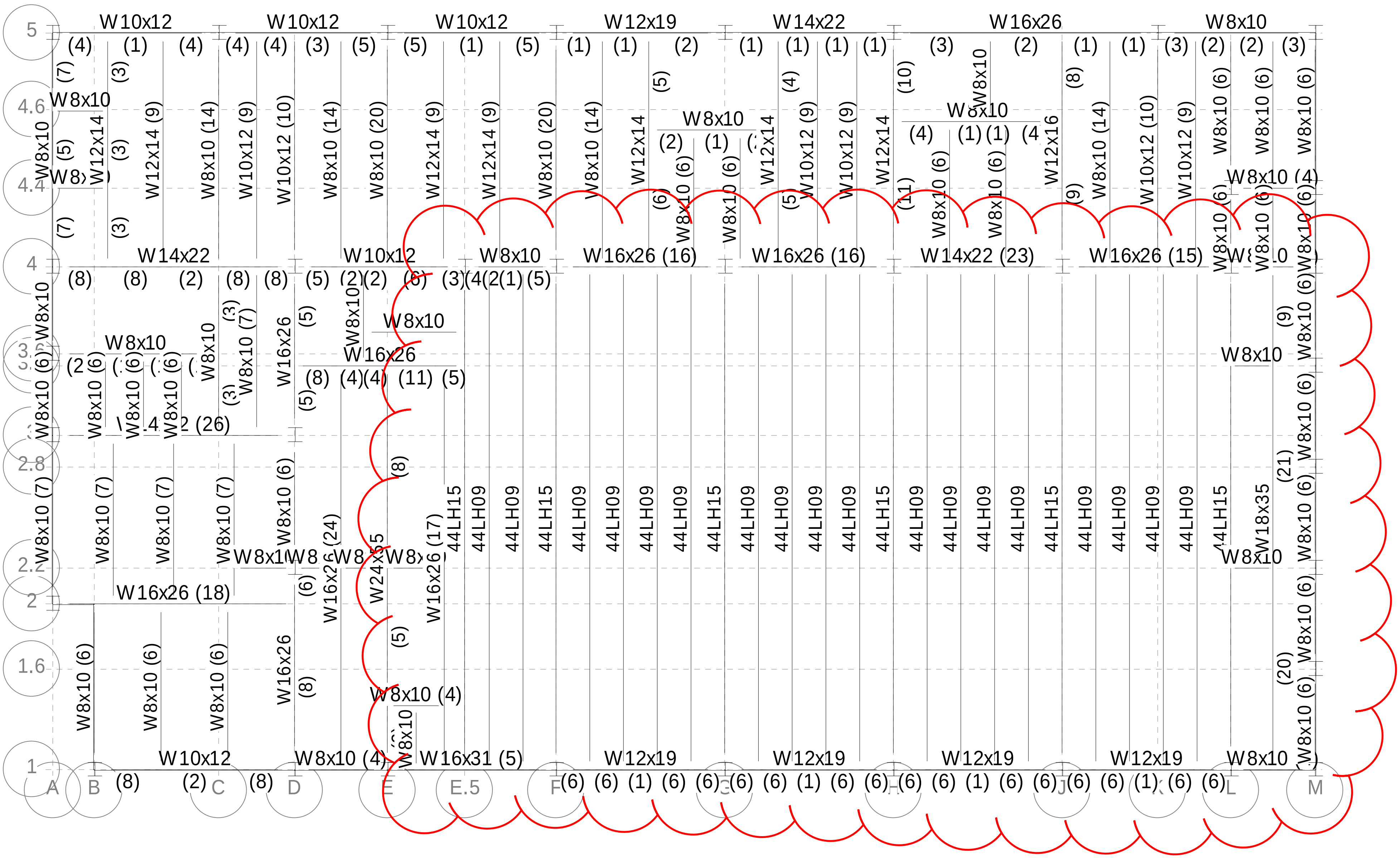


# Open-web Joist Floor Map

RAM Steel v10.0
DataBase: glinski thesis proposed
Building Code: IBC

03/22/06 21:25:40
Steel Code: ASD 9th Ed.

**Floor Type: FOURTH**



# Gravity Beam Design Takeoff

RAM Steel v10.0
DataBase: glinski thesis proposed — 03/22/06 21:25:40
Building Code: IBC — Steel Code: ASD 9th Ed.

**STEEL BEAM DESIGN TAKEOFF:**

**Floor Type: ROOF**
**Story Level 2**
**Steel Grade: 50**

| SIZE | # | LENGTH (ft) | WEIGHT (lbs) |
|---|---|---|---|
| W8X10 | 144 | 2526.26 | 25445 |
| W10X12 | 7 | 143.91 | 1734 |
| W12X14 | 4 | 88.00 | 1246 |
| W12X16 | 4 | 103.00 | 1651 |
| W8X18 | 1 | 24.00 | 430 |
| W12X19 | 1 | 31.33 | 594 |
| W14X22 | 4 | 110.25 | 2435 |
| | ----- | | ------------- |
| | **165** | | **33533** |

Total Number of Studs = **897**

**Floor Type: FOURTH**
**Story Level 1**
**Steel Grade: 50**

| SIZE | # | LENGTH (ft) | WEIGHT (lbs) |
|---|---|---|---|
| W8X10 | 59 | 870.09 | 8764 |
| W10X12 | 11 | 270.16 | 3254 |
| W12X14 | 7 | 194.25 | 2750 |
| W12X16 | 1 | 27.75 | 445 |
| W12X19 | 5 | 100.00 | 1895 |
| W14X22 | 4 | 97.50 | 2153 |
| W16X26 | 10 | 280.24 | 7324 |
| W16X31 | 1 | 20.00 | 621 |
| W18X35 | 1 | 59.75 | 2094 |
| W24X55 | 1 | 48.00 | 2662 |
| | ----- | | ------------- |
| | **100** | | **31962** |

Total Number of Studs = **1010**

**TOTAL STRUCTURE GRAVITY BEAM TAKEOFF**

**Steel Grade: 50**

# Gravity Beam Design Takeoff



| SIZE | # | LENGTH (ft) | WEIGHT (lbs) |
|---|---|---|---|
| W8X10 | 203 | 3396.35 | 34209 |
| W10X12 | 18 | 414.07 | 4988 |
| W12X14 | 11 | 282.25 | 3995 |
| W12X16 | 5 | 130.75 | 2096 |
| W8X18 | 1 | 24.00 | 430 |
| W12X19 | 6 | 131.33 | 2489 |
| W14X22 | 8 | 207.75 | 4588 |
| W16X26 | 10 | 280.24 | 7324 |
| W16X31 | 1 | 20.00 | 621 |
| W18X35 | 1 | 59.75 | 2094 |
| W24X55 | 1 | 48.00 | 2662 |
| | ----- | | ------------- |
| | **265** | | **65496** |

Total Number of Studs = **1907**

# Gravity Beam Design Takeoff



**JOIST SELECTION TAKEOFF:**

**Floor Type: FOURTH**
**Story Level 1**

**Standard Joists:**

| SIZE | # | LENGTH (ft) | WEIGHT (lbs) |
|---|---|---|---|
| 44LH09 | 18 | 1075.50 | 20435 |
| | ----- | | ------------- |
| | **18** | | **20435** |

**Special Joists:**

| SIZE | # | LENGTH (ft) | WEIGHT (lbs) |
|---|---|---|---|
| 44LH15 | 6 | 358.50 | 12906 |
| | ---- | | |
| | 6 | | |

**TOTAL STRUCTURE JOIST SELECTION TAKEOFF**

**Standard Joists:**

| SIZE | # | LENGTH (ft) | WEIGHT (lbs) |
|---|---|---|---|
| 44LH09 | 18 | 1075.50 | 20435 |
| | ----- | | ------------- |
| | **18** | | **20435** |

**Special Joists:**

| SIZE | # | LENGTH (ft) | WEIGHT (lbs) |
|---|---|---|---|
| 44LH15 | 6 | 359 | 12906 |
| | ---- | | |
| | **6** | | |

# Special Joist Selection

RAM Steel v10.0
DataBase: glinski thesis proposed 03/22/06 21:25:40
Building Code: IBC

**Floor Type: FOURTH** **Beam Number = 39**

**SPAN INFORMATION (ft): I-End (59.75,0.00) J-End (59.75,59.75)**

Joist Size (User Selected) = 44LH15
Total Beam Length (ft) = 59.75

**POINT LOADS (kips):**

| Dist | DL | RedLL | Red% | NonRLL | StorLL | Red% | RoofLL | Red% |
|---|---|---|---|---|---|---|---|---|
| 24.000 | 14.24 | | | | | | | |
| 48.000 | 14.61 | | | | | | | |

**LINE LOADS (k/ft):**

| Load | Dist | DL | LL | Red% | Type |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.140 | 0.200 | 6.4% | Red |
| | 59.750 | 0.140 | 0.200 | | |
| 2 | 0.000 | 0.000 | 0.000 | --- | NonR |
| | 59.750 | 0.000 | 0.000 | | |

**MOMENTS:**

| Span | Cond | Moment kip-ft | @ ft |
|---|---|---|---|
| Center | Max + | 413.8 | 24.0 |

**REACTIONS (kips):**

| | **Left** | **Right** |
|---|---|---|
| DL reaction | 15.57 | 21.64 |
| Max +LL reaction | 5.59 | 5.59 |
| Max +total reaction | 21.17 | 27.23 |

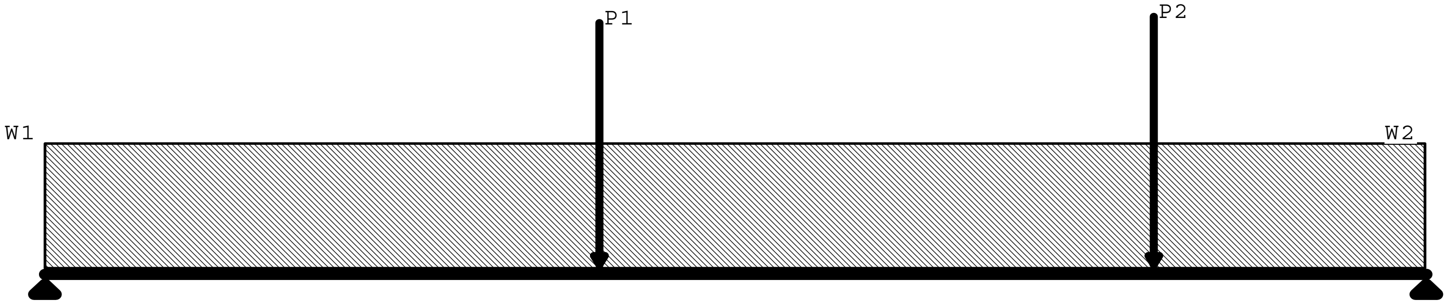
# Load Diagram

RAM Steel v10.0
DataBase: glinski thesis proposed
Building Code: IBC

03/22/06 21:25:40

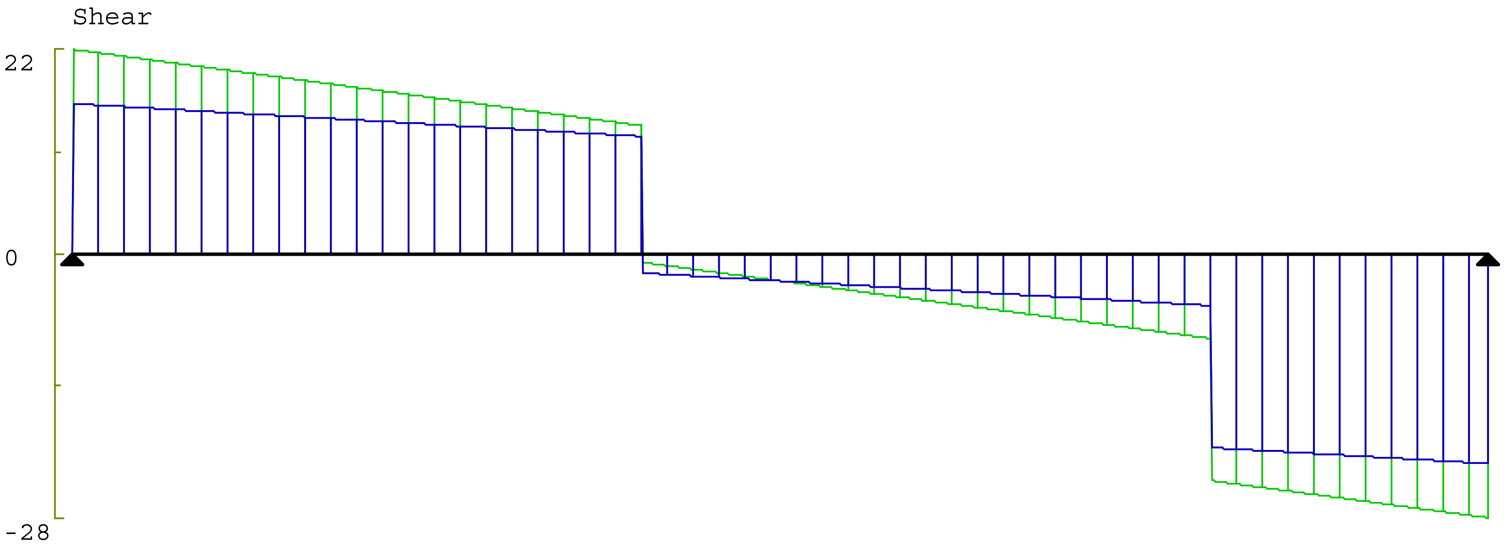
**Floor Type: FOURTH** **Beam Number = 39**

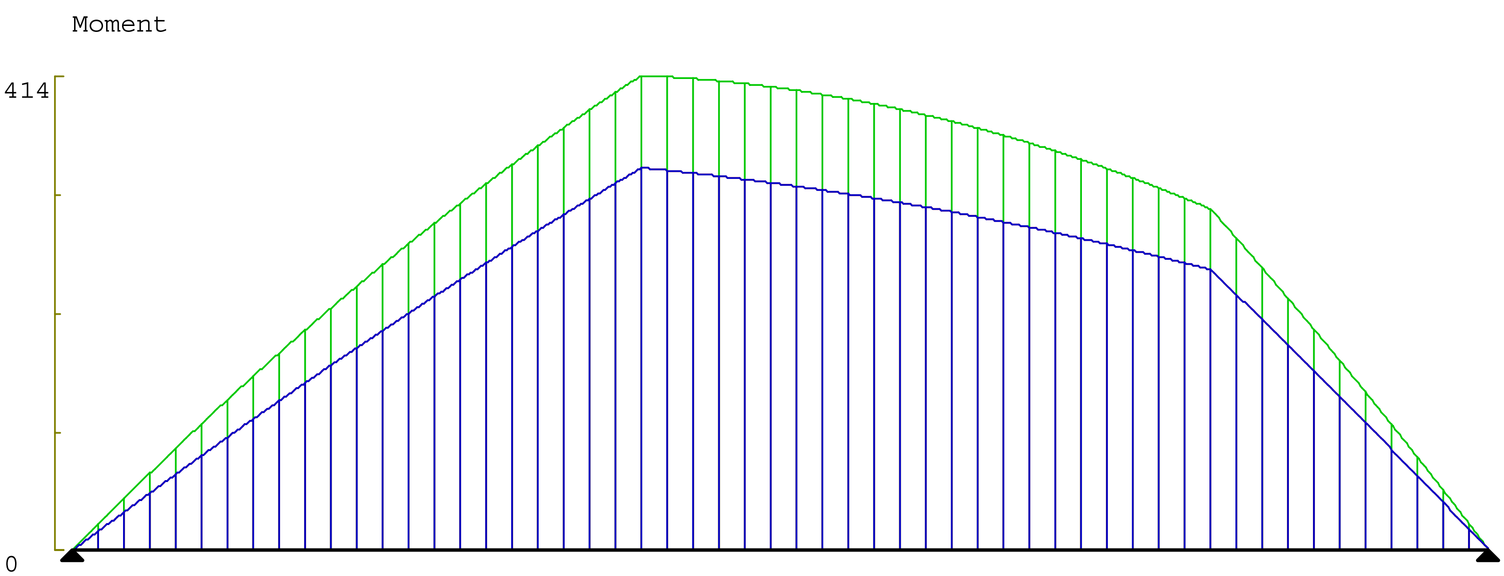
Span information (ft): I-End (59.75,0.00) J-End (59.75,59.75)




| Load | Dist | DL | LL+ | LL- | Max Tot |
|---|---|---|---|---|---|
| | ft | kips | kips | kips | kips |
| P1 | 24.000 | 14.240 | 0.000 | 0.000 | 14.240 |
| P2 | 48.000 | 14.607 | 0.000 | 0.000 | 14.607 |
| | ft | k/ft | k/ft | k/ft | k/ft |
| W1 | 0.000 | 0.140 | 0.187 | 0.000 | 0.327 |
| W2 | 59.750 | 0.140 | 0.187 | 0.000 | 0.327 |

Ram Steel v10.0 Shear, Moment, and Deflection Diagrams
DataBase: glinski thesis proposed 03/22/06 21:25:40
Building Code: IBC
Floor Type: FOURTH Beam Number = 39
Span information (ft): I-End (59.75,0.00) J-End (59.75,59.75)




Max DL Shear = 21.64 kips
Max Shear = 27.23 kips

Max Pos Moment = 413.79 kip-ft at 24.000 ft

# Standard Joist Selection

RAM Steel v10.0
DataBase: glinski thesis proposed
Building Code: IBC

03/22/06 21:25:40

**Floor Type: FOURTH** **Beam Number = 172**

**SPAN INFORMATION (ft): I-End (63.75,0.00) J-End (63.75,59.75)**

Joist Size (User Selected) = 44LH09
Total Beam Length (ft) = 59.75

**LINE LOADS (k/ft):**

| Load | Dist | DL | LL | Red% | Type |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.140 | 0.200 | 6.4% | Red |
| | 59.750 | 0.140 | 0.200 | | |
| 2 | 0.000 | 0.000 | 0.000 | --- | NonR |
| | 59.750 | 0.000 | 0.000 | | |

Maximum Total Unif. Load at any location (lbs/ft) : 327.2

Allowable Stress Ratio: 1.00

| | Design Loads | Allowable Loads (lbs/ft) |
|---|---|---|
| Dead: | 140.0 | |
| Live: | 187.2 | 240.4 |
| Total: | 327.2 | 334.6 |

**MOMENTS:**

| Span | Cond | Moment kip-ft | @ ft |
|---|---|---|---|
| Center | Max + | 146.0 | 29.9 |

**REACTIONS (kips):**

| | **Left** | **Right** |
|---|---|---|
| DL reaction | 4.18 | 4.18 |
| Max +LL reaction | 5.59 | 5.59 |
| Max +total reaction | 9.78 | 9.78 |

**DEFLECTIONS:**

| | | | | | |
|---|---|---|---|---|---|
| Dead load (in) | = | 1.160 | L/D | = | 618 |
| Live load (in) | = | 1.551 | L/D | = | 462 |
| Total load (in) | = | 2.711 | L/D | = | 264 |

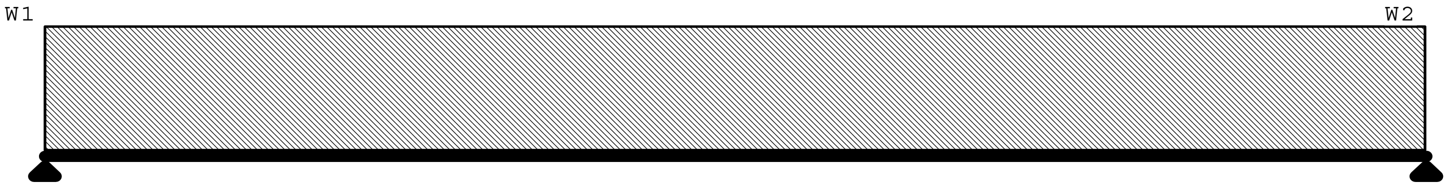
# Load Diagram

RAM Steel v10.0
DataBase: glinski thesis proposed
Building Code: IBC

03/22/06 21:25:40

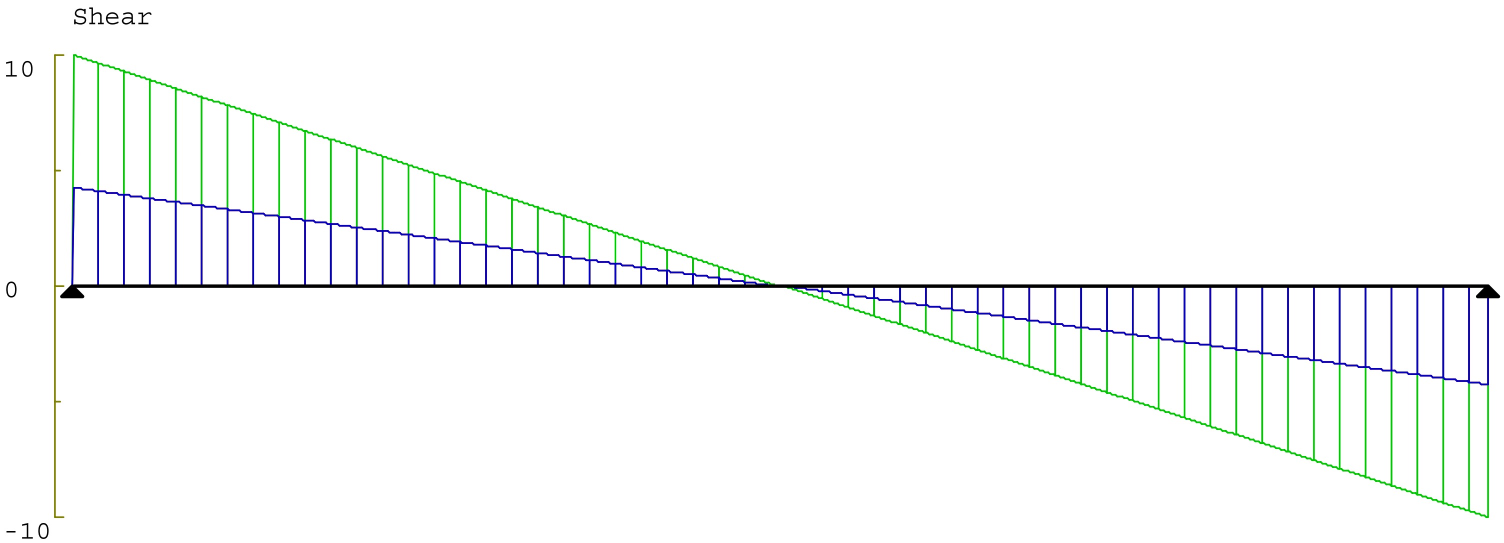
**Floor Type: FOURTH** **Beam Number = 172**

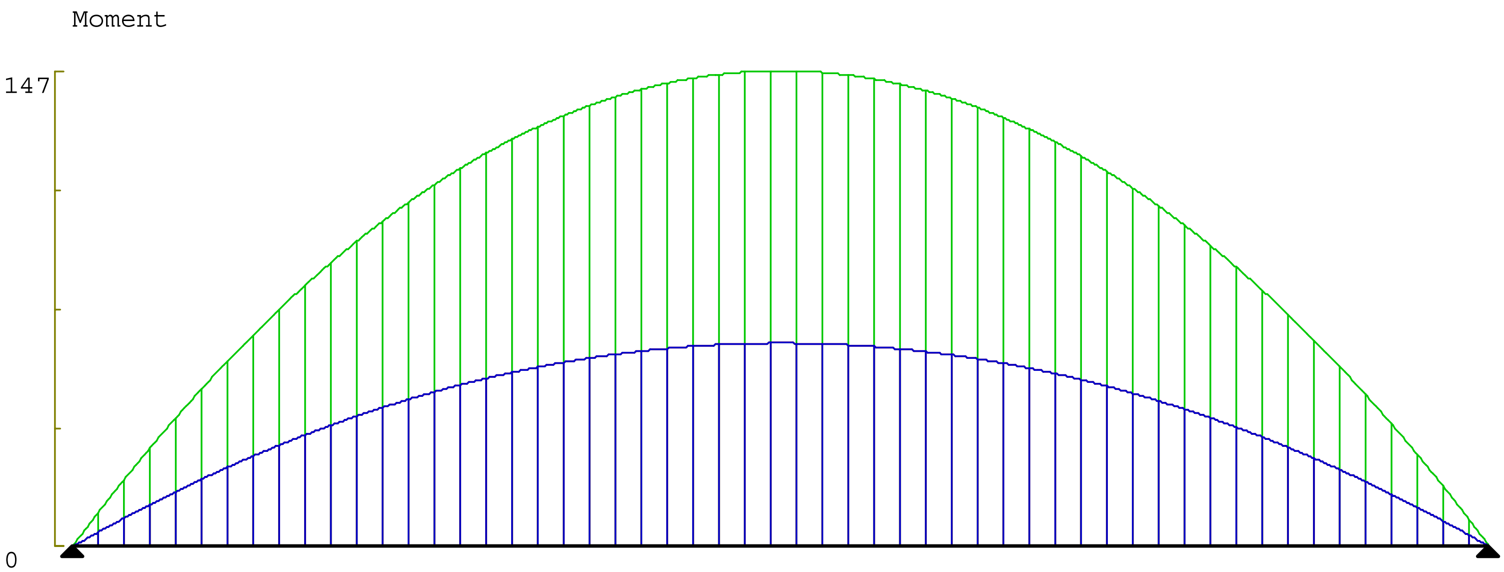
Span information (ft): I-End (63.75,0.00) J-End (63.75,59.75)




| Load | Dist | DL | LL+ | LL- | Max Tot |
|---|---|---|---|---|---|
| | ft | k/ft | k/ft | k/ft | k/ft |
| W1 | 0.000 | 0.140 | 0.187 | 0.000 | 0.327 |
| W2 | 59.750 | 0.140 | 0.187 | 0.000 | 0.327 |

Ram Steel v10.0 Shear, Moment, and Deflection Diagrams
DataBase: glinski thesis proposed 03/22/06 21:25:40
Building Code: IBC
Floor Type: FOURTH Beam Number = 172
Span information (ft): I-End (63.75,0.00) J-End (63.75,59.75)




Max DL Shear = 4.18 kips
Max Shear = 9.78 kips

Max Pos Moment = 146.02 kip-ft at 29.875 ft

**Conclusion**

Overall, the RAM Steel software was extremely helpful for redesigning the steel system in the gymnasium. After determining all the building loadings and entering that information into the RAM model, it was determined that the steel system could be reduced (still incorporating steel I-beams), or it could be changed to open-web steel joists. Each system would reduce the amount of steel material in Columbia Heights Community Center, which would yet again support the building's LEED® aspect. Along with the savings of material, costs would also be reduced. The reduced system would save approximately $85,000 while the open-web joists would save roughly $35,000. Each option would only affect the schedule by a few minutes, and thus, this should be considered negligible.

Ultimately, the option of open-web joists should be pursued. Despite the fact that it does not reduce costs and material tonnage as much as the reduced steel system, it is a more solid system that is known to handle the loads. The results from the RAM model that produced the reduced steel system were unexpected. The structural engineer must have included some extra loading in order to obtain the large sized members. Using the open-web steel joists will maximize the ceiling space in the gymnasium since the ducts could pass between the open-webs. It would also be a safer choice that would still reduce costs and material amounts.