THE FRED HUTCHINSON CANCER RESEARCH CENTER

ROBERT M. ARNOLD PUBLIC HEALTH SCIENCES BUILDING

JONATHAN P. WILLIAMS
ARCHITECTURAL ENGINEERING
STRUCTURAL OPTION

FACULTY ADVISOR:
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FRED HUTCHINSON CANCER RESEARCH CENTER

ROBERT M. ARNOLD PUBLIC HEALTH SCIENCES BUILDING

STRUCTURAL

Cast in Place Concrete
Drop panel Floor System of Post-Tensioned Concrete Slabs
Reinforced Concrete Slabs
Reinforced Concrete Columns
Shear Walls

Exposed Steel
Mechanincal Equipment
roof enclosure
Braced Frames
Prefabricated Atrium Stairwell

MECHANICAL

HVAC Requirement
1.1CFM/FT^2

Chiller Capacity
1200 tons

ELECTRICAL

Mechanical Power
2.3 watts/FT^2

Electrical Service
(4) 2500 KVA Transormers

Emergency Power
2000 KW Diesel Generator

SEATTLE, WASHINGTON

1100 FAIRVIEW
$90,825,000
372,503 FT^2

PROJECT TEAM

Architecture
Zimmer Gunsul Frasca Partnership

Construction Management
Turner Construction Company

Mechanical & Electrical
Affiliated Engineers Inc.

Structural
KPFF Consulting Engineers

ARCHITECTURE

LEED Certified

2005 Masonry Honor Award
Masonry Institute of Washington

5 stories above grade
3 stories below grade
parking garage

Masonry Facade
Horizonatal Strip Windows
Brick Veneer

Triangular Atrium

Entrance Plaza
with water feature

12,800 FT^2 of Laboratory Space
with 6000 FT^2 of support space

113,000 FT^2 of Office Space
with 34,000 FT^2 of support space

Parking
452 spaces

JONATHAN P. WILLIAMS - ARCHITECTURAL ENGINEERING STRUCTURAL
WWW.ARCHE.PSU.EDU/THESIS/EPORTFOLIO/2007/PORTFOLIOS/JPW197/

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Table of Contents

Table of Figures

Table of Tables

Executive Summary

The Robert M. Arnold Public Health Sciences Building was constructed on the campus of the Fred Hutchinson Cancer Research Center in downtown Seattle, Washington. It was built in 1997 to house laboratories and offices. The complex includes an entrance plaza, service road, and turnaround that are supported by a portion of the submerged structure.

Arnold Building is an interesting collage of structural systems. Different portions of the building employ different methods of supporting the necessary loads. The building itself consists of five stories above grade plus a mechanical "penthouse" on the roof while also extending three stories below ground. The Fred Hutchinson Cancer Research Center (FHCRC) specified that the building be designed to a standard of structural integrity higher than that of the code. The building was designed and completed prior to the city of Seattle's adoption of the International Building Code.

Following a detailed analysis of the existing building, a structural redesign using steel framing above grade is proposed. The rationale for changing to steel is to reduce the mass of the building, the cost of the building, and to improve the constructability of the building. An inherent benefit of the steel framing is that it would facilitate a more rapid construction schedule. The Plaza and the parking garage area will remain unchanged.

The Fred Hutchinson Cancer Research Center and the City of Seattle are both actively committed to the promotion of a "healthy environment". As part of this commitment, they have recognized the ecological effects of development and they have agreed to work together to promote and sponsor environmentally friendly courses of action. Given FHCRC's predisposition to such activity, the Arnold Building seemed to be a prime candidate for the promotion of green roof technology. Anticipated benefits include the mitigation of urban heat island effect, significant improvement in the effects of stormwater runoff on the environment, and the positive influence on the building occupants and visitors.

Introduction

Building Background

General Information

The Robert M. Arnold Public Health Sciences Building was constructed on the campus of the Fred Hutchinson Cancer Research Center (FHCRC). The Public Health Sciences Building Houses four Programs: Epidemiology, Cancer Biology, Biostatistics & Mathematics, and Cancer Prevention. Both laboratories and offices occupy Arnold Building. The building height is five stories (60') above grade. The structure also extends three stories below ground. There is an entrance plaza, service road, and turnaround at the building entrance. These public spaces are supported by a portion of the submerged structure.

Applicable Building Codes

The Robert M. Arnold Building was designed and completed prior to the City of Seattle's adoption of the International Building Code (IBC). The applicable building code, when the building was designed, was the 1997 Uniform Building Code (UBC) as amended by the Department of Planning and Development. The design of concrete structures was also to be in accordance with standards set forth by the American Concrete Institution (ACI). The Seattle Building Code was comprised of the 1997 Uniform Building Code and the amendments made by the City of Seattle. The current building code in Seattle is now the IBC. These design requirements will also be examined. Further investigations, analyses, and designs will comply with the current code. It is therefore necessary to look at any differences between the design requirements set forth by design professionals, the UBC and the IBC.

The Uniform Building Code refers to the American Institute of Steel Construction (AISC) for design provisions of steel structures. Regarding concrete construction, the UBC has based its own provisions on the American Concrete Institute 318 but has not explicitly adopted the standard. Certain portions of the Uniform Building Code reference specific sections of the American Society of Civil Engineers (ASCE) 7. One specific example of this is wind design. The section of ASCE 7 on wind design is referenced. However the UBC specifies its own method for determining wind pressures. The International Building Code refers to AISC's design provisions for steel construction. The IBC has also adopted ACI 318 for the design of concrete structures. ASCE 7 is referenced regarding the minimum design loads for buildings.

Systems Descriptions

Mechanical System

The Robert M. Arnold Building has multiple mechanical systems designed to serve the different types of spaces. The mechanical systems were designed according to the following codes and standards:

- 2000 Seattle Energy Code

- 2000 Uniform Mechanical Code with Seattle Amendments
- 2000 Uniform Building Code with Seattle Amendments
- 1997 Uniform Fire Code with Seattle Amendments American Society of Heating Refrigerating, & Air Conditioning Engineers (ASHRAE) Standard 62-1989
- American Industrial Hygiene Association (AIHA) Guidelines and Standards
- National Fire Protection Association (NFPA) Guidelines and Standards

The office spaces of the building are served floor by floor using variable air volume (VAV) air handling units. Each floor has its own air handlers. Floors D and E are each supplied by a single unit, while floors one through four each have three stacked units. The air flow into the spaces is controlled by variable frequency drives (VFD) on the supply fans. Outdoor air from the roof is supplied to the air handling units through air shafts. The relief exhaust system is a medium pressure VAV that vents into the parking garage.

The laboratory area is supplied 100% outdoor air, from the roof, by one VAV air handling unit. After the air is filtered, heated, and cooled it is distributed to the lab by two plenum fans that are controlled by variable frequency drives. The exhaust system for the laboratory consists of three parts; a general exhaust system, a fume exhaust system, and a second specialized fume exhaust system. The general exhaust of the laboratory is drawn by variable air volume exhaust valves up to the mechanical penthouse where an exhaust air handler is located. The regular fume exhaust system pulls air from the lab through exhaust valves placed in the ceiling where it is directed to a fan room located on the mechanical level. There, two exhaust fans discharge the air through stacks extending 15 feet above the roof level. A combination of variable frequency drives and variable geometry discharge dampers help to maintain the exit velocity of the fume exhaust. The special fume exhaust system utilizes two radioisotope fans to exhaust specific hoods located in the lab. Internal surfaces of the equipment for this system are coated with Heresite. The exhaust air is then serviced by a combination of HEPA and charcoal filters.

Electrical System

The electrical system of the building was designed in accordance with the following codes:

- WAC Washington Administrative Code
- ANSI American National Standards Institute
- IEEE Institute of Electrical and Electronics Engineers
- IES Illuminating Engineering Society of North America
- NEC 1999 National Electrical Code
- NECA National Electrical Contractors Association
- NEMA National Electrical Manufacturers Association
- NFPA National Fire Protection Association
- UL Underwriters Laboratories
- SEC 1999 Seattle Electrical Code

The electrical service at 480Y/277 volts to Arnold Building is provided by the Seattle Light and Power Company. The Public Health Sciences Building has an emergency power system. Emergency power is supplied by a 2,000 Kilowatt/ 2,500 Kilovolt-amp diesel engine generator. The generator has the ability to power the building for four hours and was designed to shed loads in order to maintain loads of higher priority. An uninterruptible power supply system was also implemented to power the server rooms in Arnold building for a minimum of 11 minutes.

Lighting System

The majority of the spaces in the Public Health Sciences Building are illuminated using energy efficient fixtures. The luminaires implemented were designed to have lamps with 3500K color temperature and a color rendering index of 85. The laboratory and its support area have luminaires that indirectly light the space each using (3) 2'x4' lamps. The clinic area is also lit using this type of fixture. The open areas of the office use luminaires similar to those in the laboratory, however, in this portion of the building there are only 2 lamp fixtures. The remaining office space is lit using 8 foot and 12 foot single lamp, pendant fluorescent fixtures. Food service rooms are illuminated by 2 or 3 lamp recessed fluorescent fixtures with acrylic lenses. General building circulation spaces are lit by compact fluorescent downlights that are 6 inches in diameter. Support areas of the building are lit using 4 foot industrial fluorescent fixtures that each have 2 lamps.

Fire Protection System

In Arnold Building the method of fire protection is dependent upon the space being protected. All interior spaces are protected using a wet pipe sprinkler system. Dry pipe sprinklers are used to protect areas that will be subjected to temperatures below 40° F such as the parking garage. The data centers in the building are protected by two systems. The primary means of fire protection is a gaseous fire suppression system. This dry protection method uses carbon dioxide for fire suppression. The secondary system is a pre-action sprinkler system. Smoke detectors and heat detectors will activate the fire alarm system, which will then initiate the pre-action system.

Architectural Features

The public health sciences building presents itself to the world in two very different manners. The northern, southern and western sides exude the image of typical suburban office building. When approaching from these directions it appears as an expansive relatively short building with nothing spectacular inside. This is a sharp contrast to the invigorating and inviting approach from the Northeast corner.

Atrium

The Robert M. Arnold Building at the Fred Hutchinson Cancer Research Center takes on an interesting form. In the center of the Arnold Building there is a large triangular atrium where catwalks and spiral stairs hover below a glass roof. This atrium allows natural light to reach more interior spaces. Arnold Building is Phase V of the development of FHCRC's privately owned campus.

Facade & Roof

The facade of the Public Health Sciences Building has various features. The Robert M. Arnold Building has earned LEED Certification and in 2006 won the Masonry Institute of Washington's highest honor. Brick masonry panels combined with the glazing compose most of the building enclosure. The upper portions of the building however, have prefabricated metal panels for their exterior surface.

The roof of Arnold Building is made up of a ballasted flexible sheet roofing membrane. All of the roof areas are flat, or low sloped roofs. The roof is given its slope by the use of tapered rigid insulation; the structure itself is not. The waterproofing is provided by a EPDM and is held down cold adhesive, combined with a washed river stone ballast.

Existing Structure

Arnold Building is an interesting collage of structural systems. Different portions of this building employ different methods of supporting the necessary loads. The building itself consists of five stories above grade plus a mechanical "penthouse" on the roof, while also extending 3 stories below grade. The triangular transfer of load around the atrium provides an element of structural complexity unseen in rectilinear buildings. Arnold Building houses the Public Health Science Department of the Fred Hutchinson Cancer Research Center. FHCRC specified that the building be designed to a standard of structural integrity higher than that of the code.

Foundation

The foundation of the Public Health Sciences Building consists mainly of spread footings and wall footings. Where the foundation is required to resist lateral loads carried down by shear walls, the building uses deeper drilled piers. The average footing is about 12 square feet, however, sizes ranging from eight feet square to 28 feet by 24 feet. The depth ranges from 30 inches to 48 inches deep, but is typically around 40 inches deep. The majority of the footings are at the same elevation, however, at the garage ramp on Level F the elevations increase incrementally with the ramp slab on grade. These footings with different elevations are spread footings. The concrete of the spread footings has an allowable compressive stress of 4000 ksi. The slab on grade for Level F has a carbon fiber concrete mix. All the walls below grade are concrete retaining walls with piers. At the northeast end of the basement there is an opening in the walls that adjoins Arnold Building to the adjacent building on campus.

Framing

The framing of Arnold Building is mainly composed of concrete structural elements, however, there are some portions of the building where steel has been used. Steel framing was used for the stairs and skylight in the atrium. A special stipulation was made by the structural engineers that the structure of the atrium be designed such that it would not cause any torsional load on the rest of the building. The columns on the fifth story are made of tube steel with the typical size being TS 12x12x5/8. Steel was also employed in the design of the roof structure that houses the building's mechanical equipment. The typical steel column in this area is a TS 4x4x4 ¼. The irregularity of the steel roof structure lends itself to atypical beam and girder sizes. They range from W 10x12 to W 30x132. There also are a few steel columns in the main structure.

Almost all of the remaining portions of the structure are made of concrete. The columns are continuous cast in place reinforced concrete. The typical columns are 24 inches square and are on an average grid of 30 feet by 30 feet. The columns do not taper towards the top, however, the amount of reinforcement can vary. The shape of some columns varies. On certain floors, columns have a diameter of 24 inches instead of a width of 24 inches. Supporting Campus Drive, the turnaround, and the entrance plaza, under which the building extends, is an area of the building which uses cast in place reinforced concrete. The average beam is 24 inches wide by 30 inches deep.

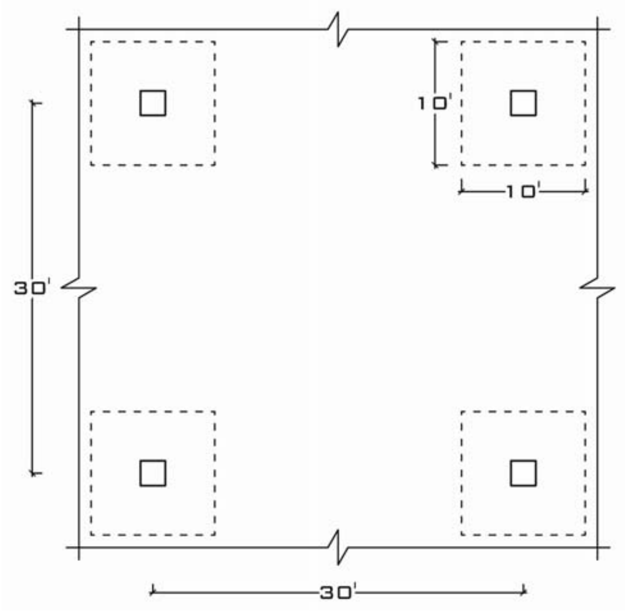


Figure 1: Typical Existing Floor Bay

Structural Slabs

The floor system of Arnold Building is mainly composed of two way post-tensioned concrete floor slabs. The slab in the basement is not post-tensioned but instead is made of fiber reinforced concrete. The portion of the building that is under the entrance plaza uses reinforced concrete slabs. The roof slab is composed of reinforced concrete. With the noted exceptions, the typical floor system is a flat post-tensioned concrete slab with drop panels.

Lateral Force Resisting System

Braced Frames

The upper levels of the structure resist lateral forces by braced frames. These upper levels are the Mechanical/ Lower Roof Level, the Penthouse Level, the Penthouse Roof, an elevator overrun, and the Penthouse Level Mechanical Room Enclosure. The braced frames are typically constructed of rectangular HSS sections. All of the braced frames start at or above Level 5. Both chevron braces (inverted V braces) and X braces are used in the current design.

Shearwalls

The main lateral force resisting system is composed of reinforced concrete shear walls. These walls range from 20 to 24 inches thick. Many of these walls require boundary element reinforcing for the compression zones. Due to obstructive nature of concrete walls many of them have significant openings; some reduced completely to boundary element piers. These openings are necessary for both pedestrian and vehicular traffic flow through the parking garage on the lower levels.

Proposed Alternative

Following the examination of the existing building an alternative structural design was proposed. The above ground portions of the building would be redesigned using steel framing. The intention of changing the above grade building to steel would be to reduce the mass of the building. Additionally the implementation of steel framing would hopefully lead to a more rapid construction schedule; something that lifts of concrete does not facilitate. The Plaza and the parking garage areas, which are primarily at or below grade, would remain unchanged from the original structure. Here height restrictions for vehicle clearances dictate that a thin floor plate be used. The post-tensioned concrete floors used here accommodate the need for a slim superstructure. The Plaza area was suggested to remain the existing reinforced concrete design due to the significant loads imparted by the concrete planters, trees and shrubs, and the private road.

Alternative Structural Design

Gravity Design

Applied Loads

The applied live loads and dead loads may be found in Table 1 and Table 2 respectively. The structural drawings specify that Level 2 through Level 4 shall have non reducible live loads. The purpose of no live load reduction is to ensure that the floor meets the required capacity for the offices filing systems.

Table 1: Live Loads

	LOAD [PSF]			
LOAD DESCRIPTION	**DWGS**	**ASCE 7**	**RAM**	**NOTES**
Roof (flat)	25	20	20	
Promenade Purposes	-	60	60	
Roof Gardens or Assembly Purposes	-	100	100	
Floors				
Offices	100	100	100	80 + 20 psf for partition loads
Levels 1 - 4	75	50	75	NON-REDUCIBLE for Filing System (File Rooms Based on Anticipated Occupancy)
Laboratories	100	-	100	
Interstitial	25	20	25	(not denoted as LL on DWGS) (ASCE - "Storage areas above ceilings")
Corridors & Stairs	100	100	100	
Parking Floor	50	40	50	
Sidewalks & Driveways	250	250	250	
Catwalks & Maintenance Access	-	40		
Corridors Above First Floor		80		
Offices		50		
Awning & Canopies (non fabric)		20		NON REDUCIBLE
Walkways & Elevated Platforms		60		(other than exit ways)
Yards & Terraces, Pedestrian		100		

Table 2: Dead Loads

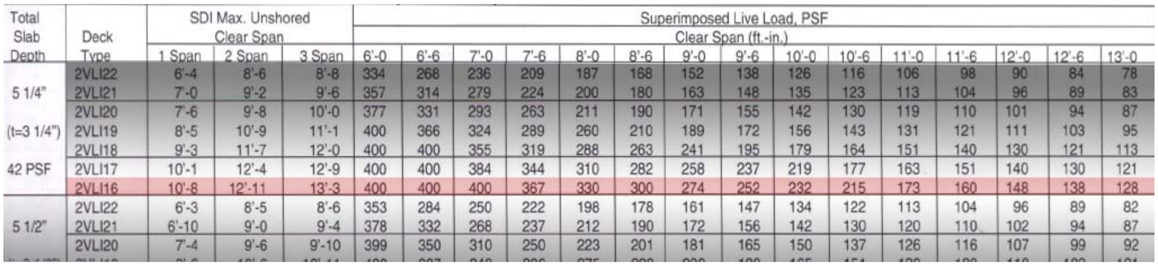
	LOAD [PSF]			
LOAD DESCRIPTION	**DWGS**	**ASCE 7**	**RAM**	**NOTES**
Superimposed Dead Load	-	-	20	
ALL OTHERS	-	-	-	Use Applicable Self Weight

New Gravity Design

The alternative design of Arnold Building was completed using Bentley's RAM Structural System. The gravity design of floor framing members was chosen to be primarily composite beams. For convenience a typical floor plan has been included here, however, for legibility member sizes and shear stud lay outs have been omitted. More complete structural framing plans have been included in the appendices.

In order to minimize the impact on the architectural design the locations of columns are almost identical to that of the original concrete design; however, one area of the building required the addition of a column. The long span created by the changing geometry and orientation of the bays resulted in an excessively large beam design. In order to have a more efficient structure a new column was added. The column has minimal impact on the architectural design of Arnold Building. On certain levels it falls in the corner of an office. The column is discontinued at level 1, where it would fall in the middle of the loading dock area.

Multiple variables were considered when a metal deck was to be chosen for the new steel framing system. The most critical factor is the load capacity, however, most of the available metal deck choices were sufficient for the loading conditions. With a standard live load for the office areas being 75 lb/ft^2, a 20 lb/ft^2 partition allowance, and a superimposed dead load of 20 lb/ft^2 the total load was 105 lb/ft^2. Of primary concern at the time of this particular design was the allowable unshored span, for constructibility reasons. The 2 VLI composite metal decking was chosen from Vulcraft's Roof and Floor Decking Catalogue as shown in Figure 2. In addition to this, fire ratings of the floor assembly were kept in mind. The 3 ¼ inch of lightweight concrete slab above the ribs of the deck provided sufficient amount of fire resistance.



Total Slab Depth	Deck Type	SDI Max. Unshored Clear Span			Superimposed Live Load, PSF Clear Span (ft.-in.)														
		1 Span	2 Span	3 Span	6'-0	6'-6	7'-0	7'-6	8'-0	8'-6	9'-0	9'-6	10'-0	10'-6	11'-0	11'-6	12'-0	12'-6	13'-0
5 1/4"	2VLI22	6'-4	8'-6	8'-8	334	268	236	209	187	168	152	138	126	116	106	98	90	84	78
	2VLI21	7'-0	9'-2	9'-6	357	314	279	224	200	180	163	148	135	123	113	104	96	89	83
(t=3 1/4")	2VLI20	7'-6	9'-8	10'-0	377	331	293	263	211	190	171	155	142	130	119	110	101	94	87
	2VLI19	8'-5	10'-9	11'-1	400	366	324	289	260	210	189	172	156	143	131	121	111	103	95
	2VLI18	9'-3	11'-7	12'-0	400	400	355	319	288	263	241	195	179	164	151	140	130	121	113
42 PSF	2VLI17	10'-1	12'-4	12'-9	400	400	384	344	310	282	258	237	219	177	163	151	140	130	121
	2VLI16	10'-8	12'-11	13'-3	400	400	400	367	330	300	274	252	232	215	173	160	148	138	128
5 1/2"	2VLI22	6'-3	8'-5	8'-6	353	284	250	222	198	178	161	147	134	122	113	104	96	89	82
	2VLI21	6'-10	9'-0	9'-4	378	332	268	237	212	190	172	156	142	130	120	110	102	94	87
	2VLI20	7'-4	9'-6	9'-10	399	350	310	250	223	201	181	165	150	137	126	116	107	99	92

Figure 2: Floor Deck Selection

Typical Bay Design

A typical bay in the building is 30 feet by 30 feet, with beams spaced 10 feet on center. A manual spot check was completed for a bay on Level 1 as noted on the plan in Figure 3. The beams are W16x31 and W12x14 and span 31 ½ ft and 20 ft respectively. The girder that carries these beams is a W21x55 and is supported by W10x68 columns.

Figure 3 – 1st Floor Framing

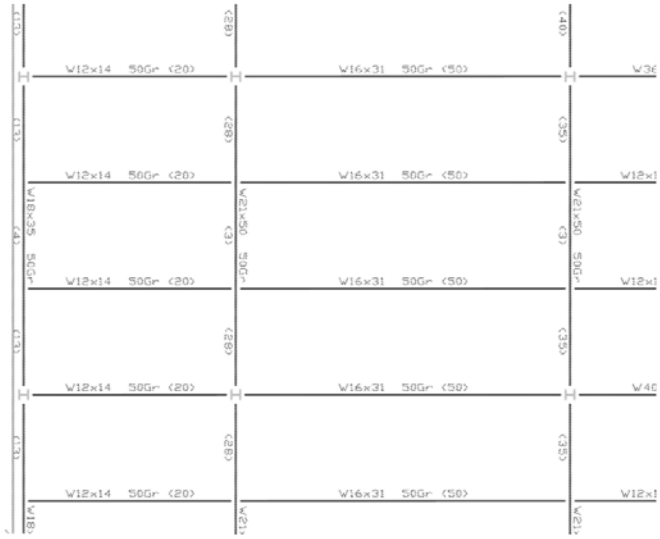


Figure 4 – Gravity Check: Selected Bay Plan

Beam Design

The beams were designed as composite members. The thickness above the steel deck is 3 ¼ inches. Two beams were manually checked. The first was one with the typical span of 30 feet. The calculations for designing this particular beam are shown in Figure 5. The resulting design was a W16x26 that is smaller than the one designed by RAM's beam module. Using the view update command in the beam module and manually assigning the beam design from the manual calculation reveals that this design would fail to meet the deflection criteria.

Following the previous verification a beam spanning twenty feet was checked. The calculations for this beam may be seen in Figure 6. The resulting design was a W12x14, which is the same size that RAM Structural System produced. This also happens to be the lightest possible shape for the given design conditions .

[BEAM 1]

span = 31.4 ft tributary width = 10 ft

DL: 62 lb/ft² → DL: 620 lb/ft
LL: 75 lb/ ft² → LL: 750 lb/ft

$$R_{DL} = \frac{(620\frac{lb}{ft})(31.5\,ft)}{2} = 9765lb = 9.77kip$$

$$R_{LL} = \frac{(750\frac{lb}{ft})(31.5\,ft)}{2} = 11813lb = 11.81kip$$

$$M_{DL} = \frac{(620\frac{lb}{ft})(31.5\,ft)^2}{8} = 76{,}899\,ft \cdot lb = 76.9\,ft \cdot kip$$

$$M_{LL} = \frac{(750\frac{lb}{ft})(31.5\,ft)^2}{8} = 93{,}023\,ft \cdot lb = 93.0\,ft \cdot kip$$

M_{D+L} = 76.9 +93.0 = 169.9 ft·kip

b_{eff} = ¼ span = 7.875
b_{eff} = spacing = 10 ft ∴ use b_{eff} = 7.875 ft = 94.5 in

assume 9 = 1″ ∴ Y_2 = 3 – ½ = 2.5 in

Try W16 x 26 w/PNA @ BFL

ΣQ_n= 194 kip $\frac{M_p}{\Omega_b} = 173\,ft \cdot kip$

a = ΣQ_n / (0.85)(fc)(b_{eff}) = 194 / (0.85)(3)(94.5)

a = 0.805 < 1 ∴ assumption of a = 1″ ok

Figure 5: Gravity Check – Beam 1

[BEAM 2]

span = 20 ft tributary width = 10 ft
DL: 620 lb/ft LL: 750 lb/ft

$$R_{DL} = \frac{(620\frac{lb}{ft})(20\,ft)}{2} = 6200lb = 6.2kip$$

$$R_{LL} = \frac{(750\frac{lb}{ft})(20\,ft)}{2} = 7500lb = 7.5kip$$

$$M_{DL} = \frac{(620\frac{lb}{ft})(20\,ft)^2}{8} = 31{,}000\,ft \cdot lb = 31.0\,ft \cdot kip$$

$$M_{LL} = \frac{(750\frac{lb}{ft})(20\,ft)^2}{8} = 37.5\,ft \cdot lb = 37.5\,ft \cdot kip$$

M_{D+L} = 68.5 ft·kip

b_{eff} = span/4 = 20/4 = 5 ft
b_{eff} = spacing = 10 ft ∴ use beff = 5 ft →60 in

assume a = 1″ ∴ Y_2 = 2.5

Try W12x14 w/PNA @ 6

ΣQn = 85.2 $\frac{M_p}{\Omega_b} = 70.4\,ft \cdot kip$

a = 85.2/(0.85)(3)(60) = 0.557 OK

W12x14 → Same as RAM Design

Figure 6: Gravity Check – Beam 2

Girder Design

Once the designs of the beams were verified a manual check of the girder was completed. The self weights of the beams designed by the engineering software were used. Since the beams were spaced 10 feet apart, the girder in question was subjected to third point loading as is depicted with the composite design calculations in Figure 7. The manual design resulted in a W18x55, while the computer model generated a W21x50. To achieve the required moment capacity 359 ft·kips, the W21x50 has a lower ∑Qn than the W18x55. Ultimately this would result in few shear studs, additionally the computer design has resulted in a more efficient structural member than the manual calculation. The optimization of the design is important to acknowledge because it reduces cost by using less material, helps to minimize the self weight of the structure, and ultimately can result in a lower building mass for seismic loading conditions.

[Girder 1]

Loads

	[BEAM 1]	[BEAM 2]
P_{DL}	9.765 kip	6.2 kip
P_{LL}	11.813 kip	7.5 kip
P_{selfwt}	(.031)(31.5)/2 =0.488	(0.014)(20)/2 = 0.14 kip

P_D = 16.593 kip
P_L = 19.313 kip
$R_{D+L} = (P_D + P_L)^2\ /2 \rightarrow 35.906$

$M_{D+L} = (10\text{ ft})\ (P_D + P_L)$
= (10 ft) (16.953 +19.313)
= 359.06 ft kip

$b_{eff}/2$ = Span/8 = 30 ft/8 = 3.75 ft

$$b_{eff}/2 = \text{Spacing}/2 < \begin{matrix} 20/2 = 10\text{ ft} \\ 31.5/2 = 15.75 \end{matrix}$$

∴ b eff = 2(3.75 ft) = 7.5 ft = 90 in
assume 9 = 1″ ∴ Y2 = 3 – 0.5″ = 2.5″

Try W18 x 55 w/ PNA 7
ΣQn = 202 kip Mp/Ωb = 369

a = 202/(0.85)(3)(60) = 0.880

a = 1″ assumption OK

Figure 7: Gravity Check Girder 1

Column Design

The loads for the column were taken down using the column's tributary areas multiplied by the applicable loads. The typical floor to floor height in the building is 12.25 feet. Using an effective length factor (k) of 1.0 the resulting KL was 12.25. For simplicity the conservative value 13 was used in the ASD compression members table. These calculations are shown in Figure 9. The design resulted in a W10x68. This design matches that of the column module in RAM structural system.

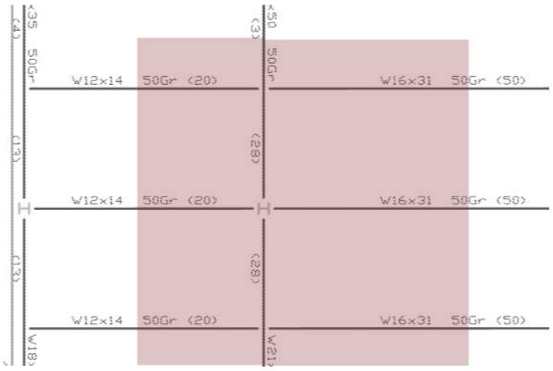


Figure 8: Gravity Check: Column Tributary Areas
[COLUMN DESIGN]

(300) (2) + (5) (472.5)
600 + 2362.5 = 2,962.5 ft 2

(2,962.5 (75 +62))/1,000 = 405,863
From table → W10 x 68 w40?
P_{RAM} = 419.14

Figure 9: Gravity Check: Column Calculations

Laboratories

The fifth floor of Robert M. Arnold Building houses laboratory facilities. It was not the primary concern of this report to analyze floor vibrations for these labs. The existing design of the facility calls for a 13 inch reinforced concrete slab, which is 4 ½ inches deeper than typical of 8 ½ inches post-tensioned floor plate. It may be deduced that the increased slab design was due to the different design requirements of the laboratory facilities compared to the offices of the majority of the building. While a qualitative analysis does not conclusively attribute the change in slab thickness to floor vibrations it raises the question. The information of the type of equipment for the lab and their tolerances for vibration were unable to be procured for the purpose of this project. As a result of these factors a preliminary analysis of a typical bay was completed to assess the floor system's susceptibility to walking induced floor vibrations.

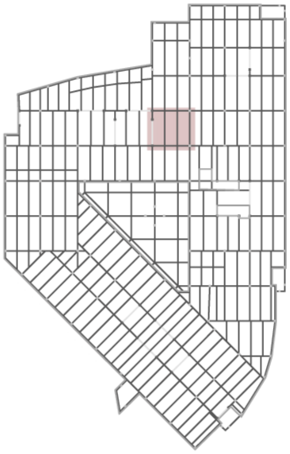


Figure 10: 5th Floor Framing

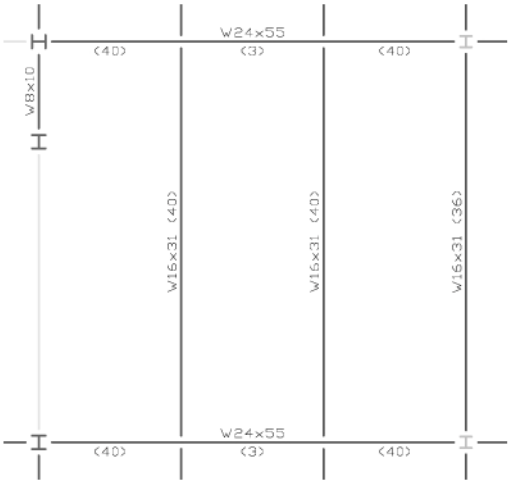


Figure 11: Vibration Analysis – Typical Bay

Typical Bay - Results of RAM Design

The structural design for Level 5 from RAM Structural System was used to assess the susceptibility of the floor system. A plan of the laboratory area is shown in Figure 10 with the area being analyzed highlighted.

Typical Bay – Vibration Analysis

The susceptibility of the floor system was determined in accordance with the procedure set forth in AISC Design Guide 11. While the calculations shown in Figure 11 demonstrate that the floor system is within the limit of 0.0005 it is fairly close to the limit. Since lab equipment can be more sensitive to vibration than human senses, a second more in depth analysis would be recommended

Table 3: Floor Vibration – General Information

Other Information	
floorwidth	240
floorlength	135
WLL	11
WSDL	4
beta	0.03

Slab Information	
wc	150
fc	3
tc	3.5
td	2
Wslab	54

Beam information	
Shape	W16x31
Ab	9.13
Ibx	375
db	15.9
wbb	31
Cj	2
lj	30
sj	10
bj	120

Girder Information	
Shape	W24X68
Ag	20.1
Igx	1830
dg	23.7
wgb	68
Cg	1.8
lg	30
sg	30

Table 4: Floor Vibrations – Joist & Girder Mode Properties

Joist Mode Properties		
de = tc+td/2 =	4.5	in
Ec = $w_c^{1.5} \cdot f'^{\,0.5}_c$ =	3181.98	psi
n = 29000/1.35Ec =	6.75098	
Bj/n =	17.7752	
Ac = (Bj/n)*tc =	62.2132	
Ybc = tc/2 =	1.75	
Ab =	9.13	
Ybb = db/2+tc+td =	13.45	
Ybar = $\frac{\text{Ac Ybc+Ab Ybb}}{\text{Ac+Ab}}$ =	3.24728	
Ij =	1528.37	in4
j = (bj/12)*(Wslab+WSDL+WLL)+wbb =	721	
Delta j = 5wl^4/384EI	0.29647	
fj = 0.18 (386.4/Delta j)^0.5	6.49836	
Ds = (de^3)/n	13.498	
Dj = Ij/sj	152.837	
Bj1 = Cj (Ds/Dj)^.25 *lj	32.7086	
Bj2 = 2(floorwidth/3)	160	
Bj = min (Bj1, Bj2)	32.7086	
Wj = ((wj/sj)*Bj*lj)/1000 =	70.7486	

Girder Mode Properties	
bg1 = 0.4 lg 12 =	144
bg2 = sg	360
bg = mi (bg1, bg2) =	144
bg / n =	21.33024
Ac1 = bg/n * tc =	74.65585
Ygc1 = tc/2 =	1.75
Ixc1 =	76.21118
Ac2 = bg/2n *td =	21.33024
Ygc2 = td/2 + tc =	4.5
Ixc2 =	7.110081
Ag =	20.1
yg = dg/2 +td+tc	17.35
Ix =	1830
YgBar = $\frac{\text{Ac1 Ygc1+Ac2 Ygc2+Ag Yg}}{\text{Ac1+Ac2+Ag}}$	4.956398
Ig =	5772.688
wg = (wj/sj)*sg*(4/3.1415)+wgb =	2822.098
Delta g = 5wl4/384EI	0.30723
lg/Bj =	0.917191
If Bj > lj adjust girder deflection p. 18 DG11	
~~Delta g2 = Delta g * (lg/Bj) =~~	~~0.281789~~
fg = 0.18 (386.4/delta g)^0.5 =	6.383506
Dg = Ig/sg =	192.4229
Bg1 = Cg (Dj/Dg)^0.25 lg =	50.97849
Bg2 = 2 floorlength/3 =	90
Bg = min (Bg1, Bg2) =	50.97849
Wg = (wg/sg)Bg*lg/1000 =	143.8663

Table 5: Floor Vibrations: Susceptibility

Vibration succeptability evaluation	
Wc =	107959
fn = 0.18(386.4/deltaj+deltag2)^0.5=	4.55388
ap = 65*e^(-0.35 fn) / (beta Wc)	0.00408
Ok if 0.0005 >	0.00408

Lateral Design

Applied Loads

Wind Loads

The wind loads were determined according to ASCE 7's Analytical Method (Method 2). The applied story forces for wind loading conditions are shown in both Table 6 and Table 7 for the principal building directions.

Table 6: Wind X - Direction

Level	Fx	Fy
	kips	kips
Level 5	343.73	0.00
Level 4	173.10	0.00
Level 3	166.67	0.00
Level 2	165.43	0.00
Level 1	172.68	0.00
Level D	155.40	0.00

Table 7: Wind Y - Direction

Wind: Y Direction

Level	Fx	Fy
	kips	kips
Level 5	0.00	283.91
Level 4	0.00	101.57
Level 3	0.00	97.07
Level 2	0.00	91.15
Level 1	0.00	114.65
Level D	0.00	100.12

Seismic Loads

The applicable method for determining the seismic loading according to ASCE 7 is the Equivalent Lateral Force Procedure. The building mass properties from RAM are displayed in Table 8. The method of analysis used in the computer model was the Equivalent Lateral Force Procedure. A manual calculation of this value was also completed in a spreadsheet. This verification is shown in Table 9. The applied seismic story forces generated by RAM are summarized in Table 10 and Table 11 for the X direction and the Y direction respectively. It should be noted in Table 9 that the resulting base seismic base shear is 3456 kips. This is significantly lower than the 5900 kips noted on the structural drawings.

Table 8: Building Mass Properties

Building Mass Properties							
Story:	Diaph #	Weight kips	Mass k-s2/ft	Xm ft	Ym ft	EccX ft	EccY ft
Floor_5	1	9218.8	286.30	196.63	180.65	12.07	19.05
Floor_4	1	4159.4	129.17	187.31	141.77	12.07	19.05
Floor_3	1	4835.2	150.16	188.41	142.40	12.07	19.05
Floor_2	1	5755.6	178.74	188.23	161.82	12.10	20.81
Floor_1	1	10536.8	327.23	143.42	209.32	14.67	20.81
Floor_D	1	13892.7	431.45	171.39	160.15	14.67	21.35
Floor_E	1	17296.5	537.16	163.48	173.14	14.67	21.35

Table 9: Equivalent Lateral Force Procedure

Site Class - B
T_L = 6
Ss = 1.25
Fa = 1.0
S1 = 0.50
Fv = 1.0

Sms = 1.25
SDS = 0.833
Sm1 = 0.50
SD1 = 0.333

Importance Factor
I = 1.0
Response Modification Factor [Table 12-2-1]
R = 5
Seismic Response Coefficient
Cs = 0.069

Fundamental Period
h_n = 102.54
Ct = 0.03
x = 0.75
Ta = 0.9666989

k = 1.9333979

Level	wi	h_x	$w_i h_i^k$	C_{vx}	Fx	Vx	Mx
LVL PH	552	102.54	4260063	0.053150	183.71	184	2082
LVL RF	1562	91.21	9619488	0.120017	414.84	599	6906
LVL ML	2209	85.04	11882350	0.148250	512.42	1111	28757
LVL 5	4897	73.50	19868752	0.247892	856.83	1968	76055
LVL 4	4178	61.25	11915261	0.148660	513.84	2482	153753
LVL 3	4835	49.00	8958513	0.111770	386.33	2868	266583
LVL 2	5844	36.75	6208445	0.077459	267.74	3136	417826
LVL 1	11535	24.50	5595315	0.069810	241.30	3377	610438
LVL D	14510	12.25	1842780	0.022991	79.47	3456	845391
	50121						

Seismic Base Shear

V = 3456 kip

Table 10: Seismic X - Direction

Seismic: X Direction

Level	Fx kips	Fy kips
Level 5	1518.65	0.00
Level 4	523.09	0.00
Level 3	436.97	0.00
Level 2	339.72	0.00
Level 1	354.2	0.00
Level D	161.31	0.00

Table 11: Seismic Y - Direction

Seismic: Y Direction

Level	Fx kips	Fy kips
Level 5	0.00	1580.29
Level 4	0.00	548.11
Level 3	0.00	461.78
Level 2	0.00	362.96
Level 1	0.00	384.32
Level D	0.00	179.71

New Lateral Design

The new lateral force resisting system for Arnold Building is composed of concentrically braced frames. For the purpose of simplifying the design process, the portion of the structure above Level 5 was lumped together with the mass at this floor. The purpose for grouping these together was due to the design limitations of RAM Structural system. Some of the braced frames located above level 5 are supported by non-frame members. In order to avoid errors in the design software, additional columns are required to be considered frame members. These additional members attract load that would be distributed to main framing members through the rigid action of the floor diaphragm. Certain braced frames above the fifth floor are not part of the main lateral system. These frames resist the lateral loads applied to mechanical enclosures, elevator over-runs, and stairway roofs that extend beyond main floor levels.

Initially, Ordinary Braced Frames were chosen for the design. Due to the lower response modification factor the lateral forces were significantly higher. As a result the forces in the columns of the braced frames rendered an interaction value >1. As the sizes of the columns were increased the lateral forces and the self-weight of the columns resulted in further unacceptable interaction values. Some of the columns that did work at this stage of design weighed upwards of 400 lbs per linear foot. Due to excessive self weight of the structure, the lateral force resisting system was changed to one of Special Concentrically Braced Frames. The response modification factor for Special Concentrically Braced frames is 5 compared to 3.25 of Ordinary Braced Frames. The higher value reduces the applied lateral forces. The costly connections of the chosen lateral system were considered, however, the excessive steel that would have been required for ordinary braced frames would have added significant construction costs also. One alternative that was briefly explored was the additional frame locations. The architectural design of the building would be greatly impacted by additional braced frames. No suitable location was found without having a significant impact on the floor plan; braces would cross through current corridors, conference rooms, etc. As a result the Special Concentrically Braced Frames were selected.

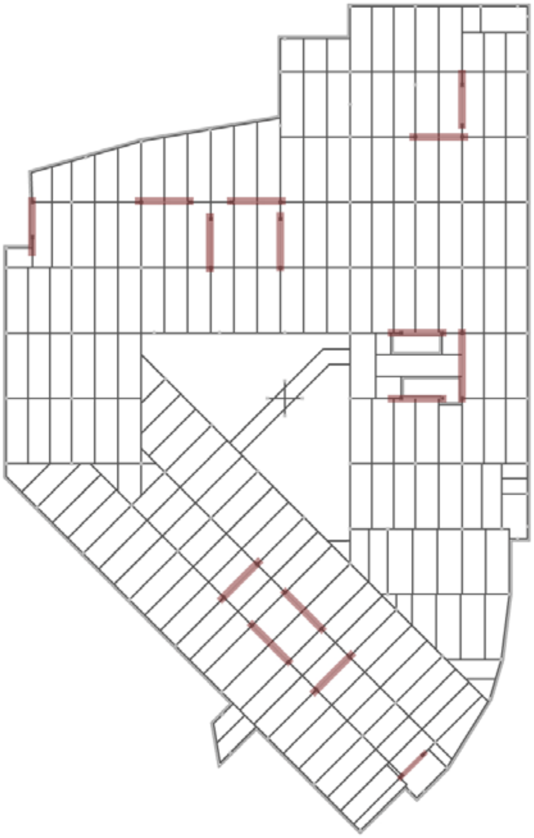


Figure 12: Braced Frame Layout

The new braced frames of Arnold Building are located where the original shear walls were located. Figure 12 shows a framing plan of Level 2 with the braced frame locations highlighted in red. The frames utilize X bracing to resist the lateral loads. The columns of the frames were designed as W14 shapes, while the braces were designed to be rectangular HSS shapes. The designs of the frames are summarized and may be found in Appendix 2.

Separate analyses were completed in RAM to determine whether the building drift due to lateral loading was within acceptable limitations. According to ASCE 7 the maximum drift ratio for both wind and seismic were within the acceptable limits. The analysis for drift incorporated the penthouse and roof structures that had been lumped down for the initial lateral design. For Arnold Building the serviceability did not control the design the lateral design

Construction Management

Cost Analysis

Cost Estimation of Proposed Alternative

In the alternative structural design of Robert M Arnold Building at the Fred Hutchinson Cancer Research Center the whole structure was not changed. Certain portions of the original design were kept, such as stairwell framing, the steel structure above the fifth floor, the spiral stair and footbridge in the atrium, and the lower levels that include the plaza and parking garage. Due to the nature of the changes in design to Arnold Building it was not necessary to carry out a complete cost analysis. The cost estimation of the alternative system was completed using MC2's Interactive Cost Estimating software. A summary of the steel design's cost is listed in Table 12. In addition to the summary shown here a cost estimate report generated by Interactive Cost Estimating can be found in Appendix 4. The cost of the additional steel framing for Arnold Building totaled to $2.6 million dollars.

Table 12: Cost Estimate Floor Summary

Cost Estimates by Level

Level	**Costs**
Columns	$ 302,703.42
Level One	$ 242,710.62
Level Two	$ 451,814.53
Level Three	$ 736,328.28
Level Four	$ 435,771.11
Level Five	$ 441,294.81
Total Estimate	$ 2,610,622.77

Comparison of Alternative Design to Existing Design

As a result of the sensitive nature of the cost estimate provided by Turner Construction, this report limits the comparison of the cost to the change in building cost. The alternative design of Arnold Building results in an additional $2.6 million dollars in steel costs. This increase also includes concrete cost for the composite slab system. While a decent amount of steel construction costs were added, they result in a reduced scope of concrete work. With the appropriate concrete work removed from the project estimate, the alternative steel design results in a $1.8 million cost savings.

Green Roof Retrofit

The Fred Hutchinson Cancer Research Center is proud of its devotion to the environment; listing its efforts to improve the center's impact on the local environment on its website. The Fred Hutchinson Cancer Research Center rightfully boasts more than 25 awards for commitment and devotion to "a healthy environment." This commitment toward new eco-friendly development should be extended to the realm of retrofit and renovation.

Located in downtown Seattle, FHCRC is in a community devoted toward reducing the negative impacts development has on the environment. Seattle's Department of Planning & Development is constantly encouraging developers and building owners to employ best management practices regarding ecological impact. Through publications and legislation the planning board is trying to reduce the negative effects of stormwater runoff. An article titled Seattle Innovations in Stormwater Management provides alternatives to conventional development practices which improve runoff by reducing the total amount of impervious surfaces. While this particular document focuses on roads and parking lots it demonstrates the City's acknowledgement of stormwater runoff as a significant problem.

Both the City of Seattle and the Fred Hutchinson Cancer Research Center have openly declared their commitment to the environment. They each have recognized the ecological effects of development and they each have taken appropriate courses of action. The combination of FHCRC's & the City of Seattle's devotion to the environment make the campus a prime candidate for the promotion of green roof technology as a stormwater management practice.

Eco-Roofing Technology: A solution to urban ecology

There are endless varieties of green roofs. The three main types of green roof systems are extensive, semi-intensive, and intensive. Extensive green roofs have minimal growing medium approximately four inches thick; allowing for minimal roof system depth. Hearty plants such as sedums are typically used in this type of construction. Intensive green roofs are significantly deeper; typically used for roof garden applications. The third category, semi-intensive, has depths varying between the two previous types.. Both intensive and semi-intensive applications have significantly more maintenance, cost, and structural implications. For the Fred Hutchinson Cancer Research Center extensive and intensive applications will be explored. The potential applications of these two systems are illustrated by the roof plan in Figure 13. The roof area accessible and viewable by the existing roof terrace is the only location where there would be additional benefit through the use of an intensive green roof system. As noted in Figure 13 it is not feasible to green the entire roof of Robert M. Arnold Building. Some sections, such as stairwell roofs, provide small areas that are difficult to access and ultimately harder to maintain. Other portions of the roof deemed impractical for roof greening include mechanical equipment enclosures, and skylights.

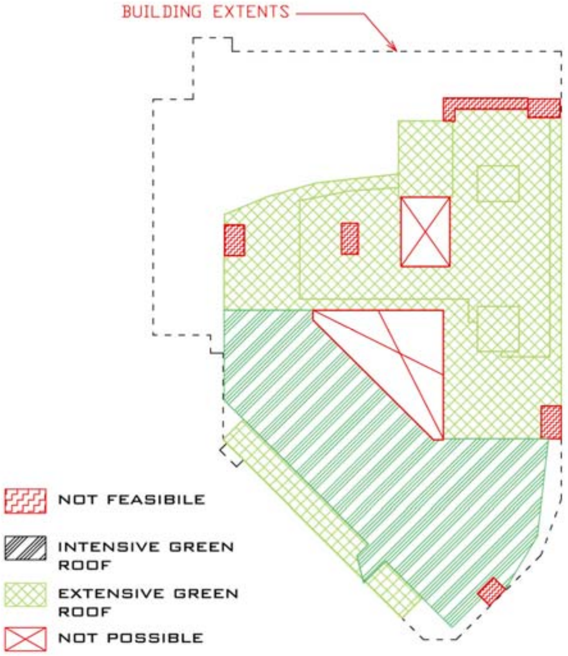


Figure 13: Potential Green Roof Layout

A green roof design was proposed as a retrofit to the existing structure. At some point in time the existing roofing will need to be replaced. Green roofing technology is a rapidly growing industry. The benefits of planted roofs are numerous. They help to retain and detain rainwater during storm events. The evapo-transpiration process that occurs in the plant material helps to actively cool the roof surface through evaporative cooling. This reduction in roof temperature has the secondary effect of helping to reduce the urban heat island effect. The urban heat island effect has been noted to contribute to changes in local/ micro climates. Additional benefits of having a green roof are the positive influence it has on building occupants and their neighbors. A green roof can help to provide an oasis in the urban desert when the roof is accessible to occupants.

All types of green roofs consist of four main components aside from plants. The first layer is made of a waterproofing membrane. This membrane is present in every type of roof construction and is not limited to green roofs. One particular advantage a green roof provides is a lifetime of approximately 50 years; almost 5 times greater than a typical asphalt roof. This longevity is greatly due in part to the roof membrane's protection from the sun's ultraviolet rays. The second layer of a green roof is a root barrier protecting the membrane from potential aggressive plant roots. Above this is the drainage layer allowing excess water to freely flow and drain below the plants. The fourth and final layer is the growing medium. Growing medium composition is greatly dependent upon plant selection, however, it typically is more mineral (sand & gravel) based with a limited amount of organic material.

Implementing a green roof system provides multiple benefits both to building occupants and the environment. One such benefit is mitigation of the urban heat island effect. The urban heat island effect is the tendency of more metropolitan areas to have a higher average temperature than surrounding rural areas. Rising temperatures of urban areas can directly impact local, and potentially global, weather patterns and environments. Green roofs radiate significantly less heat than asphalt roof systems. The plants of the green roof also actively cool the roof through the process of evapo-transpiration; the cooling effect felt by a person sitting under a tree. The release of water by plants cools the air through the process of evaporation .

Green roofs also significantly improve the effects of stormwater runoff. During storm events water collected by a roof is shed by downspouts and gutters; the ease with which typical roofs drains leads to the largest rate of rainfall to coincide with the largest rate of runoff. Stormwater runoff must be managed either by the environment of the site, or more often storm sewers. Green roofs are able to both detain and retain rainwater; allowing for peak roof runoff to be offset from peak rainfall. Peak runoff can be delayed as much as 2 hours after peak rainfall. By spreading out the demand what would normally require a larger sewer could be managed by a smaller sewer system. Additionally this offset relieves natural methods of drainage, which could reduce flooding caused by rapid soil saturation. The offset in runoff of a green roof allows the soil to drain before having to absorb the runoff from building rooftops. Chemicals, dirt, and other debris are collected as stormwater runs off; ultimately polluting waterways. Green roofs provide positive impacts for both pollution and stormwater management.

Green Roof Design

Architectural Design

Existing Roof Design

Each method of roof construction has its own specific requirements. Both ballasted and green roof systems require insulation, and water proofing membrane. A conventional roof system also requires the ballasting material. Green roofs do not require ballast due to the additional weight of materials above the membrane. A green roof does however require other materials; soil medium, plants, drainage layer, and a root barrier.

Ballasted roof construction is a typical choice for low slope roofing applications. The two main components of a ballasted roof system are the roof membrane and the ballasting material. The ballasting material serves to hold the membrane in place against wind and other forces which may cause uplift. Gravel or pavers are the two most common materials used for the ballast. Pavers are typically used for terrace or parking applications. In commercial applications a built up membrane is used. A built up roofing membrane typically includes one or two layers of rigid insulation, roofing felt and aggregate impregnated asphalt. Proprietary roof constructions may use a poly-vinyl-chloride based membrane instead of an asphalt based one.

Green Roof Replacement Design

The existing roof membrane on Arnold Building is EPDM. This is a suitable water proofing membrane for green roof construction. Hyrdotech's Gardendrain GR 30 would be used for the drainage layer just above a root barrier. This drainage layer when filled with media can retain up to 0.18 gals/ft^2. The Product Data Sheet for GR 30 may be found in Appendix 6. The growing medium selected for this project would be a Rooflite Extensive MC by Skyland USA. This product meets the Forschungsgesellschaft Landschaftsentiwicklung Landschaftsbau (FLL) Guidelines for green roof construction. This mixture is specially engineered with minimal organic content. Complete product specifications are included in Appendix 7. For planting material a sedum mixture is recommended because of its draught tolerance. While Seattle is known for its rain, these plants require little maintenance and if there is a dry spell owners would not have to be concerned with irrigating their roof.

Stormwater Runoff Analysis

The potential impact of a green roof on stormwater runoff is important. The American Society of Civil Engineers Guidelines of Urban Stormwater Systems provides the Rational Method for predicting the amount of runoff for a given area. The runoff coefficient provides an adjustment based on surface conditions such as urban, suburban, and rural areas. It does not provide an exact or comprehensive method for assessing the rate of runoff. The benefits of green roofs can be ascertained by the comparison of calculations for a typical roof and a lawn with sandy soil as shown in Table 13.

Table 13: Runoff Analysis
Standard Guidelines for the Design of Urban Stormwater Systems
ASCE/EWRI 45-05

Q_p - peak discharge in cfs
C - runoff coefficient
I - rainfall intensity in inches per hour
A - drainage area in acres
K - conversion factor 1.0 (cfs-hr/ac-in)

Rational Method Roof Area: 63750 ft^2

Typical Roof

C = 0.95
I = 1 in/hr
A = 1.463499 acres
K = 1 (ft^3/s)-hr/ac-in

Q_p = KCIA
= 1.390324 ft^3/s

Lawns

C = 0.10
I = 1 in/hr
A = 1.4634986 acres
K = 1 (ft^3/s)-hr/ac-in

Q_p = KCIA
= 0.1463499 ft^3/s

Drainage Analysis & Scupper Design and Assessment

All flat and low slope roofs must be designed to drain water collected during a storm event. As mentioned previously the total roof runoff and the rate of run off are typically less for green roofs than ballasted roofs. In a sustained storm event the peak rate of runoff, drainage can equal that of normal roofs. As a result drainage systems of green roofs cannot be designed for a reduced amount of rainfall.

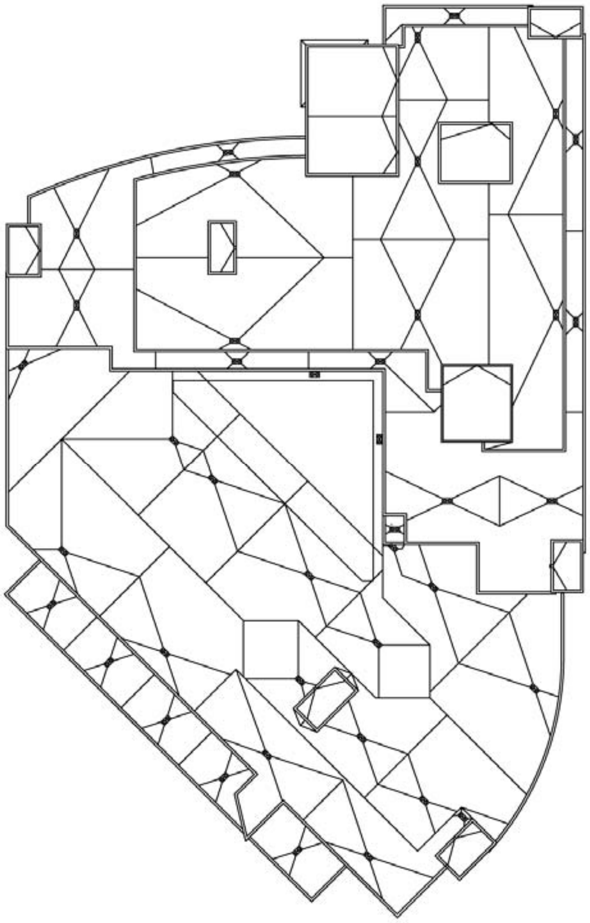


Figure 14 – Roof Drainage Layout

The design rainfall for this particular site is 1 inch / hour. The rainfall areas were calculated based on the full projected roof areas and the adjusted vertical wall areas (0.35 for two adjoining walls, and 0.5 for all other wall conditions). Certain roof sections drain onto adjacent roofs; using scuppers as opposed to leader pipes brought into the building. Such conditions typically occur above stairways, and enclosed rooftop mechanical rooms. These areas were added to the primary drainage area for sizing leaders. A roof drainage plan of Arnold building is shown in Figure 14 (this figure neglects the plaza and turnaround located on level one). Table 14 shows a summary of the roof leader quantity and size, drainage area, and drainage rate for the entire roof. A more detailed summary of the roof areas and leader sizes is provided in Appendix 8 with corresponding drain marks to roof surface areas in Appendix 7.

Table 14: Roof Drainage Summary

Roof Drainage Summary			
Total Drainage Area:		76,425.33	ft^2
Design Rainfall:		1	inch/hour
Total Drainage Rate:		19	gpm
Leader Size		**Qty**	
2	inch	28	
3	inch	14	

Assessment of Structural Impact

The current roof system of Arnold Building is a type of ballasted roof system. The structural system was designed to support the loading conditions for an EPDM roofing membrane with gravel ballast. A portion of the structure, on the fifth floor, was designed for the additional load of the roof terrace and its anticipated occupants. No strengthening of the structure would be required since its weight was accounted for in the initial design of the building.

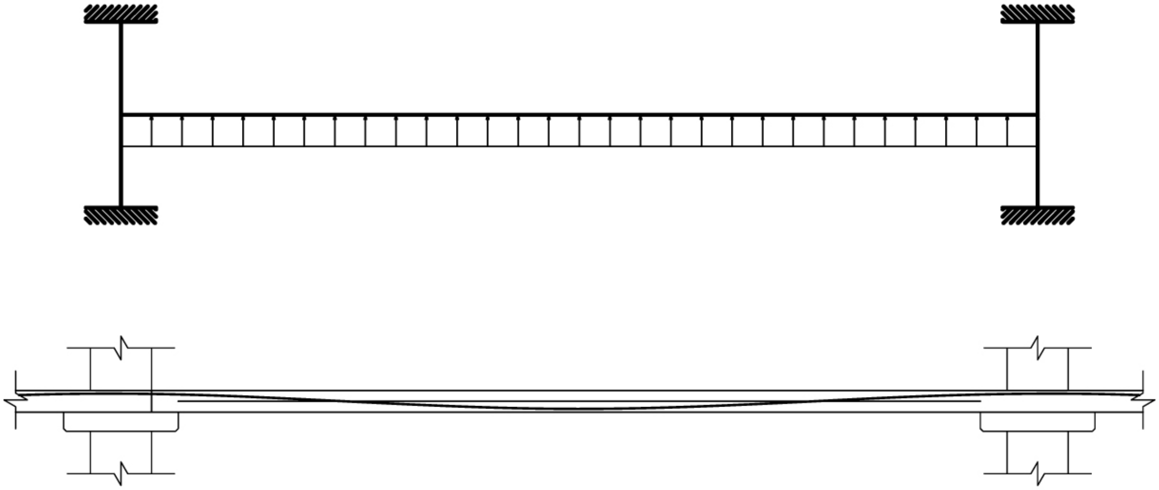


Figure 15 – Load Balancing of Post-Tensioned Slab

Analysis of Existing Roof Structure

The floor system of Arnold Building is mainly composed of two way post-tensioned concrete floor slabs. The slab located at the fifth floor is of this type of construction. Level Five is where an intensive green roof system may be able to be used, however, for the purpose of this investigation an extensive green roof will be designed. The 8 1/2 inch depth of the floor slab, and frequency of high capacity supporting elements make it the most practical location for this heavier type of construction. Additionally, the roof terrace is located on this level; giving greater accessibility to building users. A preliminary assessment of the floor system has shown that the current capacity is 153 lbs/ft per foot of slab width. This was determined based on the load balancing method for post-tension concrete members. Building code requirements require a 100 lb/ft2 of live load capacity for roof surfaces intended for human occupancy. If planting materials are limited to approximately 80 lb/ft2; strengthening of the structure could potentially be avoided.

The roof areas located above the fifth level are composed of steel framing. The roof system is designed to accommodate 50 lb/ft2 of loading. This is not a sufficient capacity for an intensive green roof design. An intensive green roof has no additional benefits compared to an extensive roof because access in these locations is limited to maintenance personnel. The current capacity would be pushed to its limit with the addition of an extensive green roof.

Construction Management of Green Roof Retrofit

Cost Estimation of Retrofit

The potential of installing a green roof retroactively on Arnold Building would ultimately be based upon a cost analysis. To estimate the cost of replacement RS Means Renovation and Maintenance Cost Data was used. First a replacement roof similar in nature to the existing roof was calculated. Second a green roof design was estimated. Some of the labor tasks here had to be adapted. Looking at Table 15 the cost for medium placement was adapted from the similar task of hand placed soil. Demolition of the existing roofing membrane was included in both cases. The costs of estimation of the square foot costs for the green roof match that of completed projects of similar construction.

Table 15 – Green Roof Cost Estimate

	BARE COSTS				TOTAL
	MAT.	LABOR	EQUIP.	TOTAL	INCL O&P
Demo					
Gravel Ballast Removal		0.73		0.73	1.21
Roll Roofing, Cold Adhesive		0.20		0.20	0.32
Replacement of Existing					
EPDM, Plain 45 Mils Thk	1.03	0.88		1.91	2.71
W/ Stone Ballast	0.07	0.13		0.20	0.31
Total Replacement Cost	1.10	1.94		3.04	$ 4.55
Demo					
Gravel Ballast Removal		0.73		0.73	1.21
Roll Roofing, Cold Adhesive		0.20		0.20	0.32
Green Roof					
EPDM, Plain 45 Mils Thk	1.03	0.88		1.91	2.71
Medium (Furnish & Place)	0.45	0.06		0.51	0.63
Plants	0.26	0.56		0.82	1.06
Drainage Layer	0.12	0.56		0.68	0.54
Total Replacement Cost	1.86	2.99		4.85	$ 6.47

Roof Area:	*55,589*
Typical Roof Replacement	$ 253,000
Green Roof Replacement	$ 360,000

After examining the costs of demolition and installation a rough life cycle cost analysis was completed. Looking at a fifty year period, the average lifetime of a green roof, a typical roof may need to be replaced approximately three times. Table 16 shows comparison of the long-term costs of the different types of roof construction. For an institution, such as the Fred Hutchinson Cancer Research Center, with a well established campus a green roof might prove to be a wise decision when it comes to managing their facilities.

Table 16 – Green Roof Life Cycle Comparison

Over 50 year period						
3 Typical Roof Installations	3 @	$	253,000	=	$	759,000
1 Green Roof Installation	1 @	$	360,000	=	$	360,000

Summary & Conclusions

The Robert M. Arnold Public Sciences Building is part of the Fred Hutchinson Research Center in Seattle, Washington. After analyzing the existing building, a structural alternative using steel framing above grade was proposed. In recognition of FHCRC's and the city of Seattle's commitment to promoting a "healthy environment", an exploration of the Arnold Building as a candidate for green roof technology was considered.

The alternative design of Arnold Building was completed using Bentley's RAM Structural System. Composite beams were primarily chosen for the gravity design of floor framing members. Choosing a metal deck for the new steel framing system required that multiple variables be taken into account, the most important being load capacity. Manual verification of framing members was carried out and compared to those generated by the computer model. Wind loads and seismic loads were determined according to ASCE 7, using the Analytical Method and Equivalent Lateral Force Procedure respectively.

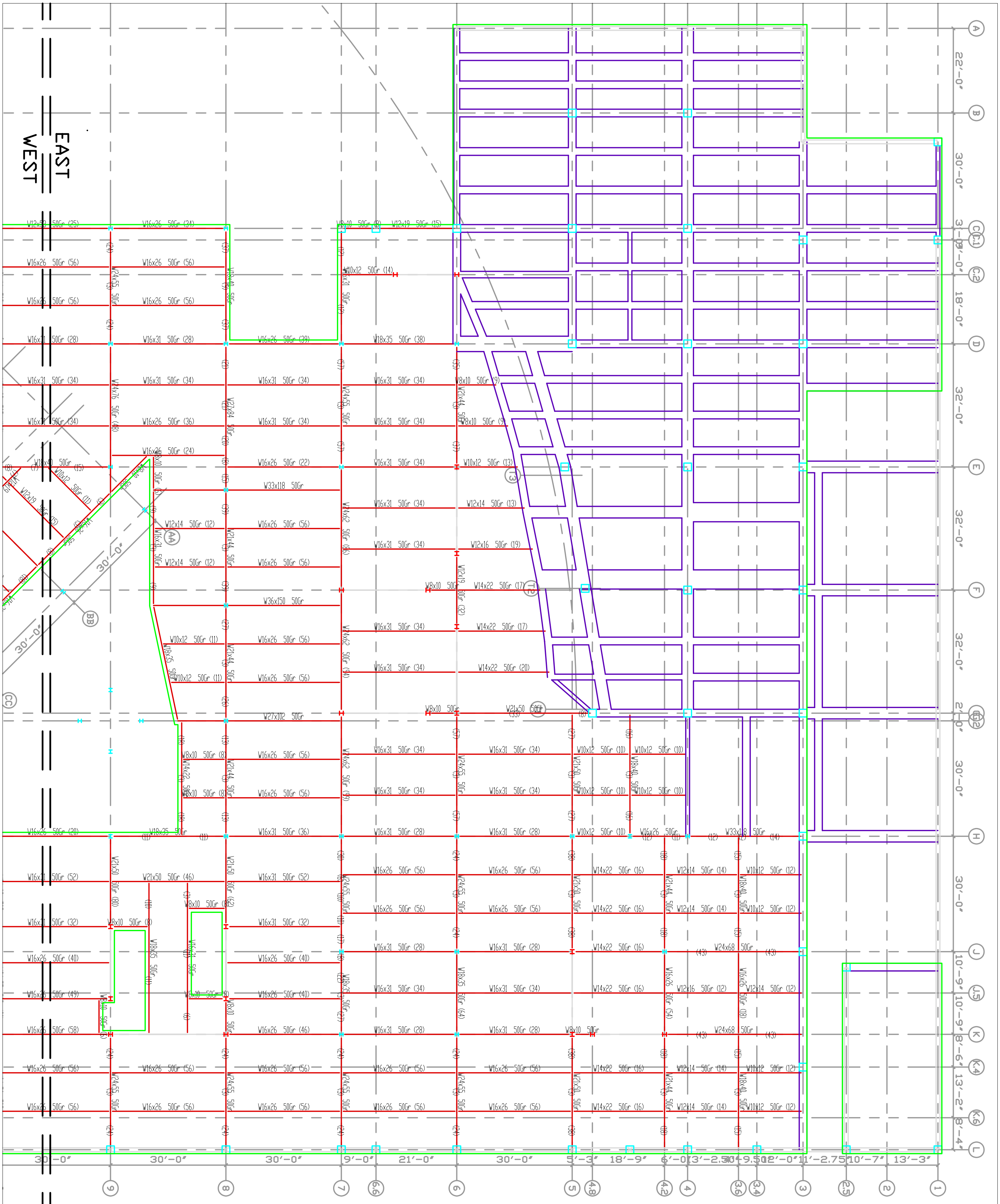
The new lateral force resisting system for Arnold Building uses special concentrically braced frames. Ordinary Braced Frames were chosen initially however, this resulted in significantly higher lateral forces. This required changing the lateral force resisting system to one of Special Concentrically Braced Frames. The alternative structural design of Arnold Building resulted in significantly lower seismic force; supporting one of the premises behind the proposal. A limited cost estimation of the alternative system was completed using MC2's Interactive Estimating Software. A cost savings of $1.8 million dollars would be possible with the alternative steel structure.

The combination of FHCRC's and the city of Seattle's devotion to the environment make the campus a prime candidate for the promotion of green roof technology as a stormwater management practice. A green roof was proposed as a retrofit to the existing structure. In conclusion the Center may want to consider choosing an extensive green roof system for the next time they replace the roof on Robert M. Arnold Building.

APPENDIX

Appendix 1

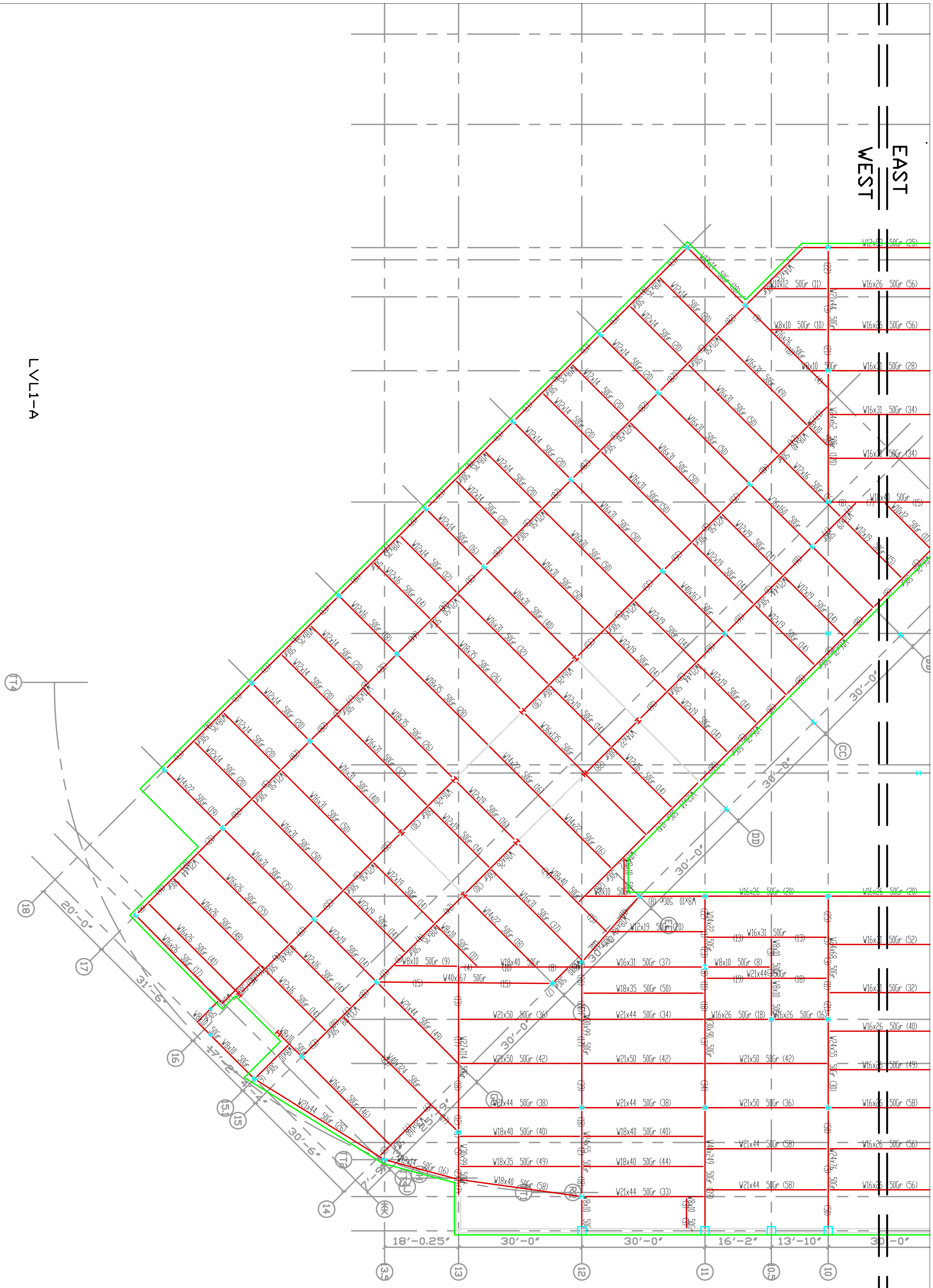
Alternative Structural Design -Framing Plans



LEVEL 1 FRAMING PLAN- East

$\frac{1}{32}'' = 1'$

LVL1-A



LEVEL 1 FRAMING PLAN- West

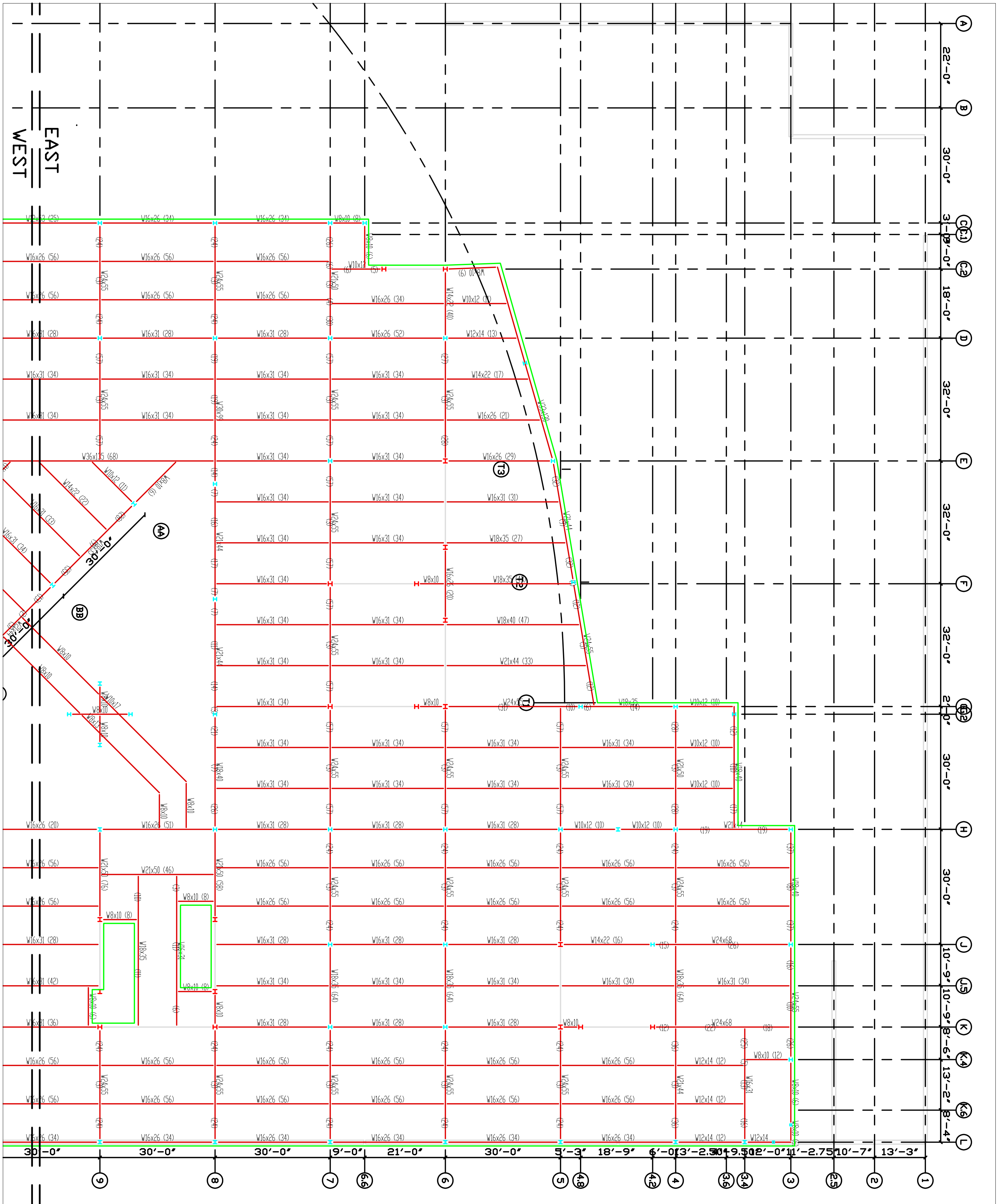
$\frac{1}{32}'' = 1'$

LEVEL 2 FRAMING PLAN- East

$\frac{1}{32}'' = 1'$

LEVEL 2 FRAMING PLAN- West

$\frac{1}{32}'' = 1'$



LEVEL 3 FRAMING PLAN- East

$\frac{1}{32}'' = 1'$

LEVEL 3 FRAMING PLAN- West

$\frac{1}{32}'' = 1'$

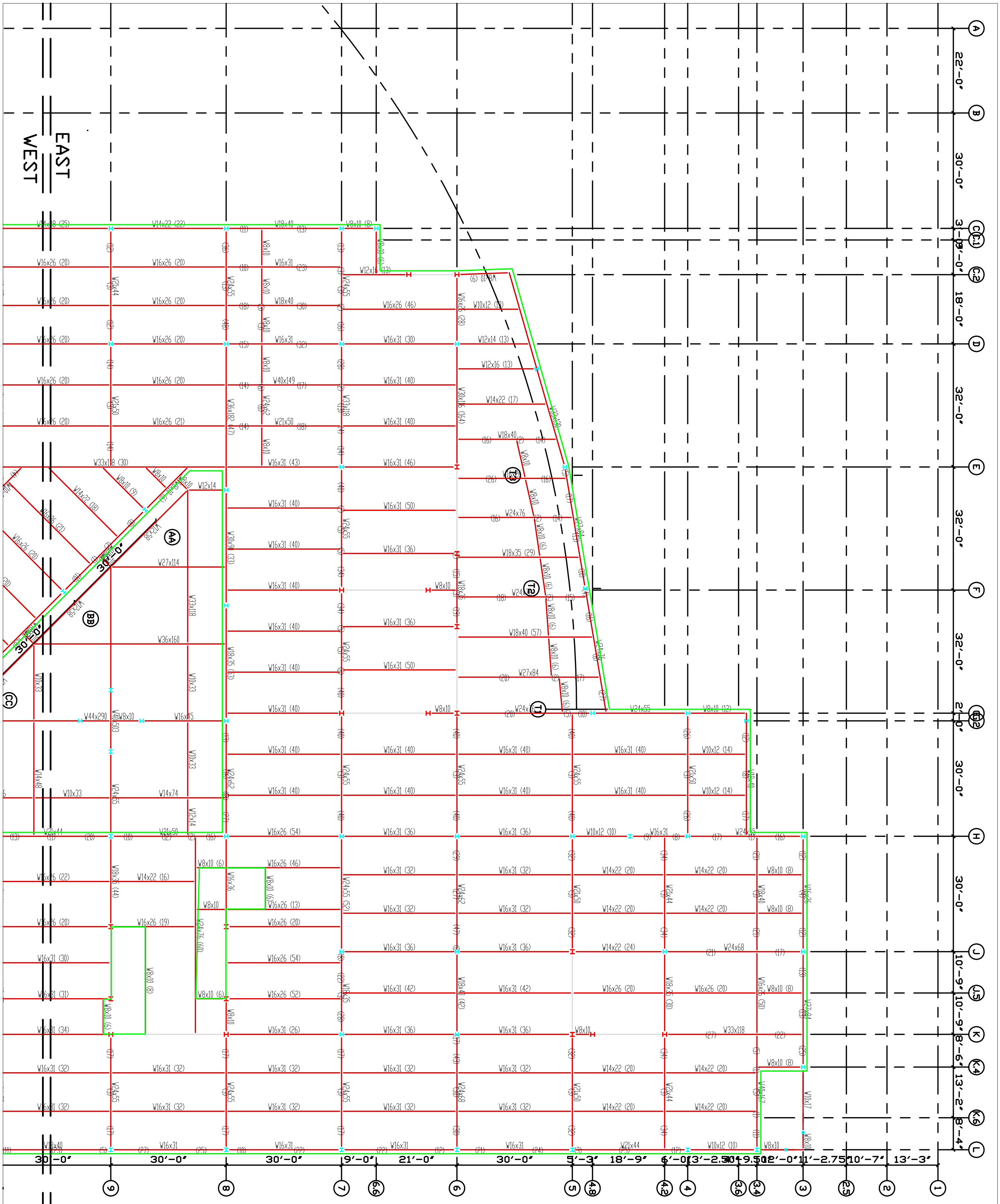
LEVEL 4 FRAMING PLAN- East

$\frac{1}{32}'' = 1'$

LVL4-A

LEVEL 4 FRAMING PLAN- West

$\frac{1}{32}$" = 1'



LEVEL 5 FRAMING PLAN- East

$\frac{1}{32}'' = 1'$

LEVEL 5 FRAMING PLAN- West

$\frac{1}{32}'' = 1'$

Appendix 2

Alternative Lateral System - Braced Frame Elevations

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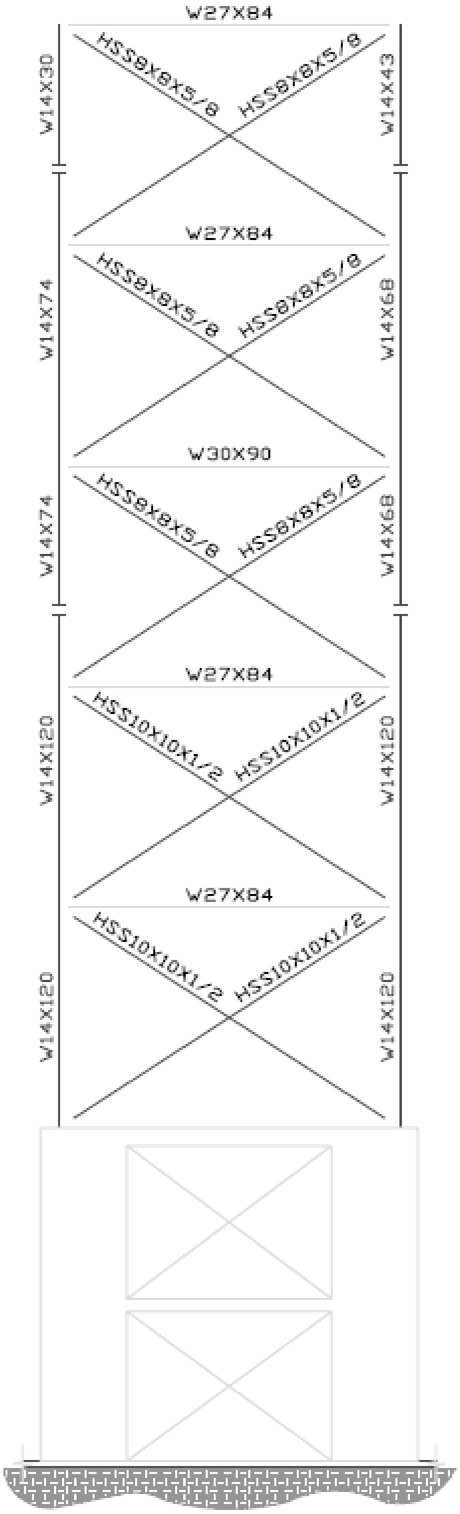
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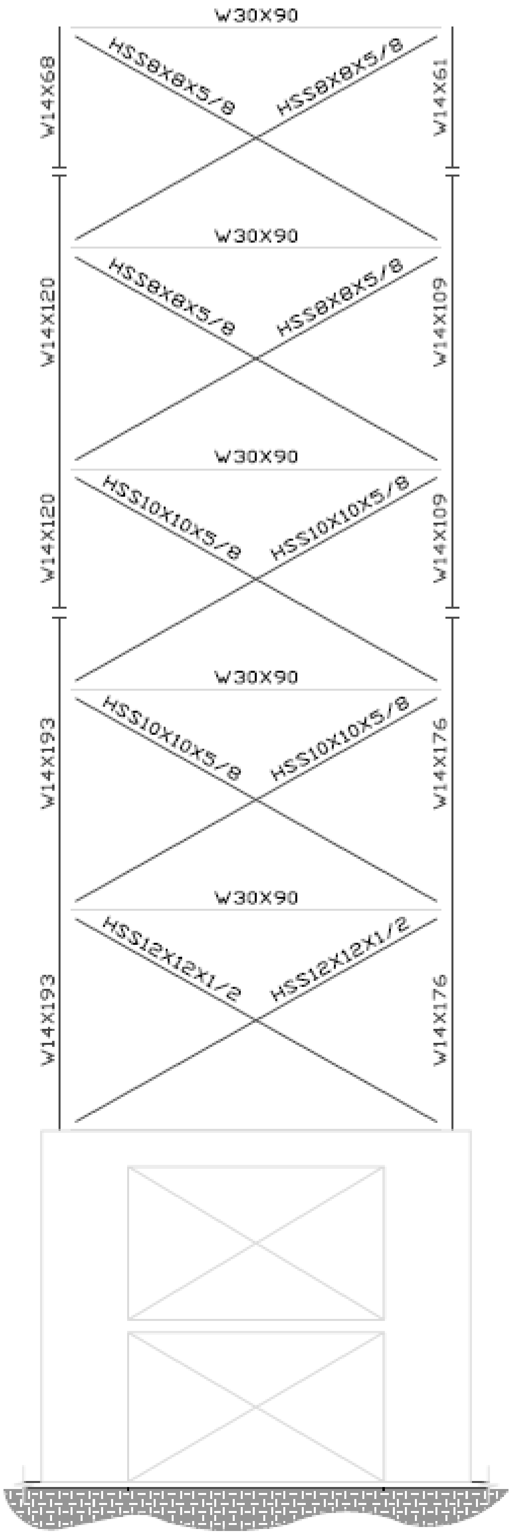
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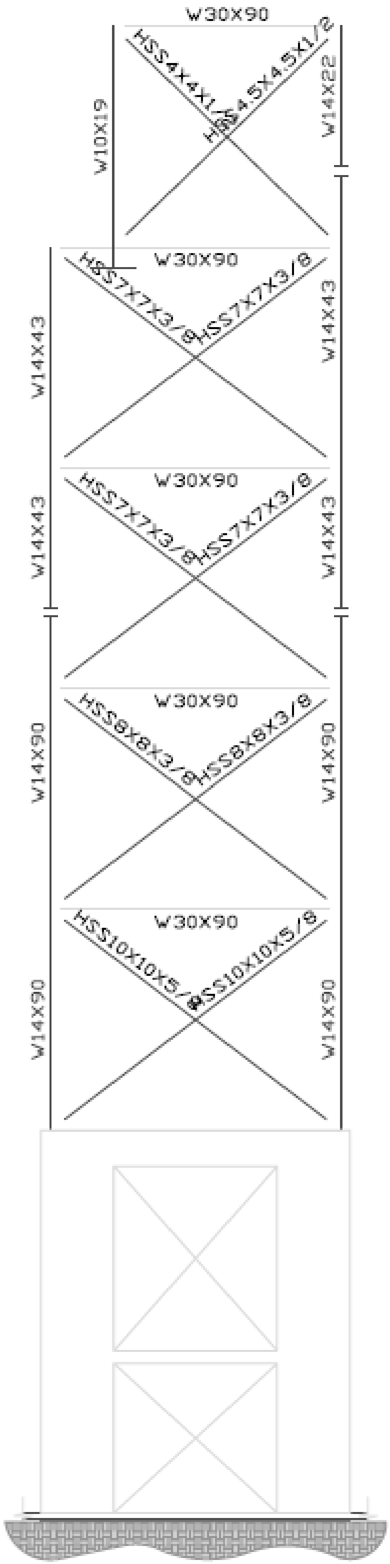
BF-304H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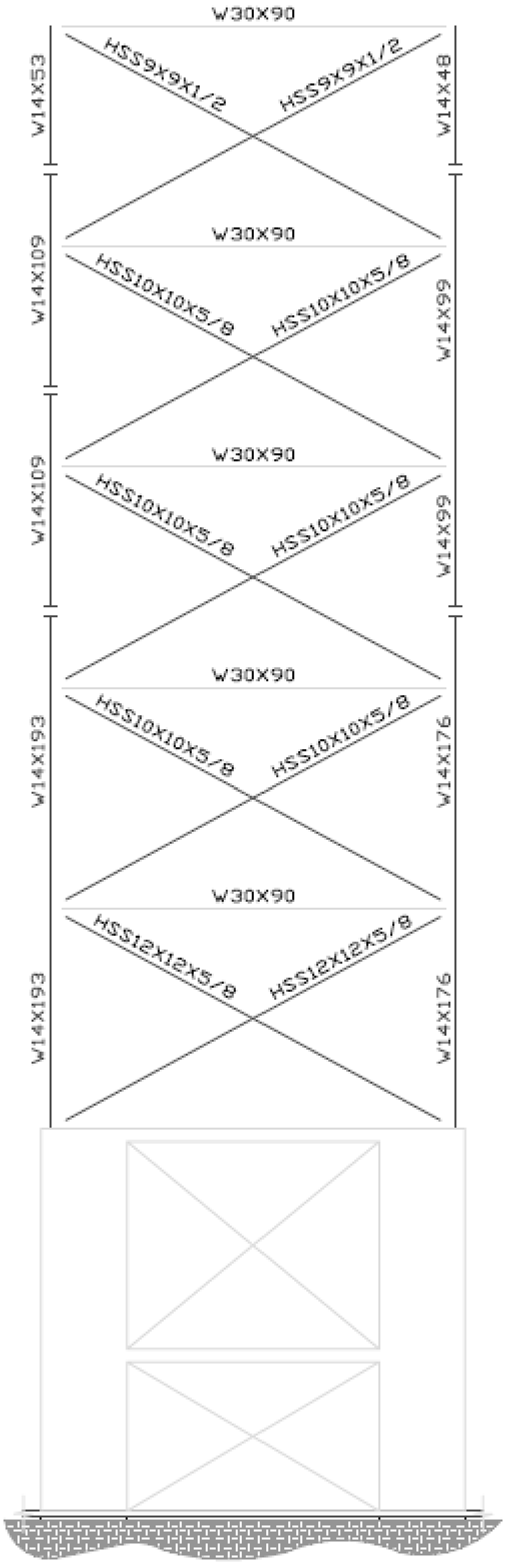
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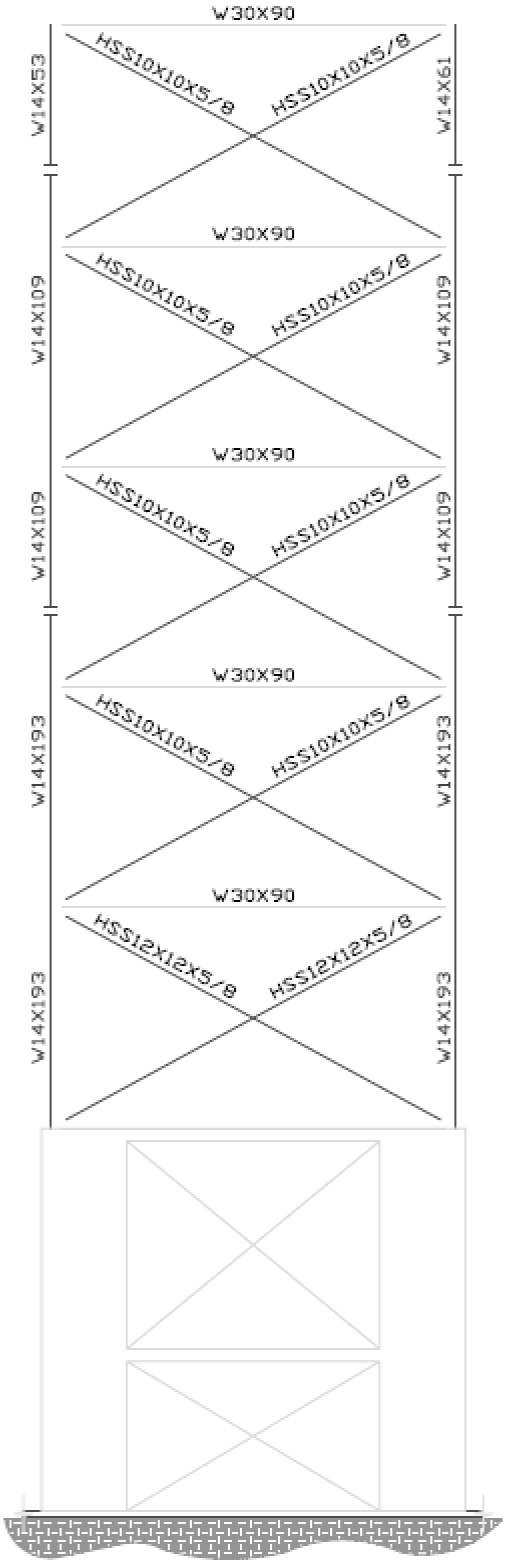
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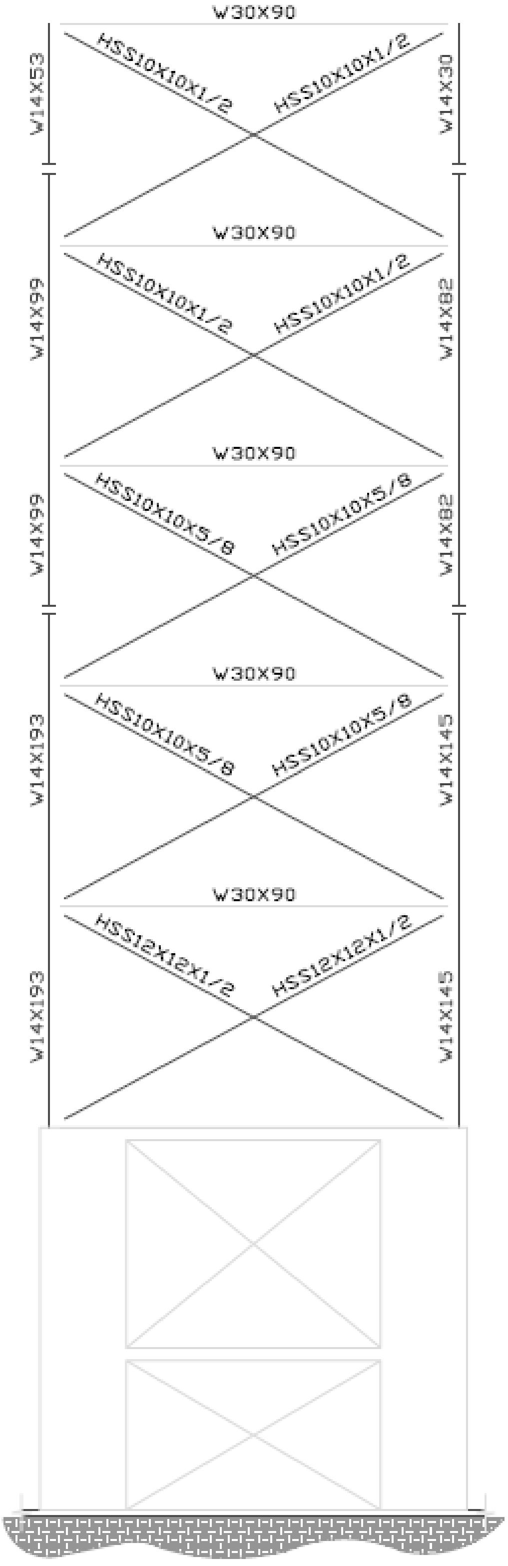
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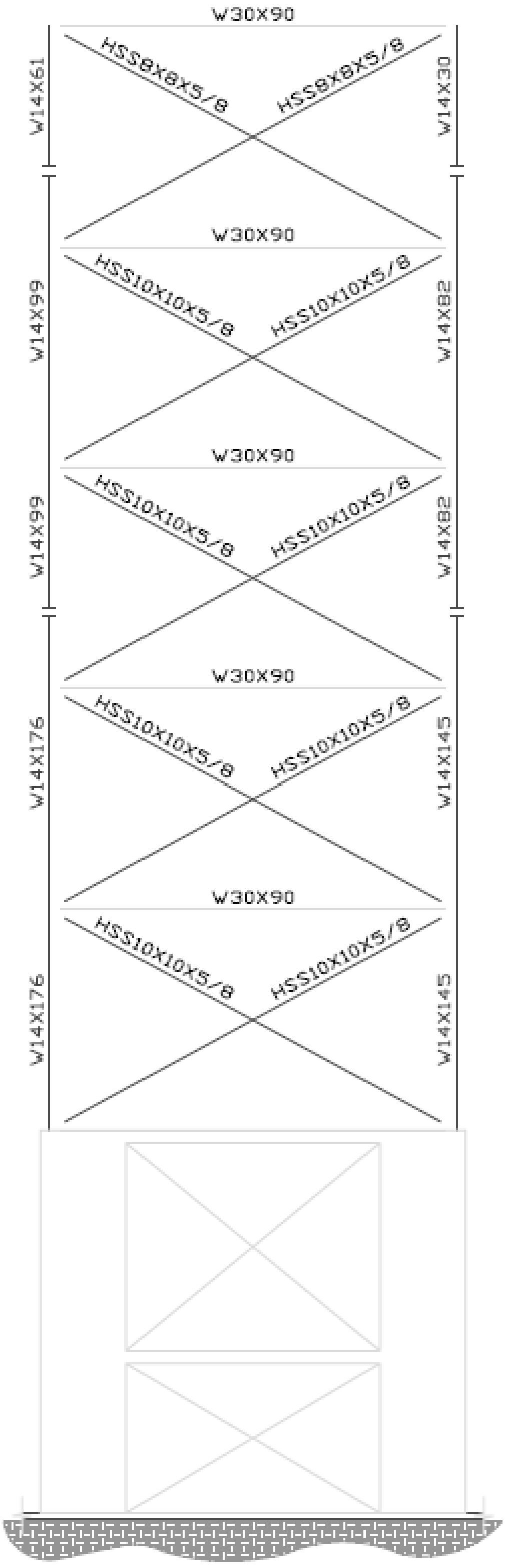
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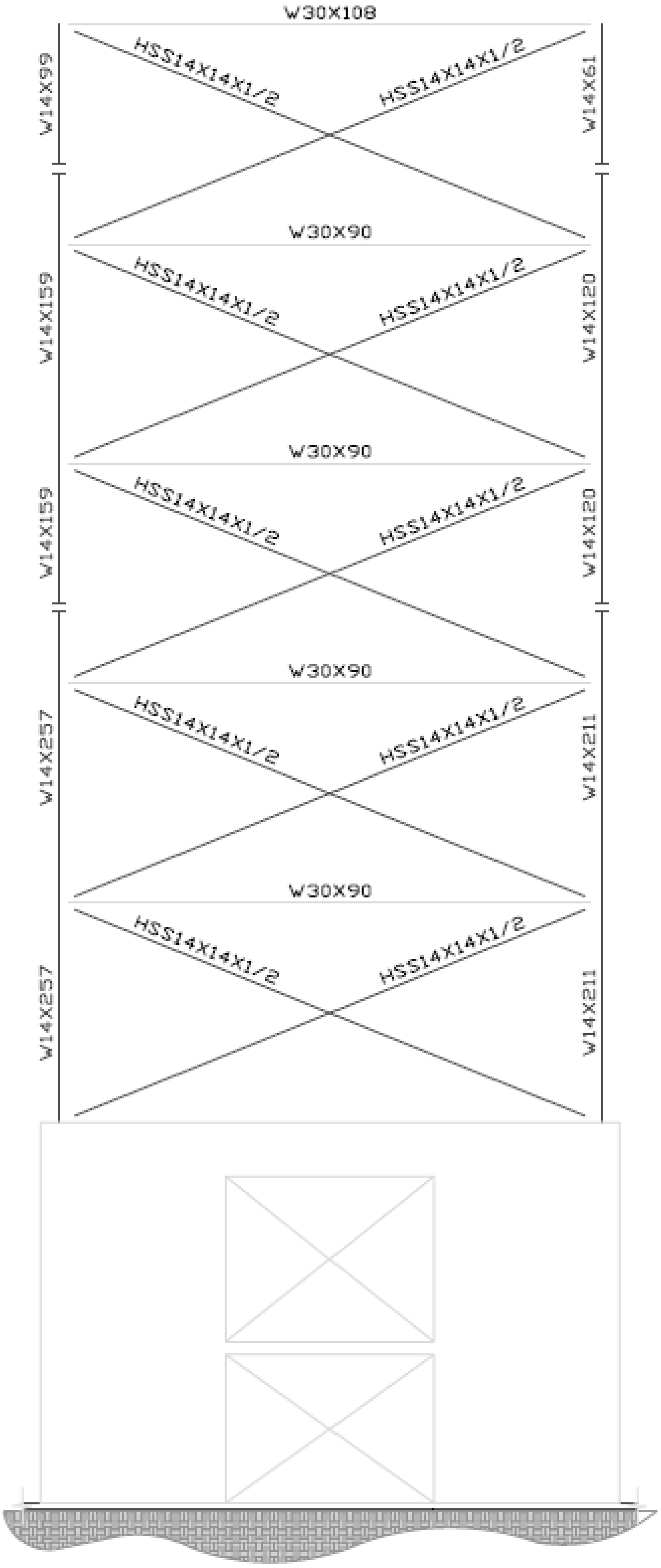
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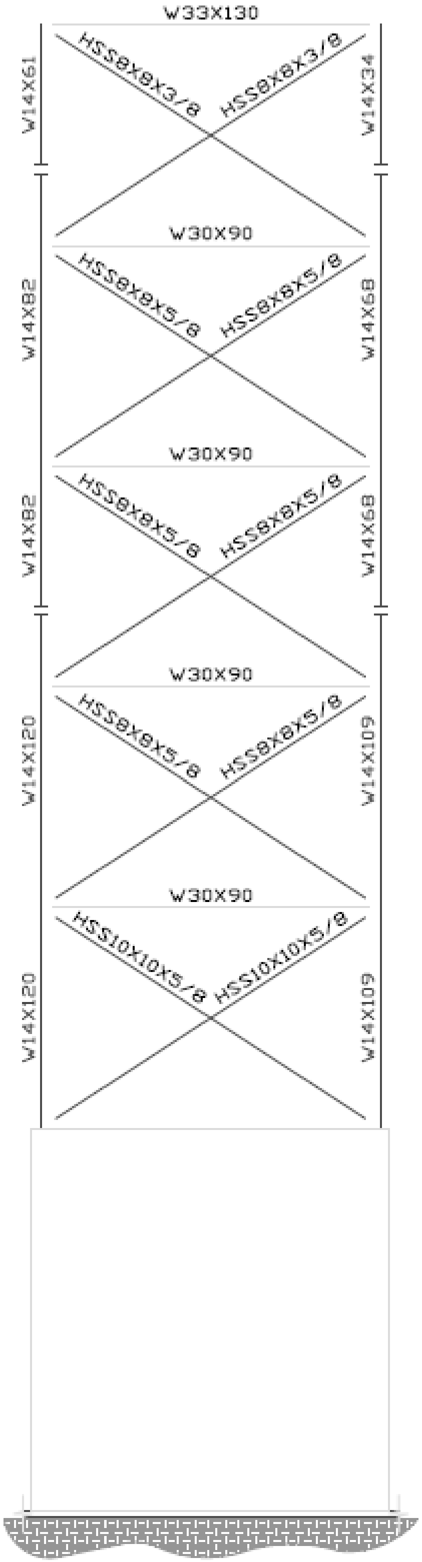
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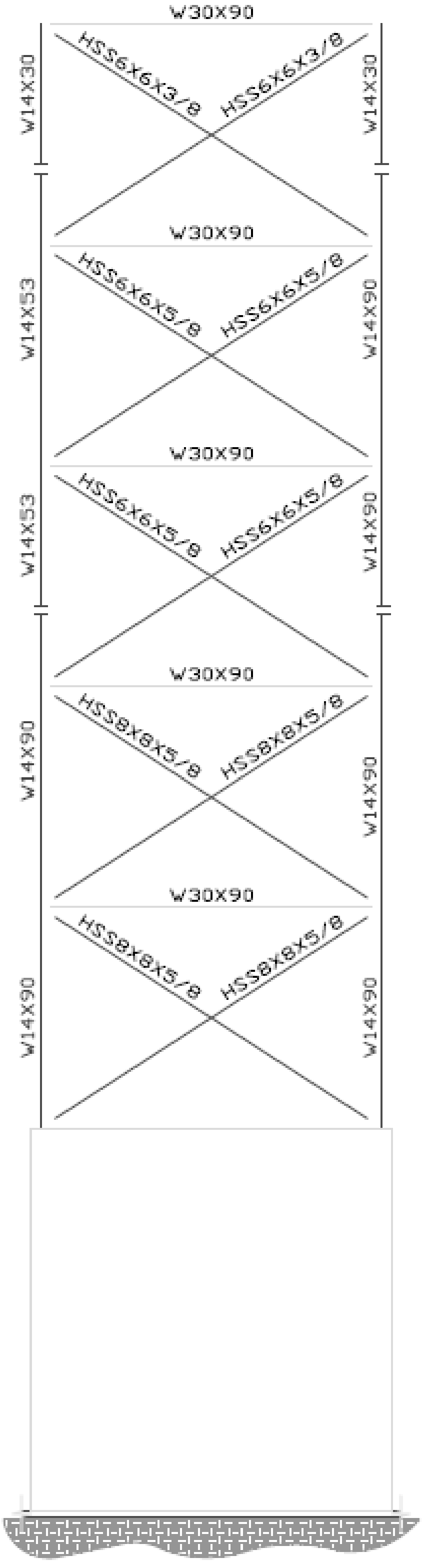
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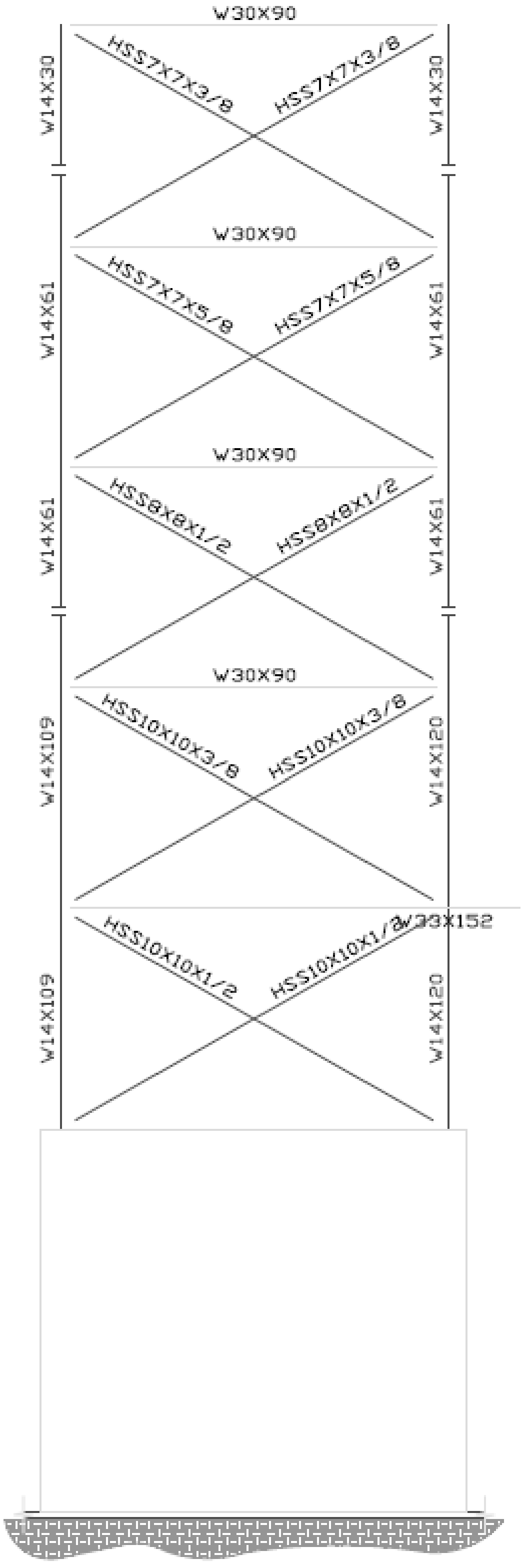
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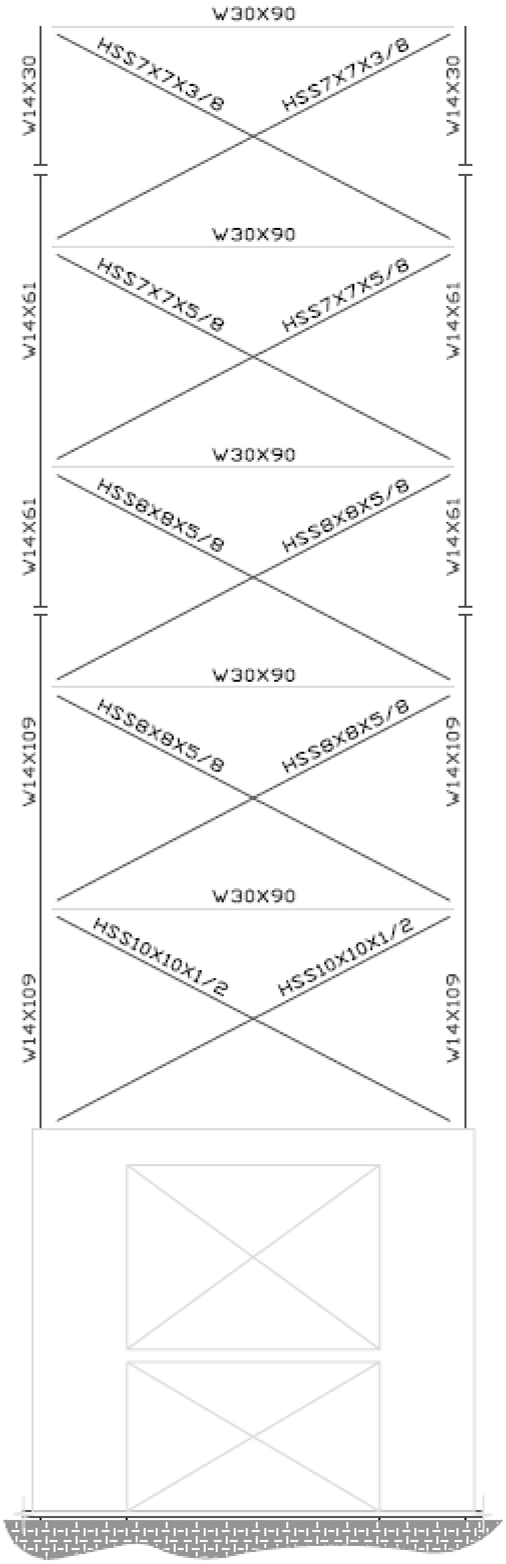
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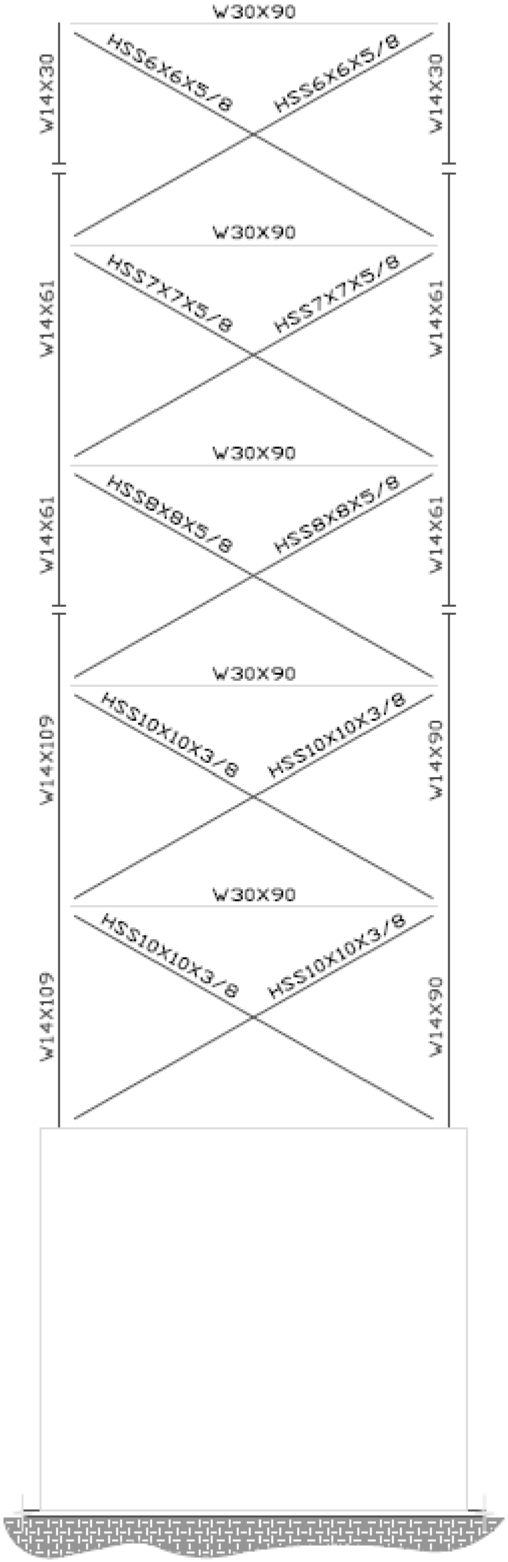
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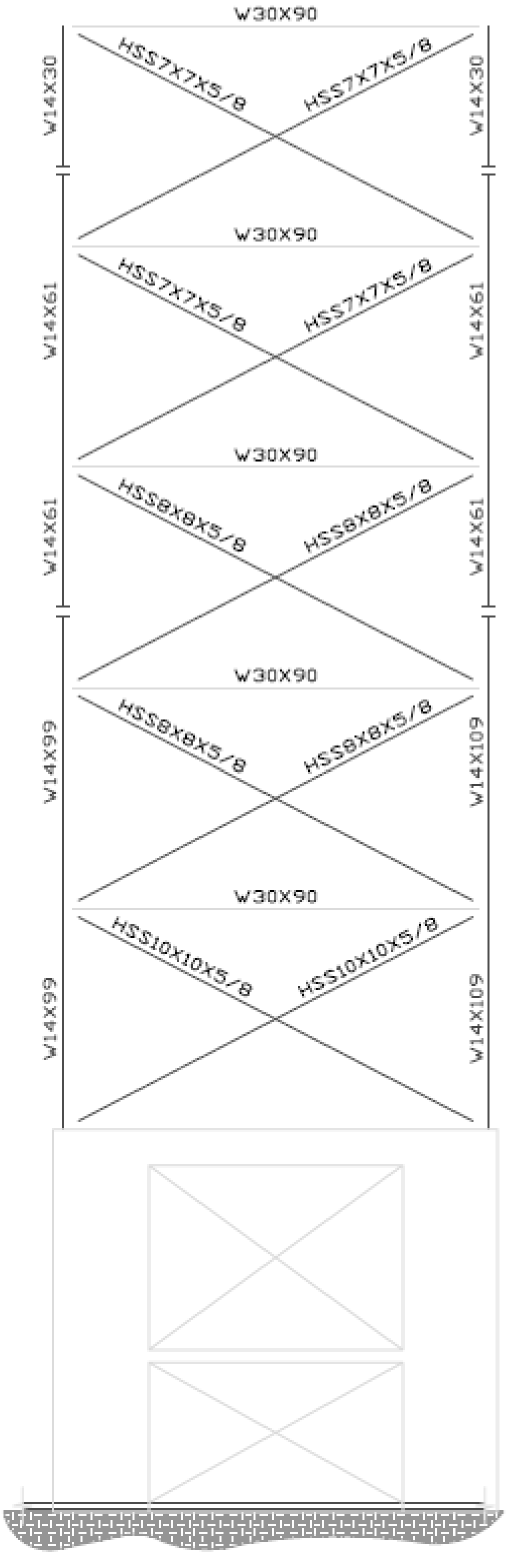
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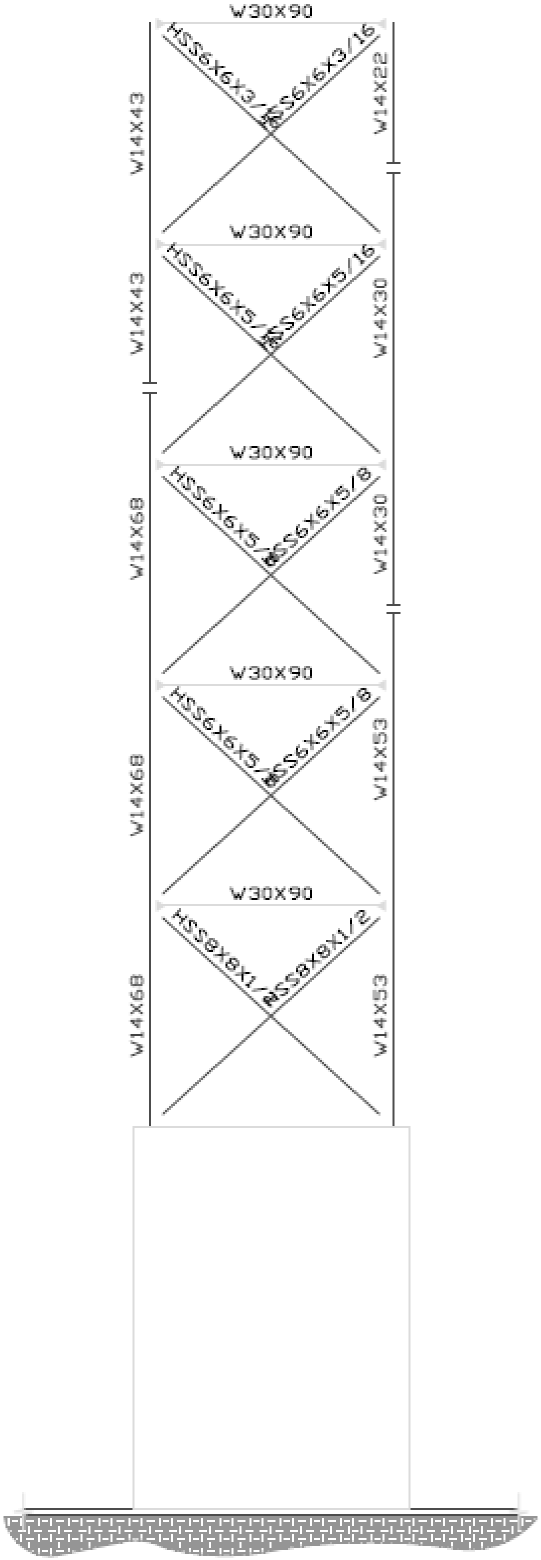
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Appendix 3

Cost Estimating Structural Steel Framing Take Offs Summary

PROJECT **LVL1-A Gravity Beam Design Takeoff**

ARCHITECT

TAKE OFF BY QUANTITIES BY PRICES BY

DESCRIPTION	NO	DIMENSIONS			QUANTITIES		
		Length ft				UNIT	
W8X10	35	355.48			3580	lbs	
W10X12	15	236.04			2843	lbs	
W12X14	26	506.21			7166	lbs	
W12X16	8	164.83			2642	lbs	
W12X19	19	398.78			7558	lbs	
W14X22	18	410.33			9062	lbs	
W16X26	53	1463.27			38240	lbs	
W16X31	54	1654.14			51390	lbs	
W18X35	20	607.14			21279	lbs	
W18X40	14	407.63			16368	lbs	
W21X44	18	540.20			23896	lbs	
W21X50	21	624.25			31226	lbs	
W12X53	1	36.00			1911	lbs	
W24X55	11	317.17			17592	lbs	
W24X62	5	153.75			9574	lbs	
W24X68	4	141.98			9711	lbs	
W24X76	2	68.65			5233	lbs	
W27X84	1	38.00			3207	lbs	
W30X90	1	34.25			3077	lbs	
W30X99	2	51.08			5058	lbs	
W27X102	1	42.50			4339	lbs	
W27X114	1	40.44			4610	lbs	
W33X118	2	78.83			9308	lbs	
W36X135	1	42.50			5741	lbs	
W36X150	1	48.83			7345	lbs	
W36X160	1	42.50			6797	lbs	
W40X167	2	85.28			14278	lbs	
W40X249	1	30.00			7483	lbs	
	338				330514	lbs	
					330512	lbs	
Total Number of Studs		11243					

PROJECT **Level 1 - Frame Takeoff**

ARCHITECT

TAKE OFF BY QUANTITIES BY PRICES BY

DESCRIPTION	NO	DIMENSIONS			QUANTITIES		
		Length ft				UNIT	
Floor Area: 86850.2 SqFt							
Columns:							
W14X53	1	12.3			650	lbs	
W14X61	1	12.3			746	lbs	
W14X90	5	61.3			5523	lbs	
W14X99	1	12.3			1213	lbs	
W14X109	6	73.5			8003	lbs	
W14X120	4	49.0			5886	lbs	
W14X145	2	24.5			3560	lbs	
W14X176	3	36.8			6478	lbs	
W14X193	5	61.3			11838	lbs	
W14X211	1	12.3			2584	lbs	
W14X257	1	12.3			3151	lbs	
	30				49632	lbs	
Beams:							
W27X84	1	18.8			1582	lbs	
W30X90	13	276.9			24876	lbs	
W33X152	1	42.5			6479	lbs	
	15				32937	lbs	
Braces:							
HSS8X8X1/2	2	36.3			1669	lbs	
HSS8X8X5/8	2	44.8			2500	lbs	
HSS10X10X3/8	2	49.5			2223	lbs	
HSS10X10X1/2	6	147.3			8620	lbs	
HSS10X10X5/8	8	189.3			13529	lbs	
HSS12X12X1/2	4	100.7			7163	lbs	
HSS12X12X5/8	4	102.5			8961	lbs	
HSS14X14X1/2	2	64.8			5425	lbs	
	30				50090	lbs	
					50091	lbs	

PROJECT **LVL2-A Gravity Beam Design Takeoff**

ARCHITECT

TAKE OFF BY QUANTITIES BY PRICES BY

DESCRIPTION	NO	DIMENSIONS			QUANTITIES		
		Length ft				UNIT	
W8X10	60	616.67			6211	lbs	
W10X12	21	337.02			4060	lbs	
W8X13	1	28.92			378	lbs	
W12X14	24	470.08			6654	lbs	
W12X16	5	102.21			1638	lbs	
W10X17	1	31.82			540	lbs	
W12X19	13	279.50			5297	lbs	
W14X22	12	285.71			6310	lbs	
W16X26	73	2061.42			53872	lbs	
W16X31	83	2492.24			77427	lbs	
W18X35	15	439.68			15410	lbs	
W18X40	12	344.48			13832	lbs	
W21X44	14	397.77			17596	lbs	
W12X50	1	36.00			1789	lbs	
W21X50	21	622.42			31134	lbs	
W24X55	16	484.00			26845	lbs	
W24X62	1	30.00			1868	lbs	
W24X68	5	171.50			11730	lbs	
W24X76	1	32.00			2439	lbs	
W27X84	1	30.00			2532	lbs	
W30X90	1	30.00			2695	lbs	
W30X99	1	38.00			3763	lbs	
W33X130	1	52.53			6846	lbs	
W40X149	1	57.08			8507	lbs	
W40X167	1	60.00			10045	lbs	
W40X183	1	59.58			10908	lbs	
	386				330326	lbs	
					330325	lbs	
Total Number of Studs		12244					

PROJECT **Level 2 - Frame Takeoff**

ARCHITECT

TAKE OFF BY QUANTITIES BY PRICES BY

DESCRIPTION	NO	DIMENSIONS			QUANTITIES		
		Length ft				UNIT	
Floor Area: 74947.8 SqFt							
Columns:							
W14X53	1	12.3			650	lbs	
W14X61	1	12.3			746	lbs	
W14X90	5	61.3			5523	lbs	
W14X99	1	12.3			1213	lbs	
W14X109	6	73.5			8003	lbs	
W14X120	4	49.0			5886	lbs	
W14X145	2	24.5			3560	lbs	
W14X176	3	36.8			6478	lbs	
W14X193	5	61.3			11838	lbs	
W14X211	1	12.3			2584	lbs	
W14X257	1	12.3			3151	lbs	
	30				49632	lbs	
Beams:							
W27X84	1	18.8			1582	lbs	
W30X90	14	298.4			26808	lbs	
	15				28390	lbs	
Braces:							
HSS6X6X5/8	2	36.3			1447	lbs	
HSS8X8X3/8	2	40.3			1426	lbs	
HSS8X8X5/8	8	195.6			10915	lbs	
HSS10X10X1/2	2	44.8			2622	lbs	
HSS10X10X3/8	4	99.0			4446	lbs	
HSS10X10X5/8	10	254.4			18181	lbs	
HSS14X14X1/2	2	64.8			5425	lbs	
	30				44462	lbs	

PROJECT **LVL3-A Gravity Beam Design Takeoff**

ARCHITECT

TAKE OFF BY QUANTITIES BY PRICES BY

DESCRIPTION	NO	DIMENSIONS			QUANTITIES		
		Length ft				UNIT	
W8X10	43	483.09			4866	lbs	
W10X12	10	155.98			1879	lbs	
W8X13	1	28.92			378	lbs	
W12X14	7	118.69			1680	lbs	
W12X16	3	61.78			990	lbs	
W10X17	1	31.82			540	lbs	
W12X19	13	278.00			5269	lbs	
W14X22	7	153.99			3401	lbs	
W16X26	76	2154.58			56306	lbs	
W16X31	90	2730.26			84822	lbs	
W18X35	13	369.36			12946	lbs	
W16X36	1	23.50			848	lbs	
W18X40	8	206.66			8298	lbs	
W21X44	17	524.72			23211	lbs	
W21X50	11	319.00			15957	lbs	
W12X53	1	63.00			1911	lbs	
W24X55	22	676.00			37495	lbs	
W24X62	1	32.00			1993	lbs	
W24X68	4	141.50			9678	lbs	
W27X84	1	30.00			2532	lbs	
W30X99	1	38.00			3763	lbs	
W33X130	2	108.44			14133	lbs	
W36X135	1	60.00			8105	lbs	
W40X149	1	59.58			8880	lbs	
	335				309881	lbs	
					309880	lbs	
Total Number of Studs		12149					

PROJECT **Level 3 - Frame Takeoff**

ARCHITECT

TAKE OFF BY QUANTITIES BY PRICES BY

DESCRIPTION	NO	DIMENSIONS			QUANTITIES		
		Length ft				UNIT	
Floor area: 66659.3 SqFt							
Columns:							
W14X43	2	24.5			1050	lbs	
W14X30	1	12.3			369	lbs	
W14X53	1	12.3			650	lbs	
W14X61	8	98.0			5969	lbs	
W14X90	1	12.3			1105	lbs	
W14X68	2	24.5			1667	lbs	
W14X38	1	12.3			467	lbs	
W14X74	1	12.3			909	lbs	
W14X99	3	36.8			3639	lbs	
W14X82	3	36.8			3001	lbs	
W14X109	4	49.0			5335	lbs	
W14X120	2	24.5			2943	lbs	
W14X159	1	12.3			1947	lbs	
	30				29051	lbs	
Beams:							
W30X90	15	317.2			28492	lbs	
	15				28492	lbs	
Braces:							
HSS6X6X5/8	4	81.1			3230	lbs	
HSS7X7X3/8	2	40.3			1230	lbs	
HSS8X8X1/2	2	49.5			2273	lbs	
HSS8X8X5/8	10	245.1			13677	lbs	
HSS10X10X5/8	10	254.4			18181	lbs	
HSS14X14X1/2	2	64.8			5425	lbs	
	30				44016	lbs	
					44017	lbs	

PROJECT **LVL4-A Gravity Beam Design Takeoff**

ARCHITECT

TAKE OFF BY QUANTITIES BY PRICES BY

DESCRIPTION	NO	DIMENSIONS			QUANTITIES		
		Length ft				UNIT	
HSS4X2X1/8	5	89.93			398	lbs	
HSS8X2X1/8	1	28.92			219	lbs	
HSS10X3X1/8	1	31.82			317	lbs	
W8X10	45	441.91			4451	lbs	
W10X12	12	182.81			2202	lbs	
W12X14	5	83.97			1189	lbs	
W12X16	2	34.21			548	lbs	
W12X19	5	107.50			2037	lbs	
W8X21	1	17.00			356	lbs	
W14X22	22	502.94			11107	lbs	
W16X26	40	1085.54			28369	lbs	
W16X31	111	3270.39			101602	lbs	
W18X35	25	748.73			26242	lbs	
W14X38	1	23.50			896	lbs	
W18X40	10	289.87			11639	lbs	
W21X44	18	552.72			24450	lbs	
W21X50	15	439.00			21959	lbs	
W12X53	1	36.00			1911	lbs	
W24X55	19	588.00			32614	lbs	
W24X62	3	100.25			6243	lbs	
W24X68	2	71.25			4873	lbs	
W30X90	1	38.00			3414	lbs	
W33X130	2	117.08			15258	lbs	
W36X135	1	52.53			7096	lbs	
W40X167	1	59.58			9975	lbs	
	349				319365	lbs	
Total Number of Studs		11274					

PROJECT **Level 4 - Frame Takeoff**
ARCHITECT
TAKE OFF BY QUANTITIES BY PRICES BY

DESCRIPTION	NO	DIMENSIONS			QUANTITIES		
		Length ft				UNIT	
Floor Area: 65969.9 SqFt							
Columns:							
W14X43	2	24.5			1050	lbs	
W14X30	1	12.3			369	lbs	
W14X53	1	12.3			650	lbs	
W14X61	8	98.0			5969	lbs	
W14X90	1	12.3			1105	lbs	
W14X68	2	24.5			1667	lbs	
W14X38	1	12.3			467	lbs	
W14X74	1	12.3			909	lbs	
W14X99	4	49.0			4852	lbs	
W14X82	3	36.8			3001	lbs	
W14X109	3	36.8			4002	lbs	
W14X120	2	24.5			2943	lbs	
W14X159	1	12.3			1947	lbs	
	30				28931	lbs	
					28930	lbs	
Beams:							
W27X84	1	18.8			1582	lbs	
W30X90	14	298.4			26808	lbs	
	15				28390	lbs	
Braces:							
HSS6X6X5/16	2	36.3			795	lbs	
HSS6X6X5/8	2	44.8			1783	lbs	
HSS7X7X3/8	2	40.3			1230	lbs	
HSS7X7X5/8	8	205.0			9765	lbs	
HSS8X8X5/8	6	139.1			7761	lbs	
HSS10X10X1/2	2	51.2			2999	lbs	
HSS10X10X5/8	6	153.7			10984	lbs	
HSS14X14X1/2	2	64.8			5425	lbs	
	30				40742	lbs	

PROJECT **LVL5-A Gravity Beam Design Takeoff**

ARCHITECT

TAKE OFF BY QUANTITIES BY PRICES BY

DESCRIPTION	NO	DIMENSIONS			QUANTITIES		
		Length ft				UNIT	
W8X10	73	772.22			7778	lbs	
W10X12	8	128.63			1549	lbs	
W12X14	20	404.39			5724	lbs	
W12X16	4	82.74			1326	lbs	
W10X17	1	17.00			289	lbs	
W12X19	3	73.17			1387	lbs	
W10X22	1	23.50			519	lbs	
W14X22	15	352.17			7777	lbs	
W16X26	87	2543.40			66468	lbs	
W16X31	60	1788.48			55563	lbs	
W10X33	4	80.00			2643	lbs	
W18X35	23	660.77			23159	lbs	
W16X36	1	23.50			848	lbs	
W14X38	1	36.00			1372	lbs	
W18X40	13	364.00			14616	lbs	
W21X44	9	273.47			12097	lbs	
W16X45	1	22.00			996	lbs	
W14X48	1	30.00			1439	lbs	
W21X50	5	152.00			7603	lbs	
W24X55	8	228.75			12688	lbs	
W12X58	4	113.14			6545	lbs	
W24X62	8	224.92			14006	lbs	
W24X68	6	190.00			12995	lbs	
W14X74	1	30.00			2225	lbs	
W24X76	2	87.50			6669	lbs	
W27X84	7	229.32			19352	lbs	
W30X90	3	90.00			8085	lbs	
W30X99	1	32.02			3171	lbs	
W24X103	1	30.00			3093	lbs	
W30X108	1	32.00			3452	lbs	
W27X114	1	30.00			3420	lbs	
W30X116	1	40.00			4655	lbs	
W33X118	5	248.66			29361	lbs	
W33X130	2	88.53			11537	lbs	
W40X149	1	30.00			4471	lbs	
W36X160	1	50.00			7997	lbs	
W40X183	2	68.00			12449	lbs	
W44X290	1	40.00			11678	lbs	
W40X503	1	48.00			24173	lbs	
	387				415175	lbs	
Total Number of Studs		10723					

PROJECT **Level 5 - Frame Takeoff**

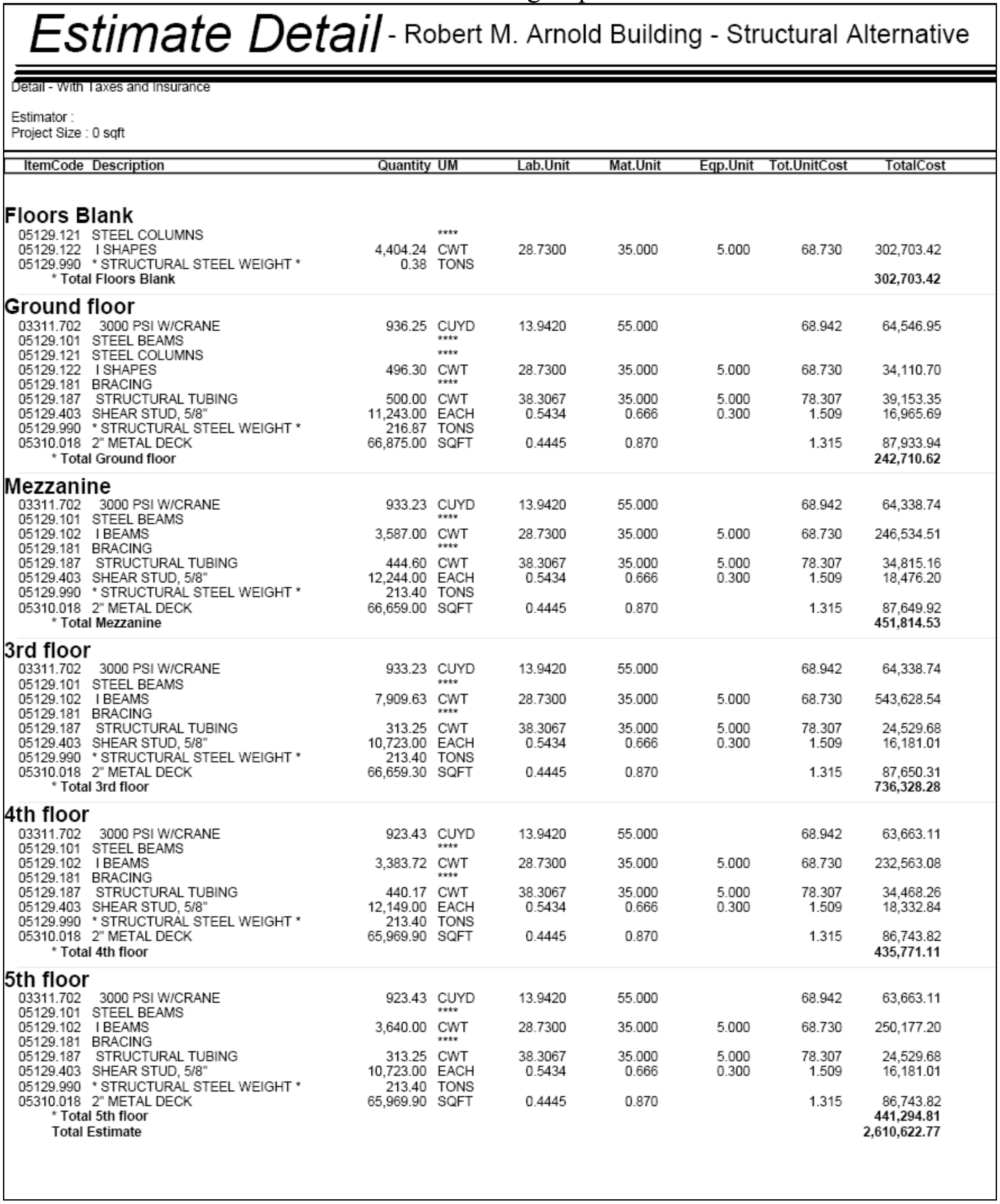
ARCHITECT

TAKE OFF BY QUANTITIES BY PRICES BY

DESCRIPTION	NO	DIMENSIONS			QUANTITIES		
		Length ft				UNIT	
Floor Area: 65959.9 SqFt							
Columns:							
W10X19	1	12.3			234	lbs	
W14X43	1	12.3			525	lbs	
W14X22	3	36.8			812	lbs	
W14X48	1	12.3			588	lbs	
W14X30	13	159.3			4796	lbs	
W14X53	3	36.8			1951	lbs	
W14X61	5	63.3			3731	lbs	
W14X34	1	12.3			417	lbs	
W14X68	1	12.3			834	lbs	
W14X99	1	12.3			1213	lbs	
	30				15101	lbs	
					15099	lbs	
Beams:							
W27X84	1	18.8			1582	lbs	
W30X90	12	246.2			22118	lbs	
W30X108	1	30.0			3236	lbs	
W30X130	1	18.8			2444	lbs	
	15				29380	lbs	
					29379	lbs	
Braces:							
HSS4X4X1/2	1	17.5			359	lbs	
HSS4.5X4.5X1/2	1	17.5			415	lbs	
HSS6X6X3/16	2	36.3			492	lbs	
HSS6X6X3/8	2	44.8			1155	lbs	
HSS6X6X5/8	2	49.5			1970	lbs	
HSS7X7X5/8	2	53.0			2525	lbs	
HSS7X7X3/8	4	102.5			3128	lbs	
HSS8X8X3/8	2	44.8			1585	lbs	
HSS8X8X5/8	6	145.5			8121	lbs	
HSS9X9X1/2	2	51.2			2667	lbs	
HSS10X10X1/2	2	51.2			2999	lbs	
HSS10X10X5/8	2	51.2			3661	lbs	
HSS14X14X12	2	64.8			5425	lbs	
	30				34502	lbs	
					34503	lbs	

Appendix 4

Cost Estimating Reports

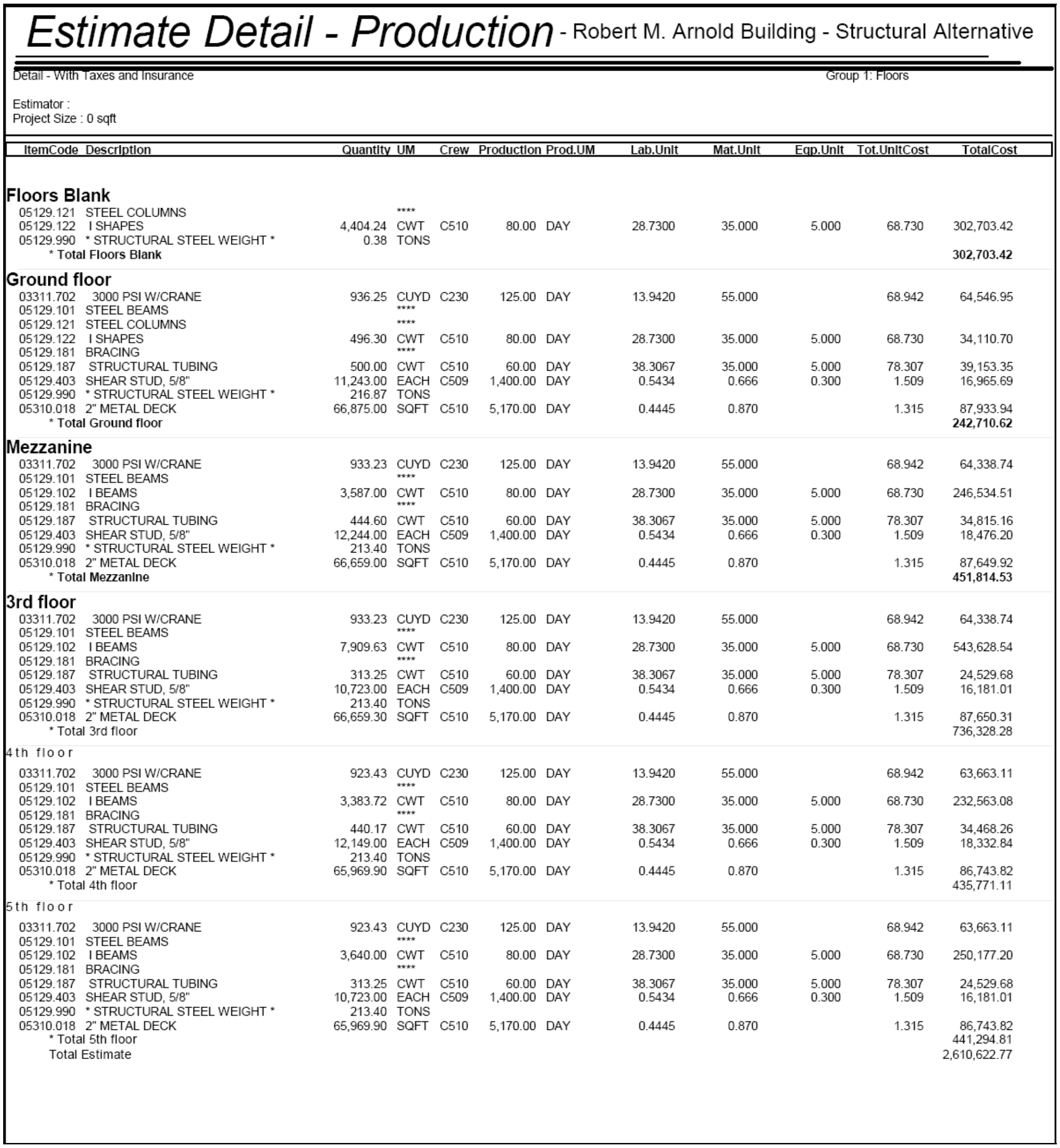


Estimate Detail - Robert M. Arnold Building - Structural Alternative

Detail - With Taxes and Insurance

Estimator :
Project Size : 0 sqft

ItemCode	Description	Quantity	UM	Lab.Unit	Mat.Unit	Eqp.Unit	Tot.UnitCost	TotalCost
Floors Blank								
05129.121	STEEL COLUMNS		****					
05129.122	I SHAPES	4,404.24	CWT	28.7300	35.000	5.000	68.730	302,703.42
05129.990	* STRUCTURAL STEEL WEIGHT *	0.38	TONS					
	*** Total Floors Blank**							**302,703.42**
Ground floor								
03311.702	3000 PSI W/CRANE	936.25	CUYD	13.9420	55.000		68.942	64,546.95
05129.101	STEEL BEAMS		****					
05129.121	STEEL COLUMNS		****					
05129.122	I SHAPES	496.30	CWT	28.7300	35.000	5.000	68.730	34,110.70
05129.181	BRACING		****					
05129.187	STRUCTURAL TUBING	500.00	CWT	38.3067	35.000	5.000	78.307	39,153.35
05129.403	SHEAR STUD, 5/8"	11,243.00	EACH	0.5434	0.666	0.300	1.509	16,965.69
05129.990	* STRUCTURAL STEEL WEIGHT *	216.87	TONS					
05310.018	2" METAL DECK	66,875.00	SQFT	0.4445	0.870		1.315	87,933.94
	*** Total Ground floor**							**242,710.62**
Mezzanine								
03311.702	3000 PSI W/CRANE	933.23	CUYD	13.9420	55.000		68.942	64,338.74
05129.101	STEEL BEAMS		****					
05129.102	I BEAMS	3,587.00	CWT	28.7300	35.000	5.000	68.730	246,534.51
05129.181	BRACING		****					
05129.187	STRUCTURAL TUBING	444.60	CWT	38.3067	35.000	5.000	78.307	34,815.16
05129.403	SHEAR STUD, 5/8"	12,244.00	EACH	0.5434	0.666	0.300	1.509	18,476.20
05129.990	* STRUCTURAL STEEL WEIGHT *	213.40	TONS					
05310.018	2" METAL DECK	66,659.00	SQFT	0.4445	0.870		1.315	87,649.92
	*** Total Mezzanine**							**451,814.53**
3rd floor								
03311.702	3000 PSI W/CRANE	933.23	CUYD	13.9420	55.000		68.942	64,338.74
05129.101	STEEL BEAMS		****					
05129.102	I BEAMS	7,909.63	CWT	28.7300	35.000	5.000	68.730	543,628.54
05129.181	BRACING		****					
05129.187	STRUCTURAL TUBING	313.25	CWT	38.3067	35.000	5.000	78.307	24,529.68
05129.403	SHEAR STUD, 5/8"	10,723.00	EACH	0.5434	0.666	0.300	1.509	16,181.01
05129.990	* STRUCTURAL STEEL WEIGHT *	213.40	TONS					
05310.018	2" METAL DECK	66,659.30	SQFT	0.4445	0.870		1.315	87,650.31
	*** Total 3rd floor**							**736,328.28**
4th floor								
03311.702	3000 PSI W/CRANE	923.43	CUYD	13.9420	55.000		68.942	63,663.11
05129.101	STEEL BEAMS		****					
05129.102	I BEAMS	3,383.72	CWT	28.7300	35.000	5.000	68.730	232,563.08
05129.181	BRACING		****					
05129.187	STRUCTURAL TUBING	440.17	CWT	38.3067	35.000	5.000	78.307	34,468.26
05129.403	SHEAR STUD, 5/8"	12,149.00	EACH	0.5434	0.666	0.300	1.509	18,332.84
05129.990	* STRUCTURAL STEEL WEIGHT *	213.40	TONS					
05310.018	2" METAL DECK	65,969.90	SQFT	0.4445	0.870		1.315	86,743.82
	*** Total 4th floor**							**435,771.11**
5th floor								
03311.702	3000 PSI W/CRANE	923.43	CUYD	13.9420	55.000		68.942	63,663.11
05129.101	STEEL BEAMS		****					
05129.102	I BEAMS	3,640.00	CWT	28.7300	35.000	5.000	68.730	250,177.20
05129.181	BRACING		****					
05129.187	STRUCTURAL TUBING	313.25	CWT	38.3067	35.000	5.000	78.307	24,529.68
05129.403	SHEAR STUD, 5/8"	10,723.00	EACH	0.5434	0.666	0.300	1.509	16,181.01
05129.990	* STRUCTURAL STEEL WEIGHT *	213.40	TONS					
05310.018	2" METAL DECK	65,969.90	SQFT	0.4445	0.870		1.315	86,743.82
	*** Total 5th floor**							**441,294.81**
	Total Estimate							**2,610,622.77**



Estimate Detail - Production - Robert M. Arnold Building - Structural Alternative

Detail - With Taxes and Insurance

Group 1: Floors

Estimator :
Project Size : 0 sqft

ItemCode	Description	Quantity	UM	Crew	Production	Prod.UM	Lab.Unit	Mat.Unit	Eqp.Unit	Tot.UnitCost	TotalCost
Floors Blank											
05129.121	STEEL COLUMNS		****								
05129.122	I SHAPES	4,404.24	CWT	C510	80.00	DAY	28.7300	35.000	5.000	68.730	302,703.42
05129.990	* STRUCTURAL STEEL WEIGHT *	0.38	TONS								
	*** Total Floors Blank**										**302,703.42**
Ground floor											
03311.702	3000 PSI W/CRANE	936.25	CUYD	C230	125.00	DAY	13.9420	55.000		68.942	64,546.95
05129.101	STEEL BEAMS		****								
05129.121	STEEL COLUMNS		****								
05129.122	I SHAPES	496.30	CWT	C510	80.00	DAY	28.7300	35.000	5.000	68.730	34,110.70
05129.181	BRACING		****								
05129.187	STRUCTURAL TUBING	500.00	CWT	C510	60.00	DAY	38.3067	35.000	5.000	78.307	39,153.35
05129.403	SHEAR STUD, 5/8"	11,243.00	EACH	C509	1,400.00	DAY	0.5434	0.666	0.300	1.509	16,965.69
05129.990	* STRUCTURAL STEEL WEIGHT *	216.87	TONS								
05310.018	2" METAL DECK	66,875.00	SQFT	C510	5,170.00	DAY	0.4445	0.870		1.315	87,933.94
	*** Total Ground floor**										**242,710.62**
Mezzanine											
03311.702	3000 PSI W/CRANE	933.23	CUYD	C230	125.00	DAY	13.9420	55.000		68.942	64,338.74
05129.101	STEEL BEAMS		****								
05129.102	I BEAMS	3,587.00	CWT	C510	80.00	DAY	28.7300	35.000	5.000	68.730	246,534.51
05129.181	BRACING		****								
05129.187	STRUCTURAL TUBING	444.60	CWT	C510	60.00	DAY	38.3067	35.000	5.000	78.307	34,815.16
05129.403	SHEAR STUD, 5/8"	12,244.00	EACH	C509	1,400.00	DAY	0.5434	0.666	0.300	1.509	18,476.20
05129.990	* STRUCTURAL STEEL WEIGHT *	213.40	TONS								
05310.018	2" METAL DECK	66,659.00	SQFT	C510	5,170.00	DAY	0.4445	0.870		1.315	87,649.92
	*** Total Mezzanine**										**451,814.53**
3rd floor											
03311.702	3000 PSI W/CRANE	933.23	CUYD	C230	125.00	DAY	13.9420	55.000		68.942	64,338.74
05129.101	STEEL BEAMS		****								
05129.102	I BEAMS	7,909.63	CWT	C510	80.00	DAY	28.7300	35.000	5.000	68.730	543,628.54
05129.181	BRACING		****								
05129.187	STRUCTURAL TUBING	313.25	CWT	C510	60.00	DAY	38.3067	35.000	5.000	78.307	24,529.68
05129.403	SHEAR STUD, 5/8"	10,723.00	EACH	C509	1,400.00	DAY	0.5434	0.666	0.300	1.509	16,181.01
05129.990	* STRUCTURAL STEEL WEIGHT *	213.40	TONS								
05310.018	2" METAL DECK	66,659.30	SQFT	C510	5,170.00	DAY	0.4445	0.870		1.315	87,650.31
	* Total 3rd floor										736,328.28
4th floor											
03311.702	3000 PSI W/CRANE	923.43	CUYD	C230	125.00	DAY	13.9420	55.000		68.942	63,663.11
05129.101	STEEL BEAMS		****								
05129.102	I BEAMS	3,383.72	CWT	C510	80.00	DAY	28.7300	35.000	5.000	68.730	232,563.08
05129.181	BRACING		****								
05129.187	STRUCTURAL TUBING	440.17	CWT	C510	60.00	DAY	38.3067	35.000	5.000	78.307	34,468.26
05129.403	SHEAR STUD, 5/8"	12,149.00	EACH	C509	1,400.00	DAY	0.5434	0.666	0.300	1.509	18,332.84
05129.990	* STRUCTURAL STEEL WEIGHT *	213.40	TONS								
05310.018	2" METAL DECK	65,969.90	SQFT	C510	5,170.00	DAY	0.4445	0.870		1.315	86,743.82
	* Total 4th floor										435,771.11
5th floor											
03311.702	3000 PSI W/CRANE	923.43	CUYD	C230	125.00	DAY	13.9420	55.000		68.942	63,663.11
05129.101	STEEL BEAMS		****								
05129.102	I BEAMS	3,640.00	CWT	C510	80.00	DAY	28.7300	35.000	5.000	68.730	250,177.20
05129.181	BRACING		****								
05129.187	STRUCTURAL TUBING	313.25	CWT	C510	60.00	DAY	38.3067	35.000	5.000	78.307	24,529.68
05129.403	SHEAR STUD, 5/8"	10,723.00	EACH	C509	1,400.00	DAY	0.5434	0.666	0.300	1.509	16,181.01
05129.990	* STRUCTURAL STEEL WEIGHT *	213.40	TONS								
05310.018	2" METAL DECK	65,969.90	SQFT	C510	5,170.00	DAY	0.4445	0.870		1.315	86,743.82
	* Total 5th floor										441,294.81
	Total Estimate										2,610,622.77

Appendix 5

Roof Lite Product Specifications

rooflite™ extensive mc

is a growing medium for extensive green roofs in multi-course construction according to the German FLL-Guidelines*. The material is a mixture of **HydRocks**™ with other mineral and organic components complying with the following requirements:

Granulometric distribution

-	passing US # 100	(d=0.15 mm)	$\leq$ 20 mass %
	passing US # 50	(d=0.30 mm)	5 – 30 mass %
	passing US # 30	(d=0.60 mm)	20 – 45 mass %
	passing US # 16	(d=1.18 mm)	30 – 60 mass %
	passing US # 8	(d=2.36 mm)	50 – 80 mass %
	passing US # 4	(d=4.75 mm)	65 – 95 mass %
	passing US 3/8	(d=9.50 mm)	95 – 100 mass %
-	proportion of slurry-forming components (d $\leq$ 0.063 mm)		$\leq$ 15 mass %

Apparent density (volume weight)

-	when dry	< 0.80 g/cm^3	(50 lb/ft^3)**
-	at maximum water capacity	< 1.20 g/cm^3	(75 lb/ft^3)**

Water and air management

-	maximum water-holding capacity	$\geq$ 35% Vol.%
-	air content at maximum water capacity	$\geq$ 10% Vol.%
-	water permeability (saturated hydraulic conductivity)	$\geq$ 0.0236 in/min

pH value, salt content

-	pH value (in $CaCl_2$)	6.5 – 8.0
-	salt content (water extract)	$\leq$ 3.5 g/l
-	salt content (gypsum extract)	$\leq$ 2.5 g/l

Organic substances

-	organic content	$\leq$ 8.0 mass %

Nutrients

- Nutrients available to plants

-	Nitrogen /N) (in $CaCl_2$)	$\leq$ 80 mg/l
-	Phosphorus (P_2O_5) (in CAL)	$\leq$ 200 mg/l
-	Potash (K_2O) (in KAL)	$\leq$ 700 mg/l
-	Magnesium (Mg) (in $CaCl_2$)	$\leq$ 160 mg/l

Additional requirements

- absence of any phytotoxic substances
- absence of foreign substances
- fire resistance
- frost resistance

Supplier: **Skyland USA LLC,**
P.O. Box 640, Avondale, PA 19311
877-268-0017 www.skylandusa.us

* *Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL). 2002. Guidelines for the Planning Execution and Upkeep of Green-Roof Sites*

** *Values may vary depending on regional availability of components*

rooflite™

rooflite^{TM} extensive mc Analysis*

Results on dry weight basis unless specified otherwise

Analysis	Units	Result	FLL Reference Values
Particle Size Distribution (See accompanying report)			
< 0.05 mm *(Fll reference value based on < 0.06 mm)*	mass %	6.2	≤ 15
Denisty Measurements			
Bulk Density (dry weight basis)	g/cm3	0.73	
Bulk Density (dry weight basis)	lb/ft3	45.75	
Bulk Density (at max. water-holding capacity)	g/cm3	1.16	
Bulk Density (at max. water-holding capacity)	lb/ft3	72.52	
Water/Air Measurements			
Moisture *(as received basis)*	mass %	13.4	
Total Pore Volume	Vol. %	53.3	
Maximum water-holding Capacity	Vol. %	46.3	≥ 35
Air-Filled Porosity (at max water-holding capacity)	Vol. %	25.6	≥ 10
Water permeability (saturated hydraulic conductivity)	cm/s	0.031	≥ 0.001
Water permeability (saturated hydraulic conductivity)	in/min	0.731	≥ 0.0236
pH and Salt Content			
pH (CaCl2)		6.6	6.5 - 8.0
Soluble salts (water, 1:10, m:v)	mmhos/cm	0.10	
Soluble salts (water, 1:10, m:v)	g (KCl)/L	0.47	≤ 3.5
Organic Measurements			
Organic matter content	mass %	5.2	≤ 8.0
Nutrients			
Phosphorus, P205 (CAL)	mg/L	26.5	≤ 200
Potassium, K2O (CAL)	mg/L	192.4	≤ 700
Magnesium, Mg (CaCl2)	mg/L	40.6	≤ 160
Nitrate + Ammonium (CaCl2)	mg/L	6.3	≤ 80

[1] *Forschungsgesellschaft Landschaftsentiwicklung Landschaftsbau (FLL). 2002. Guidelines for the Planning Execution and Upkeep of Green-Roof Sites*

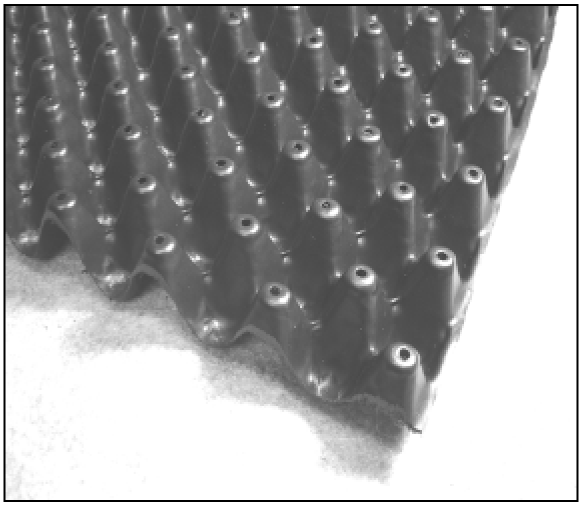
* Test results may vary within the limits set forth by the FLL. For the latest test results from your regional blender contact www.SkylandUSA.us

Appendix 6

Hydro-Tech Product Specifications

HYDROTECH

GARDENDRAIN™ GR30 PRODUCT DATA SHEET



GENERAL DESCRIPTION

Gardendrain GR30 is made of recycled polyethylene, molded into a three-dimensional panel. The unique design provides retention cups on the top side, drainage channels on top and bottom and holes in the tops of the "domes" for ventilation and evaporation.

BASIC USE

Gardendrain GR30 is specifically designed to act as a drainage and water retention element in Hydrotech's Garden Roof® Assembly. It is typically utilized under both extensive and intensive landscaping.

TECHNICAL DATA

PANEL DIMENSIONS:		4 ft. X 6 ft. (1.2 m X 1.8 m)
PANEL HEIGHT:		1 1/4 in. (30 mm)
WEIGHT:	w/cups empty	0.3 lb/ft^2 (1.5 kg/m^2) – dry; 1.6 lb/ft^2 (7.9 kg/m^2) - wet
	w/cups filled*	2.4 lb/ft^2 (12 kg/m^2) – dry; 3.8 lb/ft^2 (19.2 kg/m^2) - wet
COMPRESSIVE STRENGTH: (ASTM D1621)		5,069 lb/ft^2 (cups empty); 13,000+ lb/ft^2 (cups filled)
FLOW RATE: (ASTM D4716)		38 gal./min./ft. width (479 l./min./m.); h.g. = 1
WATER RETENTION:		≈0.16 gal/ft^2 (6.6 l/m^2) cups empty; ≈0.18 gal/ft^2 (7.6 l/m^2) cups filled
VOLUME TO FILL:		≈0.04 cu.ft. for every 1 sq. ft. in area (1.2 liters)

*cups filled = Gardendrain element filled with LiteTop® expanded aggregate level with tops of element dimples

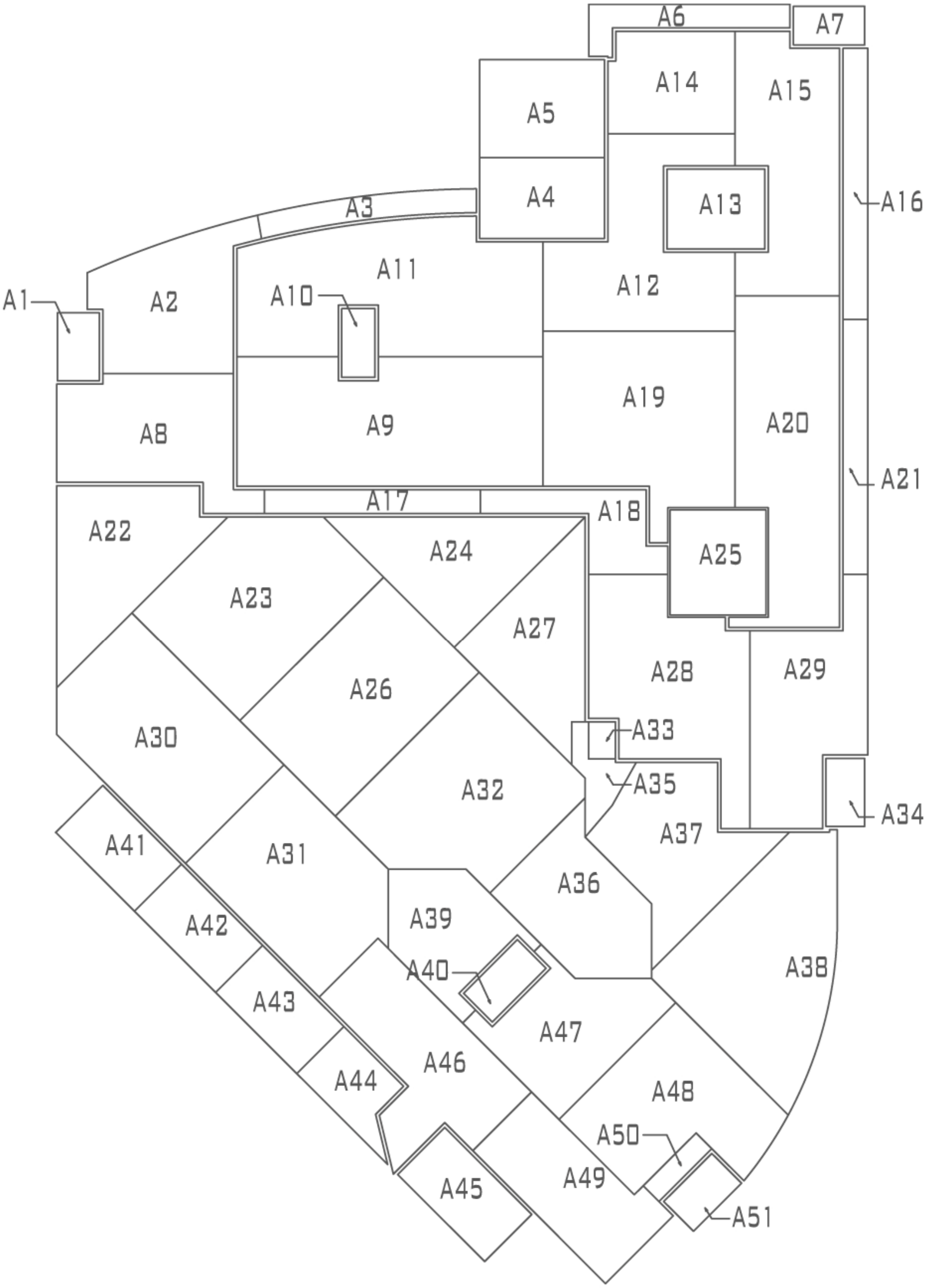
INSTALLATION

- GR30 is to be installed loose-laid over the specified root barrier, STYROFOAM® insulation or Moisture Retention Mat over the entire surface of the roof.
- GR30 is easily cut to fit around penetrations, perimeters, drains, etc. with a heavy-duty utility knife or small- toothed saw.
- Adjacent panels are typically butted together.
- The retention cups of GR30 are typically filled with lightweight expanded aggregate under lawn and hardscape areas but can be left empty under extensive applications.

American Hydrotech, Inc.
303 East Ohio Street, Chicago, IL 60611 * (312)337-4998 * (312)661-0731 fax * 10/07
www.hydrotechusa.com

Appendix 7

Roof Drainage Areas Plan



Appendix 8

Roof Drainage Area Calculations

Rainfall Area

Mark	Projected Area [ft2]	Vertical Area [ft 2]	Total Area	Drain	Total Area	Leader Size-Inch
A1	251	67	318	D2	2,277.82	3
A2	1,622	338	1,960	D2	-	-
A3	459	412	871	D3	870.87	2
A4	888	103	991	D12	-	-
A5	1,077	82	1,159	D14	-	-
A6	477	152	629	D6	629.21	2
A7	242	65	307	D15	-	-
A8	1,795	351	2,146	D8	2,145.90	2
A9	3,399	248	3,647	D9	3,646.70	3
A10	206	60	267	D11	3,938.39	3
A11	3,183	489	3,672	D11	-	-
A12	2,168	748	2,916	D12	3,906.61	3
A13	686	109	795	D15	-	-
A14	1,125	53	1,178	D14	2,337.29	3
A15	2,105	86	2,190	D15	3,292.41	3
A16	589	88	677	D16	677.13	2
A17	453	409	862	D17	862.22	2
A18	709	483	1,191	D18	1,191.32	2
A19	2,833	329	3,162	D19	4,171.88	3
A20	2,105	186	2,290	D20	2,290.29	3
A21	554	418	971	D21	971.23	2
A22	1,678	355	2,034	D22	2,033.79	2
A23	2,528	214	2,743	D23	2,742.57	3
A24	1,503	-	1,503	D24	1,502.77	2
A25	886	125	1,010	D19	-	-
A26	2,411	-	2,411	D26	2,410.92	3

Rainfall Area

Mark	Projected Area [ft2]	Vertical Area [ft 2]	Total Area	Drain	Total Area	Leader Size-Inch
A27	1,494	-	1,494	D27	1,493.98	2
A28	239	447	686	D28	685.79	2
A29	1,880	254	2,134	D29	2,134.28	2
A30	2,584	69	2,653	D30	2,652.55	3
A31	2,245	56	2,301	D31	2,301.36	3
A32	2,620	-	2,620	D32	2,619.92	3
A33	88	105	192	D33	192.27	2
A34	231	316	547	D29	546.50	2
A35	352	32	384	D35	384.38	2
A36	1,422	-	1,422	D36	1,422.21	2
A37	251	-	251	D37	250.72	2
A38	2,686	153	2,839	D38	2,838.86	3
A39	1,130	50	1,180	D39	1,524.22	2
A40	270	75	345	D39	-	-
A41	656	692	1,349	D41	1,348.59	2
A42	670	693	1,363	D42	1,362.83	2
A43	670	693	1,363	D43	1,362.83	2
A44	546	1,259	1,804	D44	1,804.11	2
A45	718	1,076	1,795	D45	1,794.53	2
A46	1,843	111	1,954	D46	1,953.61	2
A47	1,447	214	1,661	D47	1,660.99	2
A48	1,962	81	2,043	D48	2,042.83	2
A49	1,420	143	1,563	D49	1,562.71	2
A50	146	115	261	D50	585.94	2
A51	251	75	325	D50	-	-