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Cincinnati, Ohio

Courtesy of Bernard Tschumi Architects

Structural Concepts/Structural Existing Conditions Report
October 8, 2003

Executive Summary

This report investigates the structural concepts used to design the University of Cincinnati Athletic Center in Cincinnati, Ohio. It is broken down into four sections:

Building Description

The UC Athletic Center is an 8 story, 220,000 ft^2 multi-use sports facility. It has a unique curved shape and "diagrid" exterior. The floor and roof systems are composite steel wide flange beams with composite slab-on-deck. Typical bays are about 27'x27', thought the layout is highly varied by floor. Interior columns are full height. Exterior "V" columns support the rigid diagrid enclosure, transferring load into spread footings and piers below grade. Lateral bracing is composed of the diagrid structure, braced frames, and foundation shear walls.

Design Codes and Standards

The 1998 Ohio Basic Building Code is the model code. Loading is determined with ASCE 7-98.

Calculations

Gravity (structure self weight, superimposed dead and live) and Lateral (wind and seismic) loads were derived and summed. Total dead weight per above-grade floor varied from 2300-2800 kips. Critical unfactored wind base shear (408.3k) is greater than unfactored seismic base shear (392.0k).

Spot checking will be done for one floor framing element and one lateral frame. These calculations have not been performed yet.

Additional Considerations

Building Description

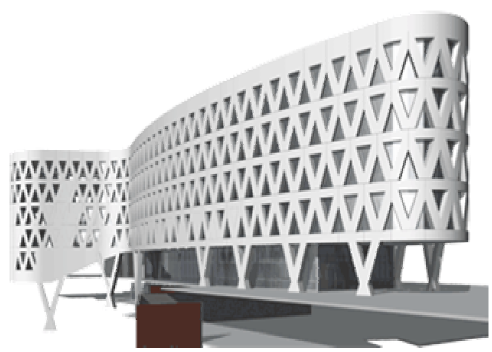
Introduction

The University of Cincinnati Athletic Center is an 8 story, 220,000 ft^2 multi-use facility to be located in the heart of UC's "Varsity Village" athletic complex. The building is designed to accommodate various sports-related activities all under one roof and to function as the social link and architectural centerpiece of a multi-stage athletic expansion plan. As such, it will be situated between two main sports facilities, the Nippert Football Stadium and the Shoemaker Center, with easy access to other sports fields and areas. See figure in Appendix A.1.

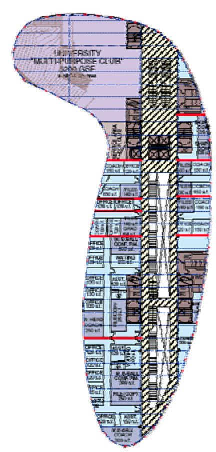
The structure is made up of 3 below-grade stories (levels 100-300) and 5 above-grade stories (levels 400-800). The structure will accommodate office space, public meeting areas, computer labs, locker rooms, treatment areas, and other related athletic support.

Architecture

Architecturally, the design is characterized by its unique exterior façade (right). The façade consists of a triangulated "exo-skeleton" of concrete-covered steel. This skeleton, referred to as a "diagrid", forms a visually dominant shell around the building. The heaviness of this exterior system is offset by its light color and appears to be lifted off the ground by a series of v-shaped columns.



Also unique to the building is its curved shape. There are no corners in above-grade plan, creating a rather unusual kidney or "link-pin" shape (right). The interior space of the building itself is divided by a 5-story atrium running down the middle of its main section. To each side are offices, meeting rooms, and administrative areas. Below ground is a more conventional rectangular footprint, with mainly sports facilities and locker rooms. Horizontal movement through the building is kept simple by its compact design, however vertical movement is facilitated by a set of elevators and a grand staircase in the atrium.



Structural System

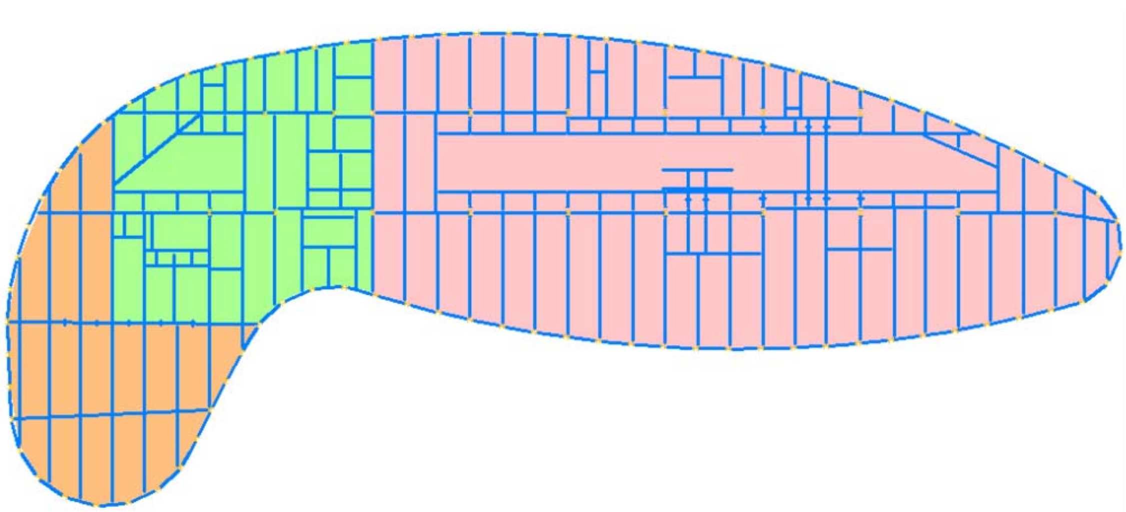
Floor system

The floor framing is typical steel composite beams with composite metal decking supporting one-way slab diaphragms. Most connections are shear only, however, some elements framing into full height columns near the atrium are designed with moment connections to support atrium walkways. The layout is not regular due to the highly curved shape of the building, however, the N-S direction spacing is typically 9' o.c. In general, three main framing areas can be identified on the above-grade floors as shown in the figure below. These are:

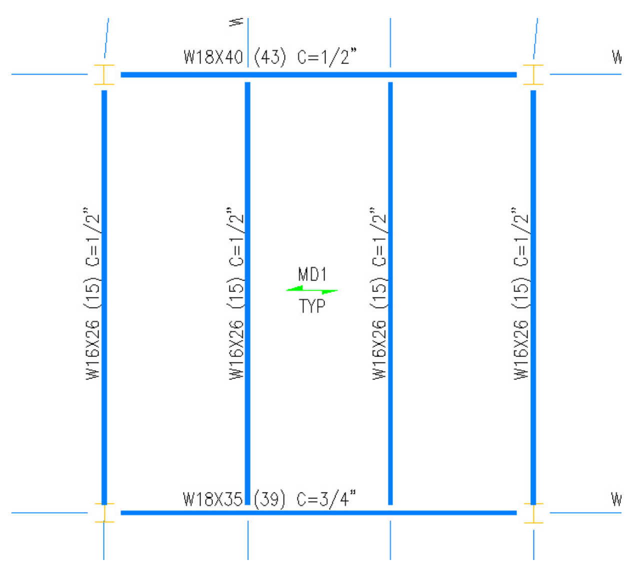
Orange – North bays (longer, more regular spans)

Green – Elevator and stair cores (highly varied, shorter spans)

Pink – Atrium bays (regular spacing with moment connections)



The closest approximation to a typical bay occurs in the rectangular basement at levels 200 and 300. A bay there measures 27' x 27'-8" with intermediate beams spaced at 9' o.c. The beams are partially composite, with a 6.5 inch slab-on-deck. Deck depth is 2 inches. A diagram representing this typical bay is shown at right.



Roof
The roof is also a composite steel beam system with composite slab. The roof consists of a lower roof and high roof. The high roof covers the atrium and the east portion of the building. The layout is consistent with the 27' bays found on lower levels. Slab thickness on the roof is 6 inches with a 2 inch deck.

Columns
Within the building there are two main rows of steel columns. These rows straddle the atrium in the N-S direction and support the interior gravity loads from the floors and partitions. All interior columns are the full height of the building.

On the upper exterior floors (levels 500-800), the diagrid carries the vertical loads, and therefore there are no typical columns. At levels 400 and 300, however, the diagrid is supported by large "V" columns. These are either heavy wide flange rolled shapes or built-up boxes. They are rigidly connected to both the diagrid and the substructure. Gravity loads from the upper floors is transferred down through the V columns into single below-grade columns. A rendering of a V column is shown right.

Foundation
The foundation utilizes a combination of spread footings and drilled piers, set into sound gray shale. Shear walls are typically 1'6" thick. Part of the foundation will be built over portions of existing facilities. These facilities have been demolished and the nearby Shoemaker Center is underpinned during excavation to ensure structural integrity. A portion of the building along the North side interfaces with the Shoemaker Center.

Enclosure
As explained above, the enclosure consists primarily of a diagrid structure. The diagrid acts as a rigid shell, and for structural purposes can be considered a very thin, deep beam. The diagrid itself is composed of wide flange rolled sections welded or bolted for full restraint. The steel will be covered with concrete or similar material to produce a monolithic appearance. Between the beams are triangular window glazings. A rendering of the diagrid connection is shown right.

Lateral bracing
Wind and seismic loading is transferred to the ground through an unusual lateral system. Loads are accumulated above grade at the diagrid façade. Since the façade acts as a rigid structure, it transfers all loads to a braced frame system at the diagrid base (level 500). The braced frame acts in tandem with the moment-connected V columns to transfer the shear into the foundation shearwalls and

substructure columns. Two braced frames for the critical E-W loading are located approximately centrically on either end of the building. These braced frames will be discussed in more detail in a later section.

Material Strengths

Material strengths were obtained from drawing general notes.

Reinforced Concrete

Location	Aggregate	f'_c (psi)
Footings, piers	Normal weight	3000
Slab on grade	Normal weight	3000
Walls and columns	Normal weight	4000
Beams and slabs	Normal weight	4000
Slab on steel deck	Normal weight	3000
Equipment pads/curbs	Normal weight	3000
Lean concrete	Lightweight	3000

Reinforcement

Type	ASTM Standard	f_y (ksi)
Deformed reinforcing bars	A615 Gr. 60	60
Welded wire fabric	A185 Gr. 70	70

Structural Steel

Shape	ASTM Standard	f_y (ksi)
Wide flanges	A992	50
Channels and tees	A572 Grade 50	50
Rectangular & round HSS	A500 Grade B	46
Pipes	A53 Type E	35
Angles	A36	36
Plates	A36	36
Built-up sections (box & I)	A572 Grade 50	50

Design Codes and Standards

Building Codes

1998 Ohio Basic Building Code
2002 Ohio Building Code (Seismic Design Only)

Design Specifications and Standards

Loads

ASCE 7-98 “Minimum Design Loads for Buildings and Other Structures”

Concrete

ACI 301 “Specifications for Structural Concrete for Buildings”
ACI 315 “Manual of Standard Practice for Detailing Reinforced Concrete Structures”
ACI 318 “Building Code Requirements for Reinforced Concrete and Commentary”

Structural Steel

AISC “Manual of Steel Construction, Load and Resistance Factor Design”, 3rd Edition
AISC “Code of Standard Practice for Steel Buildings and Bridges”

AWS D1.1 “Structural Welding Code”
AISC “Specification for Structural Joints Using ASTM A325 or A490 Bolts”
AISI “Specification for the Design of Cold-Formed Steel Structural Members”
AISC/CISC – Steel Design Guide Series 11: Floor Vibrations Due to Human Activity

Calculations

Loads

Building loads were obtained using ASCE 7-98 Standard, which is referenced in the 1998 Ohio Basic Building Code. The loading can be split into two main categories, gravity loads and lateral loads. Most of this section is referenced in appendices for convenience and ease of reading, due to its computation-intensive nature.

Gravity

Gravity loads consist of the superstructure dead load, the superimposed dead load, and live loading.

Superstructure load – The structural engineer used a computer analysis program to determine the self weight of the superstructure. Since this is a preliminary report, these loads were estimated using a simplified procedure. The theory behind the procedure is found in Appendix B.1, while the load calculations are tabulated in Appendix B.2.

Superimposed load – Loading diagrams on the drawings were used to compile total superimposed loads for each floor. Appendix B.3 shows the dead load for each type of occupancy in the “Total Dead” column. Appendix B.4 tabulates the total load for each floor. These calculations will be used in a later section. Dead Loads are summarized below.

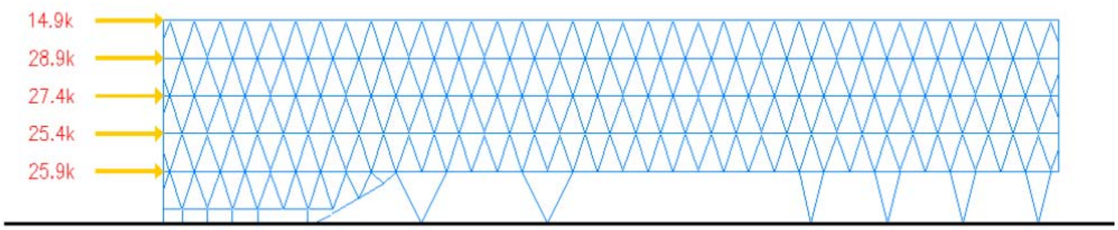
Level	Superimposed (kip)	Superstructure (kip)	Total (kips)
Roof	1973	368	2341
800	2084	438	2522
700	2100	438	2538
600	2361	438	2800
500	2209	390	2600
400 (ground)	5026	460	5486

Live load – Loading diagrams on the drawings were used to compile live loads for each floor. Appendix B.3 shows the live load for each type of occupancy in the “Live Load” column. Snow loads were assumed to be 30psf with 50psf drifts as indicated on the drawings.

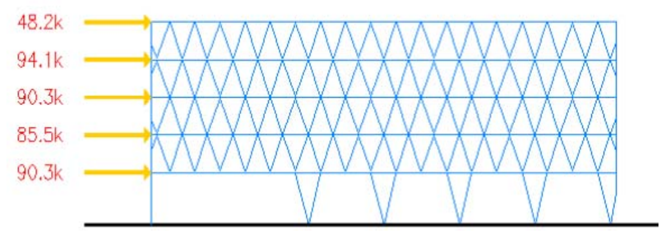
Lateral

Lateral loads were evaluated for wind and seismic loading.

Wind – Wind loads were based on a 90mph basic wind speed, exposure B, and an importance factor of 1.15. Though the shape of the building is unusual, the structural engineer made the assumption that the building could be modeled as a simple rectangular box, 5 stories high. The high roof was not taken into consideration for purposes of simplicity. The preliminary calculations are found in Appendix C.1. Wind pressures gradients were evaluated in both the N-S and E-W directions, as found in Appendix C.2. The summation of story shear is evaluated in Appendix C.3. They are summarized in graphical format below.

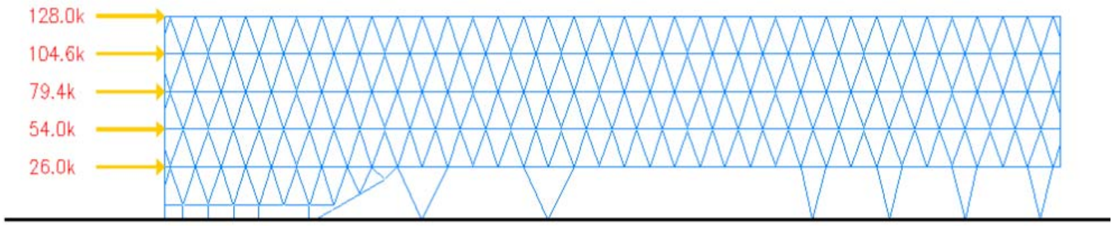


Wind shear in N-S direction



Wind shear in E-W direction

Seismic - The governing code used in the structural design of the UCAC is the 2002 OBBC, which is adapted from the IBC 2000. IBC 2000 references ASCE 7, and therefore seismic analysis was performed using ASCE 7-98 for consistency with the wind analysis. The design is based on Seismic Use Group II, Site Class B, and an importance factor of 1.25. Using these provisions, the building fell under Seismic Design Category A, and therefore the story shear could be calculated as F_x=0.01*g. Preliminary calculations to determine the SDC are found in Appendix C.4. Seismic story shear is summarized in the figure below, with the total base shear equal to 392 kips.



Seismic shear in both directions.

Spot Checking

Spot checking for one floor framing element and one lateral frame was done using the loads calculated in the Loads section.

Floor framing element

Not yet completed

Lateral frame

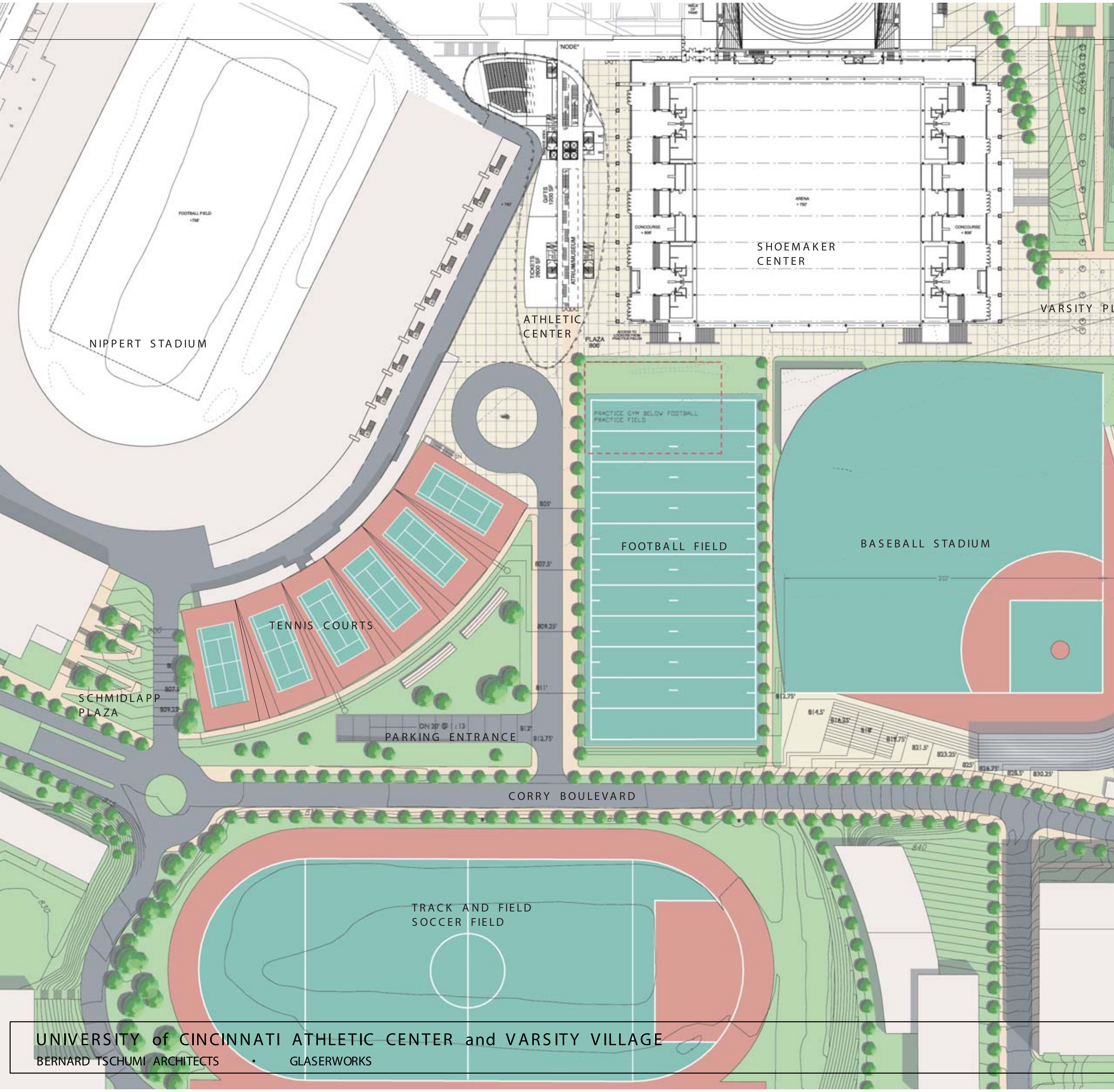
Not yet completed

Additional Considerations

Not yet completed

Notes:

Full calculations and design materials are available upon request.
All images courtesy of Bernard Tschumi Architects or Arup Services.


NIPPERT STADIUM
ATHLETIC CENTER
SHOEMAKER CENTER
VARSITY PL
FOOTBALL FIELD
BASEBALL STADIUM
TENNIS COURTS
SCHMIDLAPP PLAZA
PARKING ENTRANCE
CORRY BOULEVARD
TRACK AND FIELD
SOCCER FIELD
UNIVERSITY of CINCINNATI ATHLETIC CENTER and VARSITY VILLAGE
BERNARD TSCHUMI ARCHITECTS • GLASERWORKS

SUPERIMPOSED LOADS

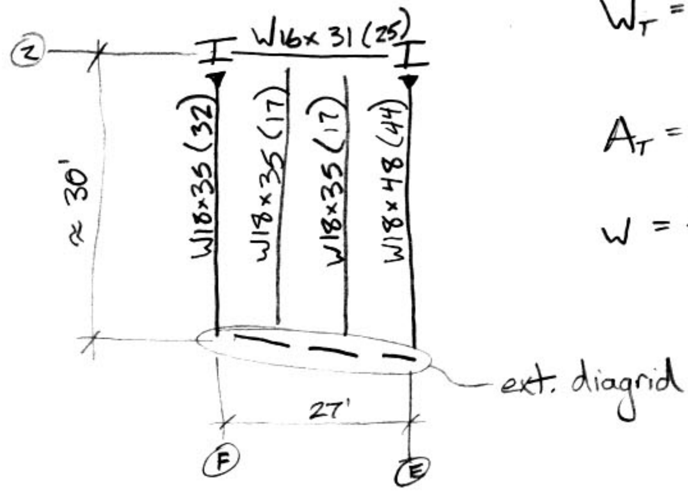
SEE Excel Spreadsheet, taken from drawings

CONST. LOADS

FLOOR FRAMING

Find a "typical" bay:

FLOOR 4 (700)



$W_T = 31 \cdot 27' + 35 \times 30' \cdot 3 + 48 \cdot 30' + (25 + 32 + 2 \cdot 17 + 44) \cdot 10 = 6780$ lbs.

$A_T = 30' \cdot 27' = 816$ sf.

$w = \frac{W_T}{A_T} = \frac{6780}{816} = 8.37$ psf

$\Rightarrow$ 10 psf (conservative)

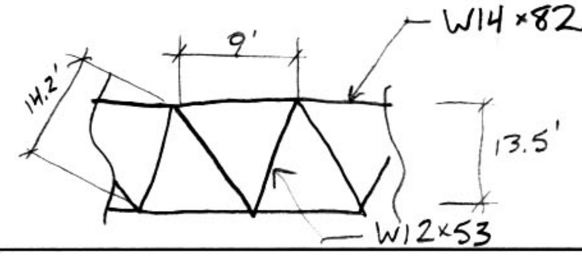
COLUMNS

	# of cols	Typ weight (plf)	Height	Wt/floor
not necessary { LEVELS 100-300	44 cols	170	15'	112.2^k
not necessary { LEVEL 300-400	63 cols	170	14'	149.9^k
LEVEL 400-500	21 cols	120	18'	45.4^k
LEVELS 500-Roof	17 cols	60	13.5'	13.8^k

Summarized in Excel

ENCLOSURE

Typ Frame size + geometry:
(from dwgs.)



ARUP

Job No.	Sheet No. Appendix B.1	Rev.
Member-Location		
Drg. Ref.		
Made by	Date	Chd.

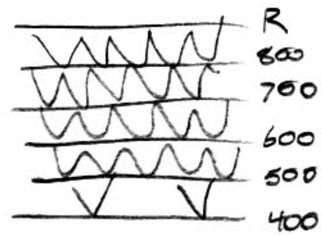
Job Title

ENCLOSURE (CONT'D)

Perimeter found by CAD = 760'

Horiz. members: $82 \cdot 760' = 62.3^{k}$ / level

Diag. members: $53 \cdot 14.2' \cdot \frac{760'}{4.5'} = 127.1^{k}$ / level



CALCS IN EXCEL

Superstructure Dead Load

	Floor Framing			Columns					Enclosure			
Level	Dist. Load (psf)	Area (ft^2)	Weight/floor (kips)	# of cols.	Typ. weight (plf)	Story Ht. (ft)	Wt./floor (kips)	Trib. Wt. (kips)	Horiz. Mem. (kips)	Diag. Mem. (kips)	Trib. Wt. (kips)	Total
Roof	10	23500	235					6.9	62.3		63.6	367.7
				17	60	13.5	13.8			127.1		
800	10	23500	235					13.8	62.3		127.1	438.2
				17	60	13.5	13.8			127.1		
700	10	23500	235					13.8	62.3		127.1	438.2
				17	60	13.5	13.8			127.1		
600	10	23500	235					13.8	62.3		127.1	438.2
				17	60	13.5	13.8			127.1		
500	10	23500	235					29.6	62.3		63.6	390.4
				21	120	18	45.4					
400	10	37500	375					22.7	62.3			460.0

Superimposed Load Types

	Area Occupancy	Floor Finish (psf)	Floor Slab (psf)	Ceiling/Services (psf)	Partitions (psf)	Additional (psf)	Total Dead (psf)	Live Load (psf)	Total Unfactored (psf)
1	High Roof		60	10			70	30	100
2	Office		66	10	20		96	50	146
3	Multi-purpose club		66	10			76	100	176
4	Stair					30	30	100	130
5	Atrium/Corridor	25	66	10			101	100	201
6	Mechanical room		66	10		50	126	125	251
7	Computer lab	25	66	10			101	100	201
8	Fixed seating		110	10		10	130	60	190
9	Stage	25	66	10			101	100	201
10	Lobby/General assembly	25	66	10			101	100	201
11	Locker room	25		10	20		55	100	155
12	Work area	25	65	10	20		120	100	220
13	Showers/Rest room	25	66	10			101	60	161
14	Storage	25	66	10			101	125	226
15	Laundry	25		10			35	150	185
16	Ramp	25	66				91	100	191
17	Elevator machine room		66				66	250	316
18	Meeting room		66	10			76	60	136
19	Treatment area	25	66	10	20		121	100	221
20	Video room	25	66	10	20		121	100	221
21	Hydrotherapy	25	66	10			101	400	501
22	Loading dock	30	66	10			106	100	206
23	Ambulance parking	30	79	10			119	100	219
24	Walkway roof	13	5				18	30	48
25	Theater control room	25	66	10	20		121	100	221
26	Trash compactor		66	10			76	350	426
27	Roof	25	60	10			95	60	155
28	Exterior truck loading	90	79	10			179	100	279
29	Exterior non-truck loading	90	66	10			166	100	266

Appendix B.4

Superimposed Dead Load Calculations

	Level																	
	100		200		300		400		500		600		700		800		Roof	
Type	Area (ft^2)	Total (kip)	Area (ft^2)	Total (kip)	Area (ft^2)	Total (kip)	Area (ft^2)	Total (kip)	Area (ft^2)	Total (kip)	Area (ft^2)	Total (kip)	Area (ft^2)	Total (kip)	Area (ft^2)	Total (kip)	Area (ft^2)	Total (kip)
1																	10382	727
2			2224	214	997	96	3586	344	7583	728	10249	984	9973	957	10038	964		
3													4234	322	4772	363		
4			483	14	669	20	1046	31	1615	48	1428	43	1694	51	1655	50		
5			3750	379	3598	363			6170	623	5887	595	6106	617	6058	612		
6			1558	196	10932	1377					5472	689						
7									2228	225								
8							2307	300	2485	323								
9							803	81					544	55				
10							8907	900										
11	17259	949																
12																		
13							2017	204	1053	106	501	51	969	98	955	96		
14			641	65														
15	4393	154																
16					887	81												
17	358	24																
18			8510	647	548	42												
19			3529	427	1749	212												
20																		
21			943	95														
22					2556	271												
23					1033	123												
24																		
25									1282	155								
26					451	34												
27																	13119	1246
28					5050	904	4723	845										
29							13982	2321										
Sums	22010	1127	21638	2037	28470	3523	37371	5026	22416	2209	23537	2361	23520	2100	23478	2084	23501	1973

ARUP

Job No.	Sheet No. Appendix C.1	Rev.
Member-Location		
Drg. Ref.		
Made by BJG	Date 10.6.03	Chd.

Job Title: UCAC Wind Calcs.
ASCE 7-98 Ch. 6

Is the building rigid?

From ASCE 7-98, 9.5.3.3 $T_a = C_T \cdot h_n^{\frac{3}{4}}$ (period)

$C_T = .02$ (for braced w/ moment frames)

$h_n = 72'$ (from level 400)

$T_a = .02 \cdot 72^{\frac{3}{4}} = .49\ s$

$f = \frac{1}{T_a} = \frac{1}{.49} = 2.02\ \frac{cyc.}{s}$ (frequency)

$f > 1\ Hz$ ∴ building is rigid

Find pressures

$p_w = q_z \cdot G \cdot C_p$ (rigid)

$p_\ell = q_h \cdot G \cdot C_p$

$q_z = .00256\, K_z \cdot K_{zt} \cdot K_d \cdot V^2 \cdot I$

K_z = (Exposure B, Case 2 - Table 6-5)

K_z	Height
.57	0-15 ft
.62	20'
.66	25'
.70	30'
.76	40'
.81	50'
.85	60'
.89	70'
.93	80'

$K_{zt} = (1 + K_1 K_2 K_3)^2 = (1 + .6 \cdot 1.0 \cdot .14)^2 = 1.18$ (from Figure 6-2 using geotech data)

$K_d = .85$ (Table 6-6)

$V = 90$ mph (Figure 6-1)

$I = 1.15$ (Table 6-1, Category III)

$G = .85$ (assumed)

$C_p = .8$ (windward)

$-.2$ ($L/B \approx \frac{300}{120} = 2.5$, leeward N-S)

$-.5$ ($L/B \approx \frac{120}{300} = .4$, leeward E-W)

ARUP

Job No.	Sheet No. Appendix C.1	Rev.
Member-Location		
Job Title: UCAC Wind Calcs ASCE 7-98	Drg. Ref.	
Made by: BJG	Date: 10.6.03	Chd.

$q_h = \frac{72-70}{80-70}(.93-.89)(q_z) + (q_z) \cdot .89$

$q_z = .00256 \cdot 1.18 \cdot .85 \cdot 90^2 \cdot 1.15 \cdot K_{zt} = 23.9 \; K_z$

$q_h = 21.5$ psf

$p_w = 23.9 \cdot K_z \cdot .85 \cdot .8 = 16.3 \cdot K_z$ (Windward, N-S or E-W)

$p_l = 21.5 \cdot .85 \cdot (-.2) = -3.7$ psf (Leeward, N-S)

$p_l = 21.5 \, .85(-.5) = -9.1$ psf (Leeward, E-W)

Calculations

Done in Excel

University of Cincinnati Athletic Center
Brian Genduso

10/8/2003

N-S Direction

Coefficients	
Windward	16.3
Leeward	-3.7

Height (ft)	Kz	Windward (psf)	Leeward (psf)	Total MWFRS (psf)
0-15	0.57	9.3	-3.7	13.0
15-20	0.62	10.1	-3.7	13.8
20-25	0.66	10.8	-3.7	14.5
25-30	0.70	11.4	-3.7	15.1
30-40	0.76	12.4	-3.7	16.1
40-50	0.81	13.2	-3.7	16.9
50-60	0.85	13.9	-3.7	17.6
60-70	0.89	14.5	-3.7	18.2
70-80	0.93	15.2	-3.7	18.9

E-W Direction

Coefficients	
Windward	16.3
Leeward	-9.1

Height (ft)	Kz	Windward (psf)	Leeward (psf)	Total MWFRS (psf)
0-15	0.57	9.3	-9.1	18.4
15-20	0.62	10.1	-9.1	19.2
20-25	0.66	10.8	-9.1	19.9
25-30	0.70	11.4	-9.1	20.5
30-40	0.76	12.4	-9.1	21.5
40-50	0.81	13.2	-9.1	22.3
50-60	0.85	13.9	-9.1	23.0
60-70	0.89	14.5	-9.1	23.6
70-80	0.93	15.2	-9.1	24.3

N-S Direction

Building height (ft)	72
Building trib width (ft)	120

Level	Story ht. (ft)	Trib ht. (ft)	Total ht. (ft)	P 1 (psf)	H 1 (ft)	P 2 (psf)	H 2 (ft)	P 3 (psf)	H 3 (ft)	Story Dist. Load (plf)	Cum. Dist. Load (plf)	Story Shear (kips)	Cum. Shear (kips)
Roof		6.75		18.2	4.75	18.9	2			124	124	14.9	14.9
	13.5		65.25										
800		13.5		17.6	8.25	18.2	5.25			241	365	28.9	43.8
	13.5		51.75										
700		13.5		16.1	1.75	16.9	10	17.6	1.75	228	593	27.4	71.2
	13.5		38.25										
600		13.5		14.5	0.25	15.1	5	16.1	8.25	212	805	25.4	96.6
	13.5		24.75										
500		15.75		13	6	13.8	5	14.5	4.75	216	1021	25.9	122.5
	18		9										
400 (ground)		9		13	9					N/A	N/A	N/A	122.5

E-W Direction

Building height (ft)	72
Building trib width (ft)	300

Level	Story ht. (ft)	Trib ht. (ft)	Total ht. (ft)	P 1 (psf)	H 1 (ft)	P 2 (psf)	H 2 (ft)	P 3 (psf)	H 3 (ft)	Story Dist. Load (plf)	Cum. Dist. Load (plf)	Story Shear (kips)	Cum. Shear (kips)
Roof		6.75		23.6	4.75	24.3	2			161	161	48.2	48.2
	13.5		65.25										
800		13.5		23	8.25	23.6	5.25			314	474	94.1	142.3
	13.5		51.75										
700		13.5		21.5	1.75	22.3	10	23	1.75	301	775	90.3	232.6
	13.5		38.25										
600		13.5		19.9	0.25	20.5	5	21.5	8.25	285	1060	85.5	318.0
	13.5		24.75										
500		15.75		18.4	6	19.2	5	19.9	4.75	301	1361	90.3	408.3
	18		9										
400 (ground)		9		18.4	9					N/A	N/A	N/A	408.3

Determine Seismic Design Category

From Wind Analysis, Table 1-1, Occupancy Category = III
∴ Seismic Use Group = II (Table 9.1.3)

Site classification

From Basis of Design report, in conjunction w/ the geotech report from H.C. Nutting Co., Site class. = B
(rock w/ $2500 \frac{ft}{s} \le v_s \le 5000$)

Spectral Response Accelerations

$S_s = .20$ (from Figure 9.4.1.1 (a))
$S_1 = .09$ (from Figure 9.4.1.1 (b))

$F_a = 1.0$ (Table 9.4.1.2.4a)
$F_v = 1.0$ (Table 9.4.1.2.4b)

$S_{MS} = F_a \cdot S_s = 1.0 \cdot .2 = .20g$ ← gravitational constant
$S_{M1} = F_v \cdot S_1 = 1.0 \cdot .09 = .09g$

$S_{DS} = \frac{2}{3} S_{MS} = \frac{2}{3} \cdot .2 = .133g$
$S_{D1} = \frac{2}{3} S_{M1} = \frac{2}{3} \cdot .09 = .06g$

From Table 9.4.2.1a, SDC = A
From Table 9.4.2.1b, SDC = A
} ∴ SDC = A

Section 9.5.2.5.1 specifies that a building in SDC = A can be designed using $F_x = .01 w_x$

Excel used to calculate story shear