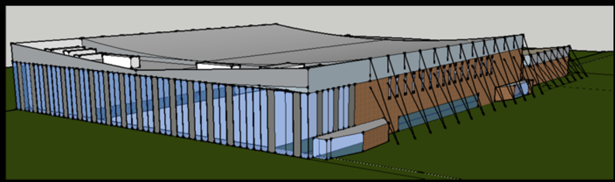
lightsout DESIGN



Mission Statement:
To deliver innovative designs, with an integrated, streamlined approach to building systems and construction management

Nate Babyak Alex Ho Brian Sampson Alex Schreffler

AGENDA

- Introduction
- BIM Process
- Roof Design
- Lobby Design
- Moving Forward

BIM THESIS GOALS

To develop a greater understanding of the wants and needs of each discipline

To recognize design conflicts before they reach construction

To design with constructability in mind

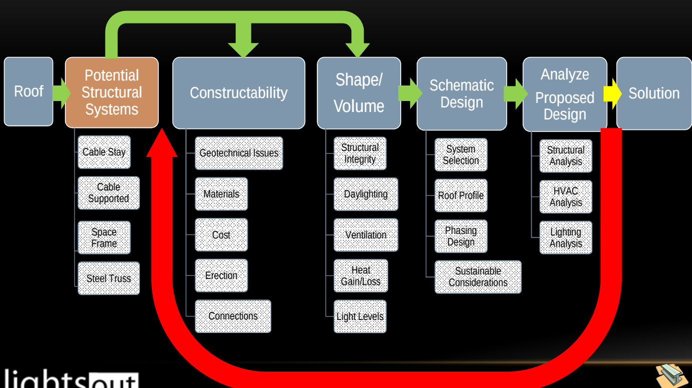
DECISION MAKING PROCESS

Vote on all decisions with Majority Ruling

In the case of a tie:

Step Back & Reanalyze from Different Viewpoints
↓
Consult Faculty
↓
Discuss Faculty Thoughts
↓
Consult Team Member w/ Most Topical Knowledge
↓
Revote

ROOF DESIGN PROCESS



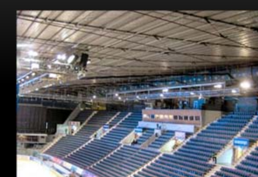
WHY CABLE STRUCTURES

Unique Image for Penn State Hockey

Aesthetics

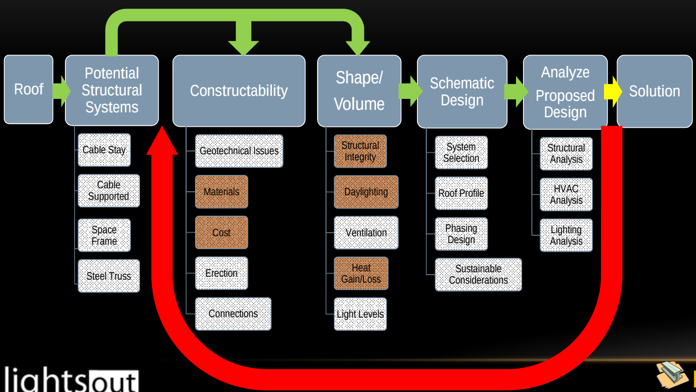
Expanded Span Potential

Economic Potential



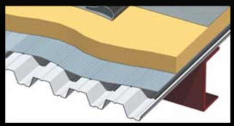
Cable Truss Ice Hockey Arena
Hovet
(Johannesov Isstadion)
Stockholm, Sweden

ROOF DESIGN PROCESS



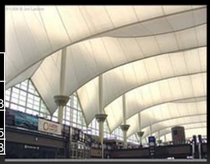
ROOF MATERIALS

Precast Concrete

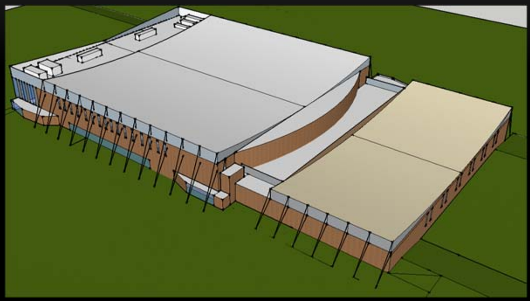


Metal Roof Deck

Roof Type	U-factor (Btu/h*ft²*°F)	Roof Conduction (Btu/hr)
Steel Sheet, 6" Ins	0.04684	236,308
6" HW Conc., 4" Ins	0.06586	129,735
Fabric	0.0833	316,188



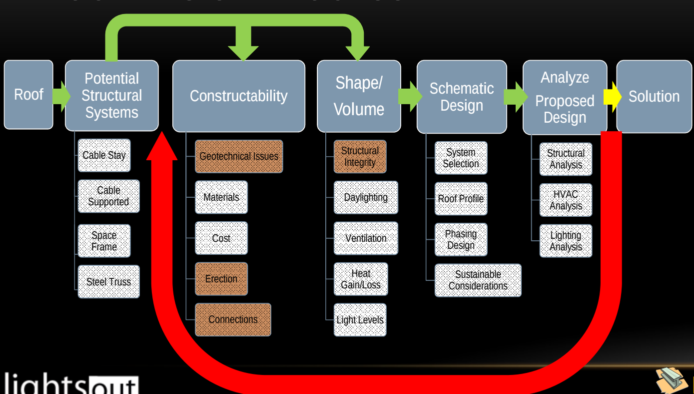
Tensile Fabric

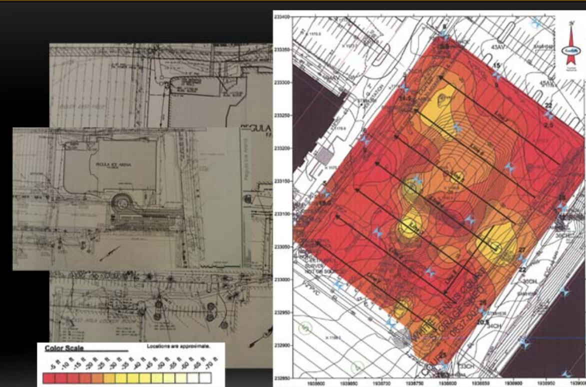


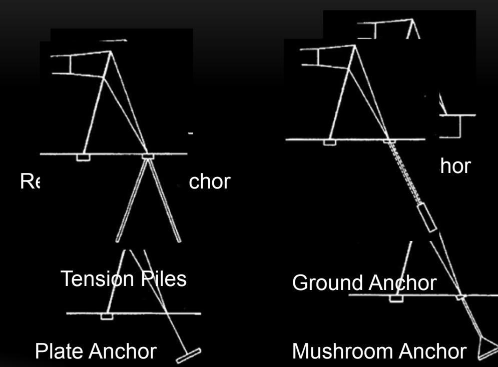
Nate Babyak Alex Ho Brian Sampson Alex Schreffler

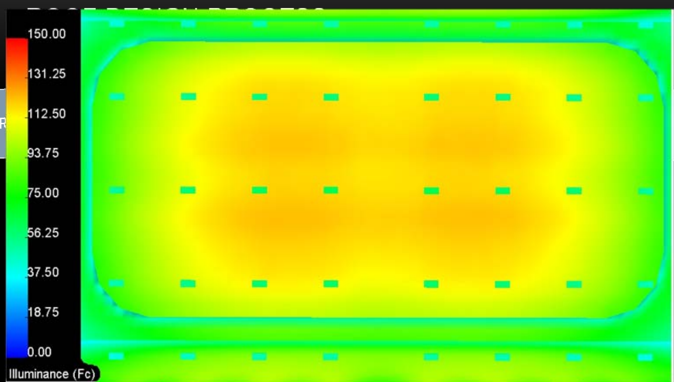
lightsout DESIGN

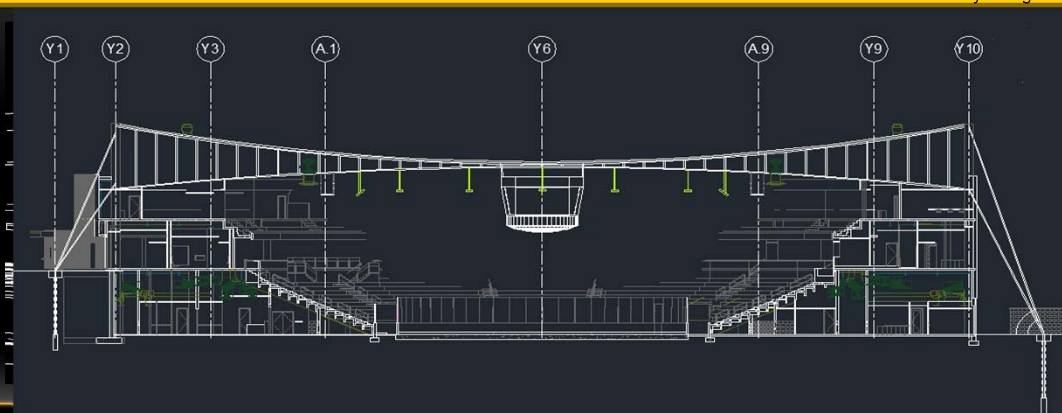
ROOF DESIGN PROCESS



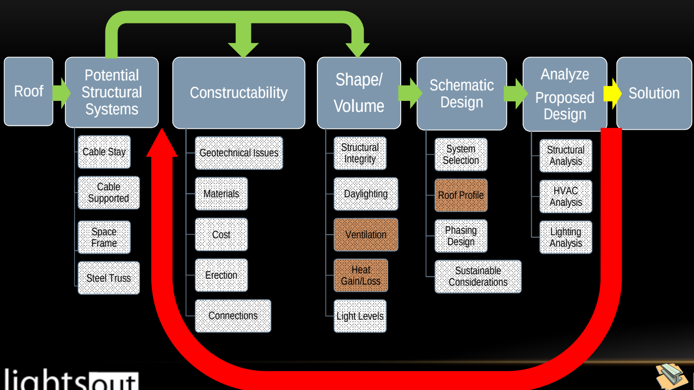


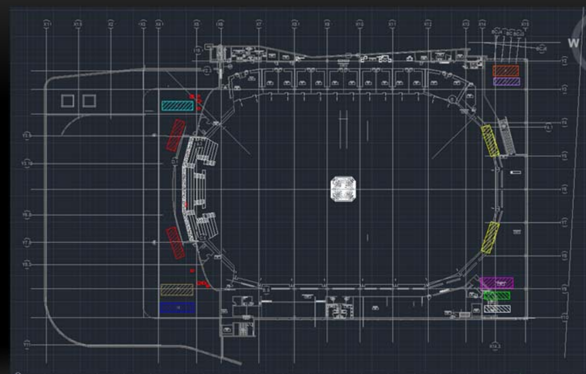


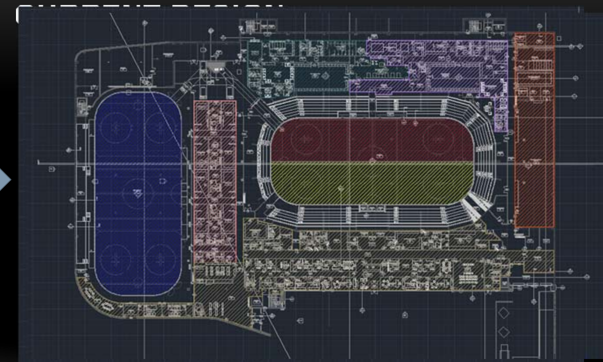

150.00
131.25
112.50
93.75
75.00
56.25
37.50
18.75
0.00
Illuminance (Fc)


Y1
Y2
Y3
A.1
Y6
A.9
Y9
Y10

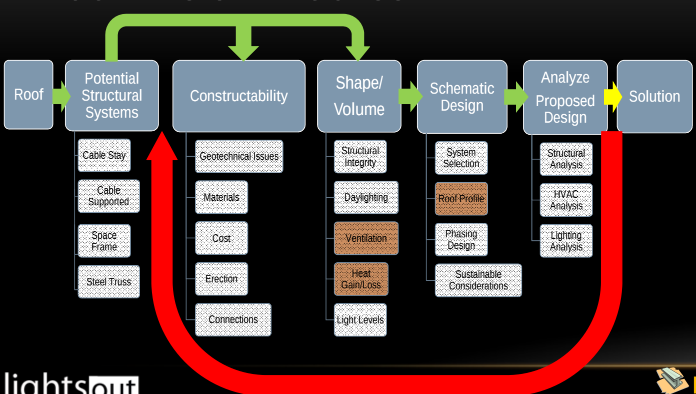
ROOF DESIGN PROCESS

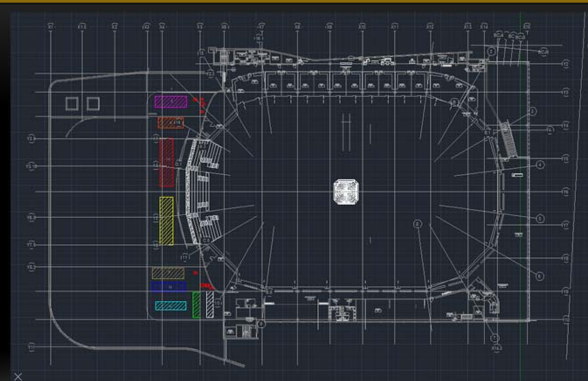


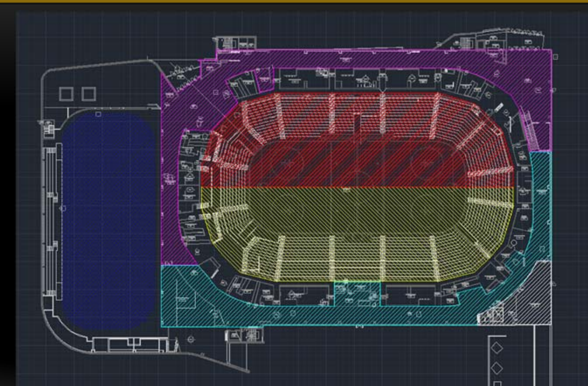




ROOF DESIGN PROCESS

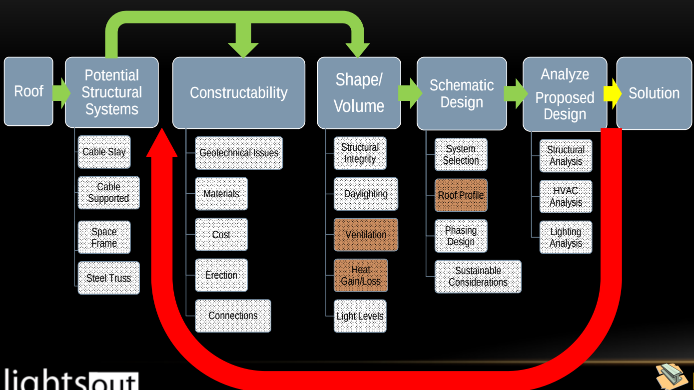


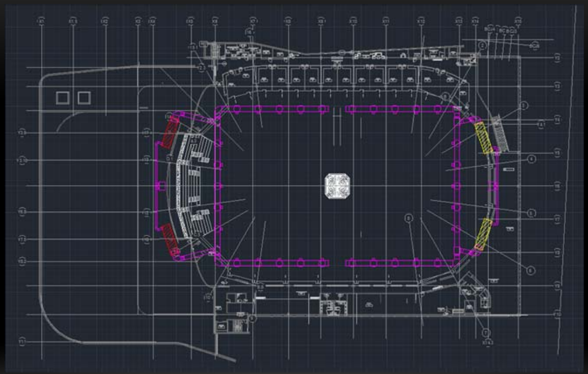


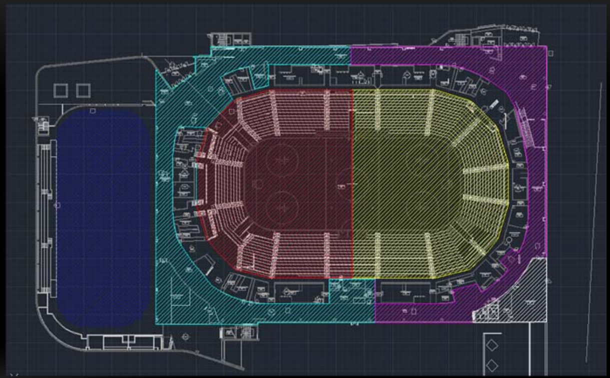


lightsout DESIGN

ROOF DESIGN PROCESS

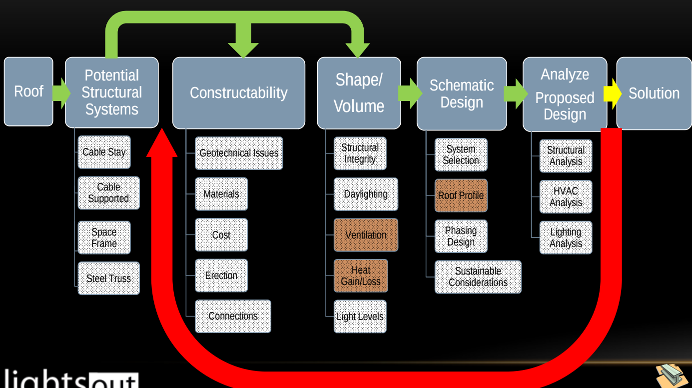


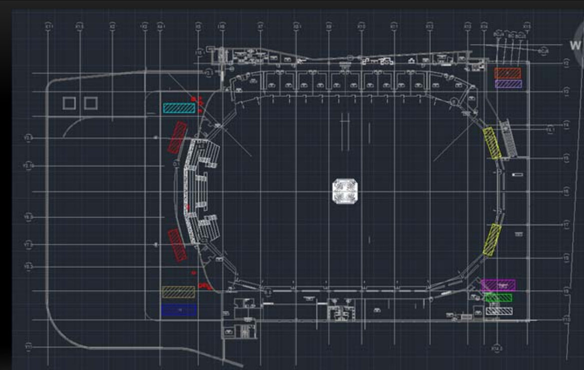


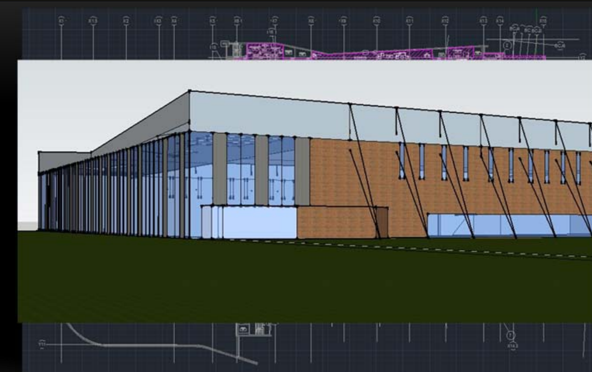


Nate Babyak Alex Ho Brian Sampson Alex Schreffler

ROOF DESIGN PROCESS



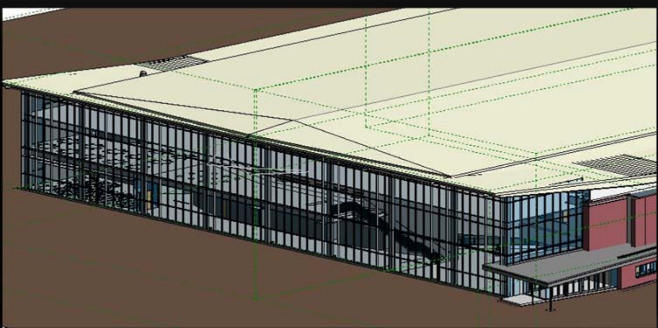


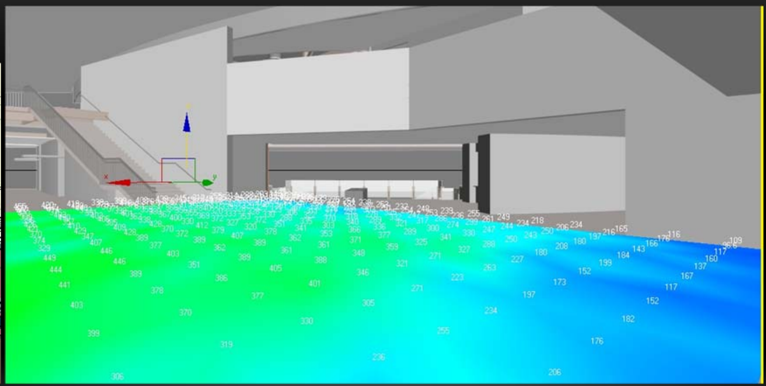


Nate Babyak Alex Ho Brian Sampson Alex Schreffler

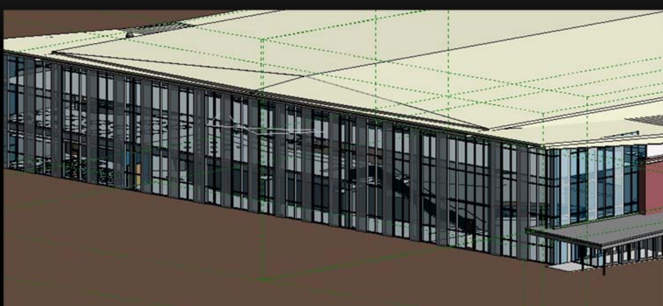
lightsout DESIGN

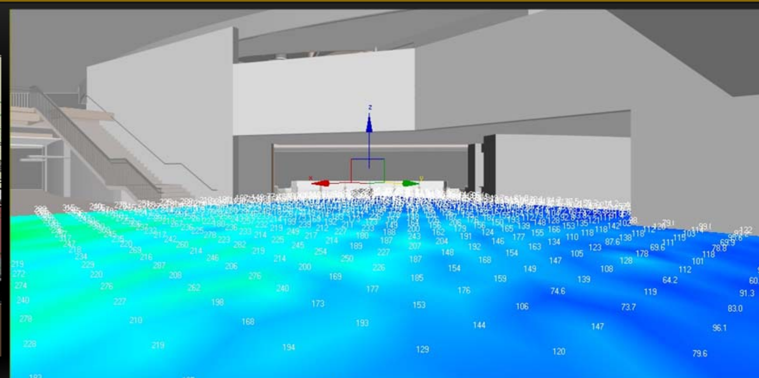
LOBBY DESIGN: UNSHADED



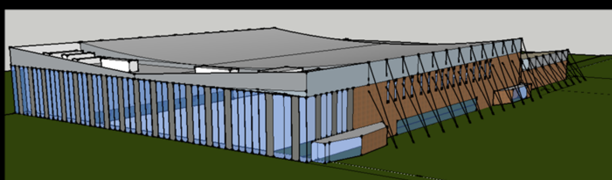


LOBBY DESIGN





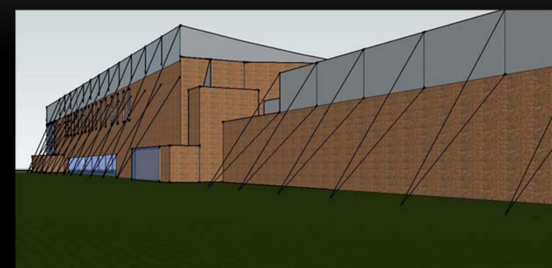
MOVING FORWARD

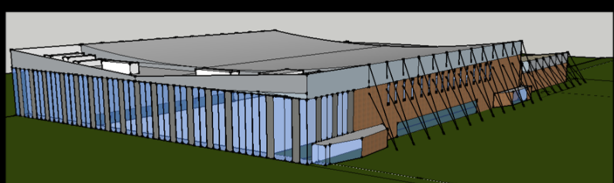


Main Roofs
- Anchorage
- Erection Process
- Acoustic Investigation

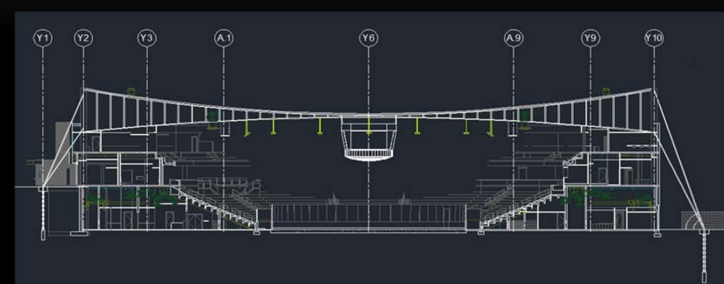
Main Lobby
- Shading Orientation for Views
- Structural Detailing
- Coordinate Mechanical Shafts

Community Rink
- Confirm Shape
- Resolve Roof Daylighting Analysis
- Resolve Material Cost





QUESTIONS/COMMENTS?



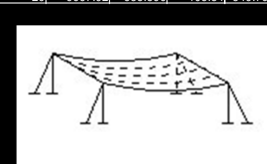
SINGLE CURVATURE FORCES

Uniformly Loaded Cables w/ Horizontal Chords				
M_{max}= 1/8(wl^2)				
H= M/f				
T_{max} = (V^2+H^2)^.5				
SL=	34	psf		
DL=	50	psf		
SDL=	0	psf		
LL=	0	psf		
Total=	84	psf		

5' Spacing		Span Length, l=		252	ft
w=	0.42	klf			
Cable sag, f, (ft)	M_{max} (k-ft)	H (k)	V (k)	T_{max} (k)	
5	3333.96	666.792	52.92	668.8887	
7.5	3333.96	444.528	52.92	447.6669	
10	3333.96	333.396	52.92	337.5699	
12.5	3333.96	266.7168	52.92	271.9161	
15	3333.96	222.264	52.92	228.4772	
17.5	3333.96	190.512	52.92	197.7254	
20	3333.96	166.698	52.92	174.8964	

7.5' Spacing		Span Length, l=		252	ft
w=	0.63	klf			
Cable sag, f, (ft)	M_{max} (k-ft)	H (k)	V (k)	T_{max} (k)	
5	5000.94	1000.188	79.38	1003.333	
7.5	5000.94	666.792	79.38	671.5004	
10	5000.94	500.094	79.38	506.3548	
12.5	5000.94	400.0752	79.38	407.8742	
15	5000.94	333.396	79.38	342.7157	
17.5	5000.94	285.768	79.38	296.5882	
20	5000.94	250.047	79.38	262.3446	

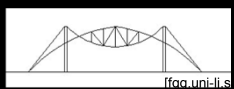
10' Spacing		Span Length, l=		252	ft
w=	0.84	klf			
Cable sag, f, (ft)	M_{max} (k-ft)	H (k)	V (k)	T_{max} (k)	
5	6667.92	1333.584	105.84	1337.777	
7.5	6667.92	889.056	105.84	895.3338	
10	6667.92	666.792	105.84	675.1397	
12.5	6667.92	533.4336	105.84	543.8322	
15	6667.92	444.528	105.84	456.9543	
17.5	6667.92	381.024	105.84	395.4509	
20	6667.92	333.396	105.84	349.7928	



DOUBLE CURVATURE FORCES

Double Cable System w/ Vertical Ties
Equations
q is assumed uniformly distributed load
p is external uniform load
Horizontal Components of Cable Tension
$H_t = ql^2/8f_t$
$H_b = H_t*(f_t/f_b)$
Changes in Horizontal Components under load p
$\Delta H_t = (p-\Delta q)*l^2/(8f_t)$
$\Delta H_b = \Delta q*l^2/(8f_b)$
$\Delta q = p(A_b f_b^2)/(A_t f_t 2 + A_b f_b^2)$
Resulting Horizontal Components of Cable Tension
$H_t = H_t + \Delta H_t$
$H_b = H_b - \Delta H_b$
Maximum Tension in the Cables
$T_t = H_t*(1+16n_t^2)^{.5}$
$T_b = H_b*(1+16n_b^2)^{.5}$

Roof Loads		
SL=	34	psf
DL=	20	psf
SDL=	0	psf
LL=	0	psf
Total=	54	psf



Double Curvature

Possible Setup		
Span (l)=	252	feet
f_t=	12	feet
n_t=	1/21	
f_b=	7	feet
n_b=	1/36	
Spacing=	20	feet
D.L. (w_D)	0.4	k/ft
L.L. (w_l , p)	0.68	k/ft
D.L.+T.L. (w_{tot})	1.08	k/ft
If All Loads Carried by Top Cable:		
$H_t = (w_{tot})*l^2/(8*f_t)$ =	714.42	k
$T_{t\ max} = H(1+16n^2)^{.5}$=	727.26	k
LL Only:		
$T_t = T_{max} *w_l /w_{tot}$=	457.9072994	k
DL Only:		
$T_t = T_{max} *w_D/w_{tot}$=	269.3572349	k
Assume Residual Tension (T_{res})=	725	k
$H_t = T_{res}/(1+16n_t^2)^{.5}$=	712.20	k

Find Uniform Load, q, on Diaphragm		
$q+w = w_{tot}*T_{res}/T_{tmax}$=	1.076637129	k/ft
$q = (q+w) - w_{DL}$ =	0.676637129	k/ft
Initial Tension in Bottom Cable		
$H_b = q*l^2/(8*f_b)$ =	767.306504	k
$T_b = H_b*(1+16n_b^2)^{.5}$ =	772.03	k
Cable Properties		
	Top Cable	Bottom Cable
Diameter (in)	4.375	3.75
Area (in²)	15.03301172	11.04466167
Weight (lb/ft)	40.2	29.5
E=	22000	ksi
Stress in Cable under DL		
Top: T_{res}/A_t	48.22719582	ksi
Bot: T_b/A_b	69.90059611	ksi

Under LL:		
$\Delta q = p*(f_b^2 A_b/(f_t^2 A_t + f_b^2 A_b))$=	0.136	k/ft
Load on Top: $p - \Delta q$ =	0.544	k/ft
Load on Bot: Δq=	0.136	k/ft
Change in T		
$\Delta T_t = T_{tmax}*(p-\Delta q)/w_{tot}$ =	366.3258395	k
$\Delta T_b = T_b*\Delta q/q$ =	154.4056869	k
Max Tensions		
$T_t = T_t + \Delta T_t$ =	1091.325839	k
$T_b = T_b - \Delta T_b$	617.62	k
Stresses in Cable under TL		
Top: T_t/A_t =	72.5952896	ksi
Bot: T_b/A_b =	164.6993994	ksi

Cable Lengths		
Top:		
$L_t = l*(1+(8/3)*n_t^2)$ =	253.52	ft
$\Delta H_t = H_t*(\Delta T/T_{tmax})$ =	359.856	k
$\Delta L_t = (\Delta H_t l/AE)*(1+(16/3)*n_t^2)$=	0.28	ft
=	3.33	in
Change in sag:		
$\Delta f = 15\Delta L_t/(16n_t(5-24n_t^2))$ =	13.26	in
Total Horizontal Force at Anchorage		
DL ONLY		
$H = H_t + H_b$ =	1481.726504	k
DL + LL		
$H = T_t/(1+16n_t^2)^{.5} + T_b/(1+16n_b^2)^{.5}$ =	1685.897	k

Nate Babyak Alex Ho Brian Sampson Alex Schreffler

STRAND DIAMETER inches	STRAND DIAMETER mm.	APPROXIMATE WEIGHT (lb./ft.) SPIRAL STRAND	APPROXIMATE WEIGHT (lb./ft.) SS-265	NOMINAL STRENGTH (tons) SPIRAL STRAND Class A	NOMINAL STRENGTH (tons) SPIRAL STRAND Class B*	NOMINAL STRENGTH (tons) SPIRAL STRAND Class C*	NOMINAL STRENGTH (tons) SS-265 Class A
1/2	13.0	0.52	--	15.0	14.5	14.2	--
9/16	14.5	0.66	--	19.0	18.4	18.0	--
5/8	16.0	0.82	--	24.0	23.3	22.8	--
11/16	18.0	0.99	--	29.0	28.1	27.5	--
3/4	19.0	1.18	1.16	34.0	33.0	32.3	39.1
13/16	21.0	1.39	1.36	40.0	38.8	38.0	46.0
7/8	22.0	1.61	1.59	46.0	44.6	43.7	52.9
15/16	24.0	1.85	1.85	54.0	52.4	51.3	62.1
1	26.0	2.10	2.12	61.0	59.2	57.9	70.1
1-1/16	27.0	2.37	2.36	69.0	66.9	65.5	79.4
1-1/8	29.0	2.66	2.63	78.0	75.7	74.1	89.7
1-3/16	30.0	2.96	2.91	86.0	83.4	81.7	98.9
1-1/4	32.0	3.28	3.23	96.0	94.1	92.2	110
1-5/16	33.0	3.62	3.59	106	104	102	122
1-3/8	35.0	3.97	3.94	116	114	111	133
1-7/16	37.0	4.34	4.29	126	123	121	145
1-1/2	38.0	4.73	4.66	138	135	132	158
1-9/16	40.0	5.13	5.04	150	147	144	172
1-5/8	42.0	5.55	5.45	162	159	155	186
1-11/16	43.0	5.98	5.92	176	172	169	202
1-3/4	45.0	6.43	6.39	188	184	180	216
1-13/16	46.0	6.90	6.80	202	198	194	232
1-7/8	48.0	7.39	7.26	216	212	207	248
1-15/16	49.0	7.89	7.75	230	226	221	264
2	52.0	8.40	8.23	245	241	238	282
2-1/16	53.0	8.94	8.79	261	257	253	300
2-1/8	54.0	9.49	9.39	277	273	269	319
2-3/16	56.0	10.1	10.0	293	289	284	337

STRAND DIAMETER inches	STRAND DIAMETER mm.	APPROX. WEIGHT (lb./ft.) SPIRAL STRAND	APPROX. WEIGHT (lb./ft.) SS-265	NOMINAL STRENGTH (tons) SPIRAL STRAND Class A	NOMINAL STRENGTH (tons) SPIRAL STRAND Class B*	NOMINAL STRENGTH (tons) SPIRAL STRAND Class C*	NOMINAL STRENGTH (tons) SS-265 Class A
2-5/16	59.0	11.2	11.0	327	322	317	376
2-3/8	60.0	11.7	11.6	344	339	334	396
2-7/16	62.0	12.5	12.2	360	355	349	414
2-1/2	64.0	12.8	12.9	376	370	365	432
2-9/16	65.0	13.6	13.6	392	386	380	451
2-5/8	67.0	14.5	14.4	417	411	404	480
2-11/16	68.0	15.2	15.0	432	425	419	497
2-3/4	70.0	15.9	15.6	452	445	438	520
2-7/8	74.0	17.4	17.2	494	486	479	568
3	76.0	18.9	18.8	538	530	522	618
3-1/8	79.0	20.5	20.4	584	575	566	672
3-1/4	83.0	22.2	21.8	625	616	606	719
3-3/8	86.0	23.9	23.6	673	663	653	774
3-1/2	89.0	25.7	25.5	724	713	702	832
3-5/8	92.0	27.6	27.1	768	756	745	883
3-3/4	96.0	29.5	29.4	822	810	797	934
3-7/8	99.0	31.5	--	878	865	852	--
4	103.0	33.6	--	925	911	897	--
4-1/8	105.0	35.7	--	985	**	**	--
4-1/4	109.0	37.9	--	1,002	**	**	--
4-3/8	111.0	40.2	--	1,108	**	**	--
4-1/2	115.0	42.5	--	1,173	**	**	--
4-5/8	117.0	44.9	--	1,239	**	**	--
4-3/4	122.0	47.4	--	1,306	**	**	--
4-7/8	124.0	49.9	--	1,376	**	**	--
5	128.0	52.5	--	1,448	**	**	--
5-1/4	133.0	57.9	--	1,596	**	**	--
5-1/2	140.0	63.5	--	1,752	**	**	--

Spiral Strand and SS-265

Based on Class A coatings, the minimum moduli of elasticity of the spiral strand are shown below. For heavier coatings, please consult WW's Engineering Department.

CABLE SPECS

Basis of Economic Analysis

Current Span:
196' = 59.7 m

Our Span:
252' = 76.8 m

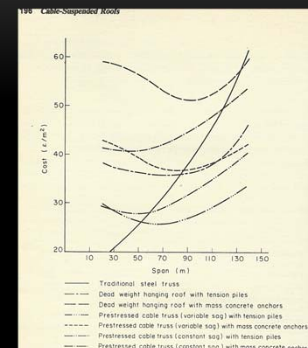
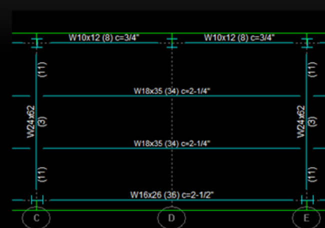
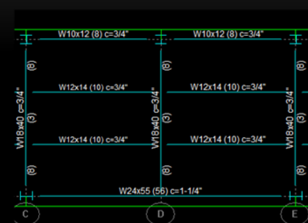


FIGURE 6-1 Cost comparisons for different forms of cable roofs. Effect of the mode of pretensioning, geometry, and anchoring arrangement is studied. (1 £/m² = 0.093 £/ft², 1 m = 3.28 ft) (Ref. 100; courtesy of the authors.)

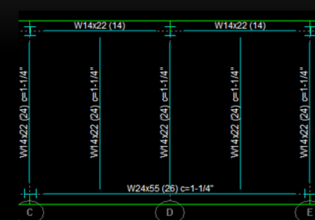
Current Designed Bay
7 Bay Wt: 52.288 k



Trial Design 1
6 Bay Wt: 36.582 k

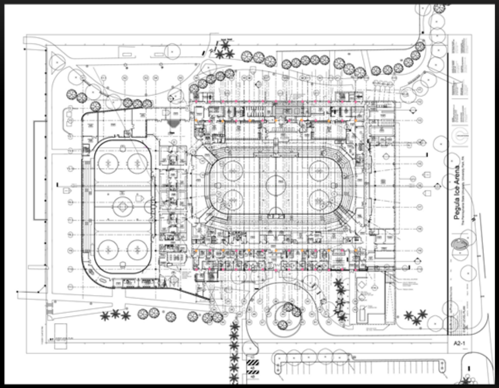


Trial Design 2
6 Bay Wt: 44.08 k



Trial Design 3
6 Bay Wt: 43.12 k

Note: New Design add 4 columns



NEW COLUMN LAYOUTS