

MIDAS SQUARE 공학 기술강연

대공간 구조물 설계 사례

김종수 | (주)C·S 구조엔지니어링

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SPATIAL STRUCTURE of CSSE

OTHERS PROJECT of CSSE

INTRODUCTION

국내 대공간 건축물 과거와 현재

경제 발전과 대공간 건축물 수요



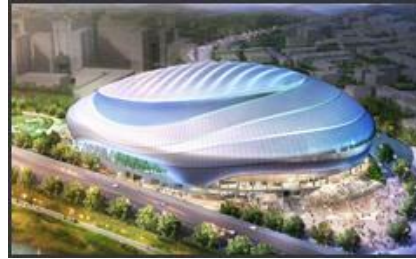
SPATIAL PROJECT of CSSE

대공간 설계 사례

C·S구조엔지니어링



2002 World Cup Jeonju Stadium



Gocheok Sky Dome



Philippine Arena



Gwang Myeong Cyclodrome



2002 Asian Games Geum Jeong



Ansan Dome Stadium



Taekwondo One



2015 U Stadium



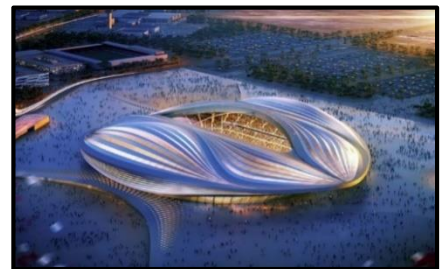
Incheon Airport Terminal 2



Korea University Info Center



Angola Stadium

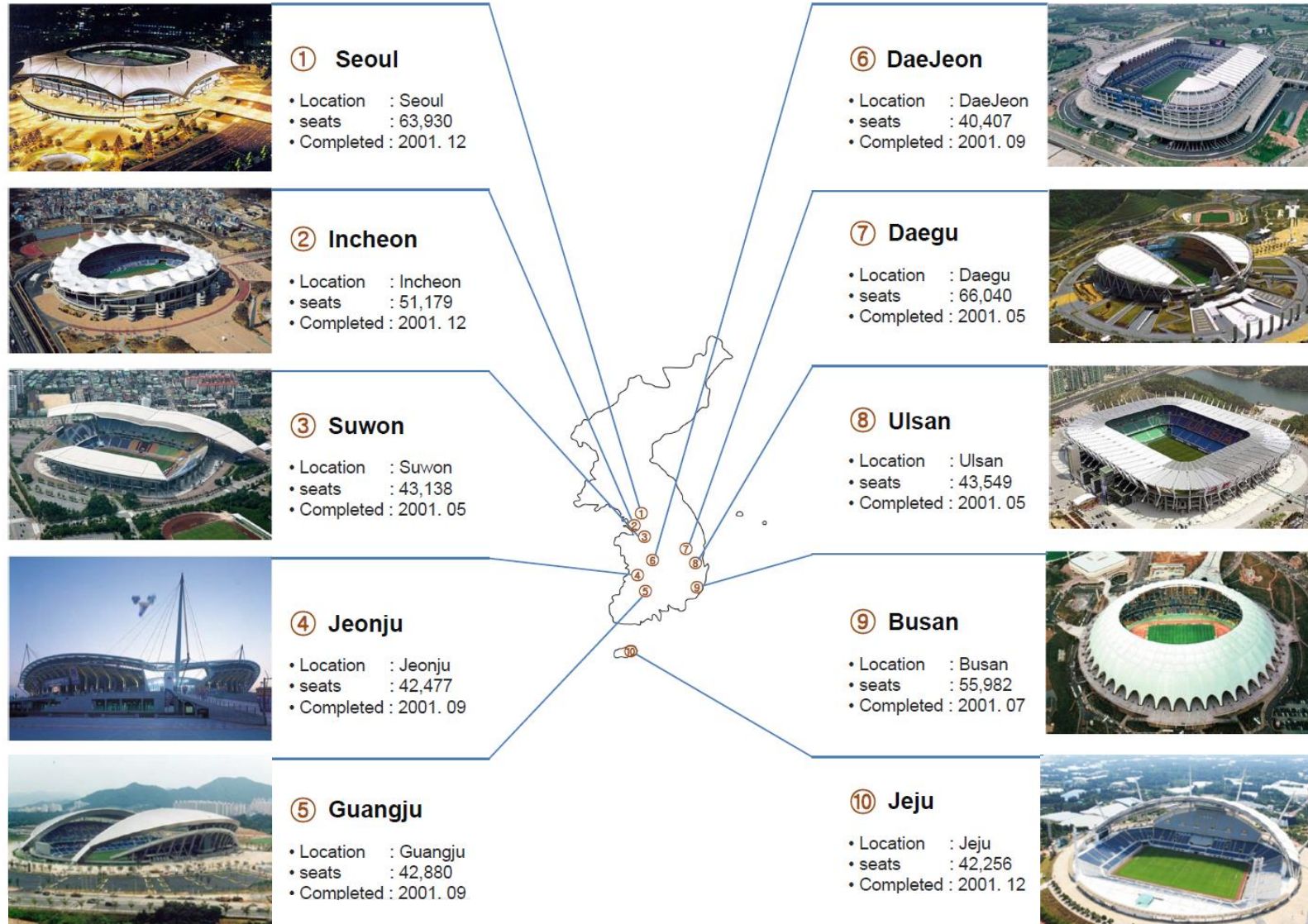


Al Wakrah Stadium

SPATIAL PROJECT of CSSE

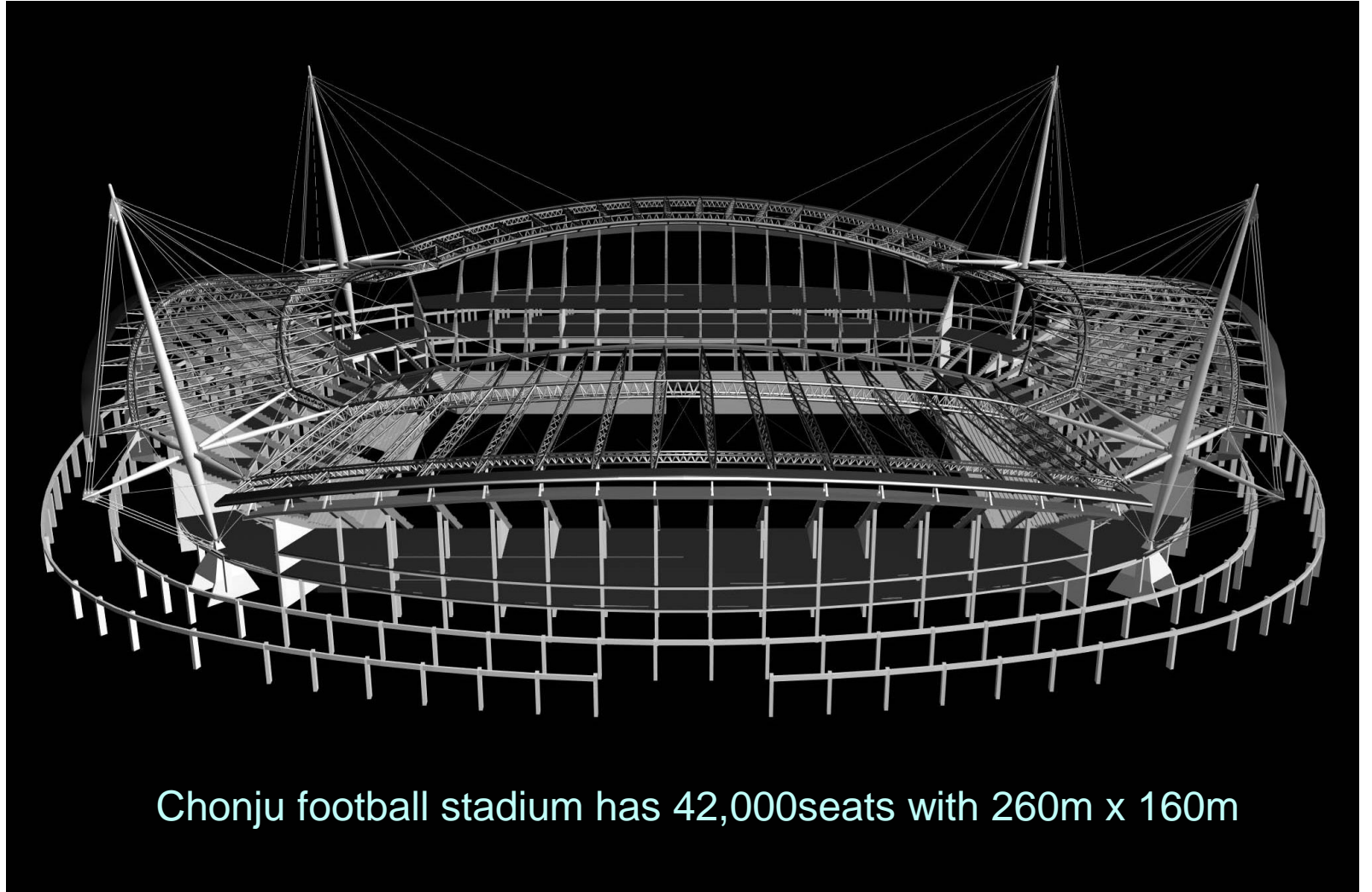
전주월드컵 경기장

전주월드컵경기장



전주 월드컵 경기장

전주, 1998년



Chonju football stadium has 42,000seats with 260m x 160m

전주 월드컵 경기장



Architect: POS.AC

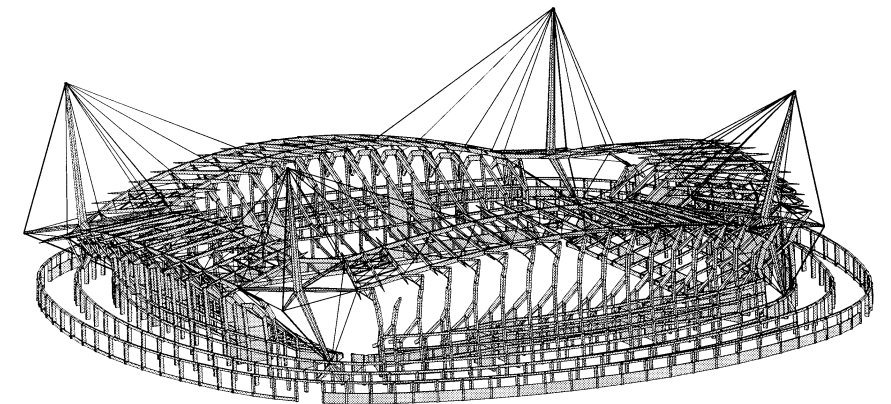
Contractor: Sung-Won

Size: 91,000 m² (42,000 seats), 200m x 230m

Structure System: Roof - Steel Truss + Tensile Structure

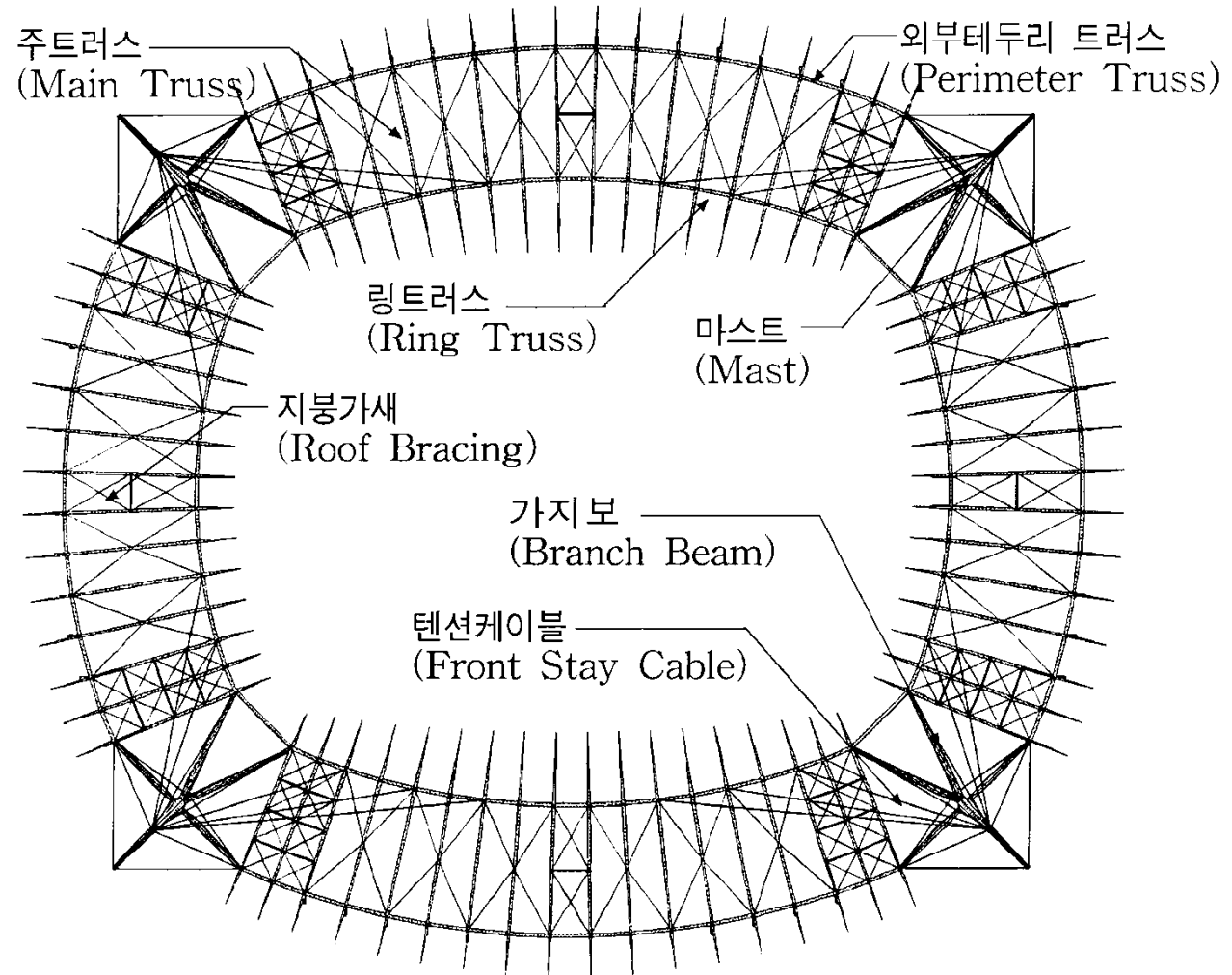
Stand - Pre-stress Concrete Structure

Sub Stand - PC + RC Structure



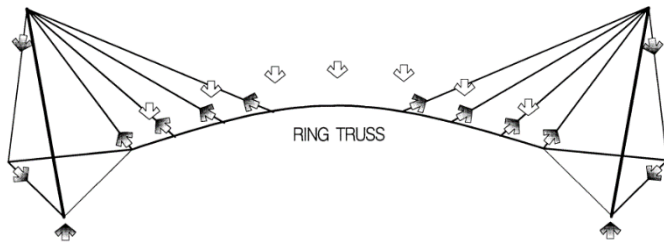
전주 월드컵 경기장

Roof Structural Plan

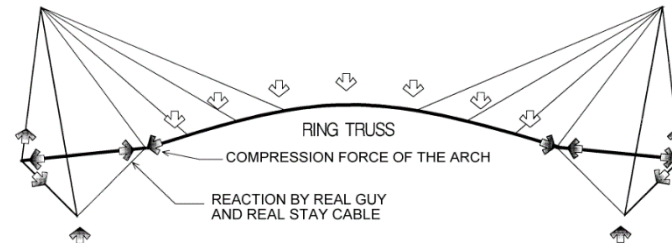


전주 월드컵 경기장 Structural System of Roof

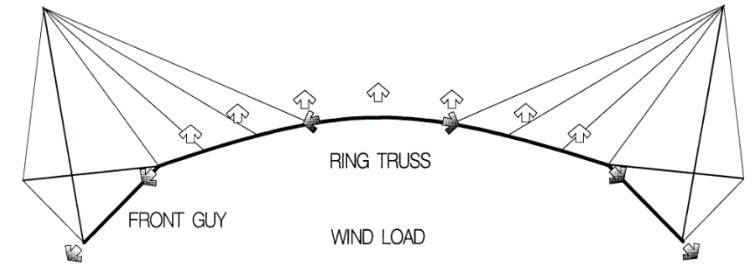
Suspension



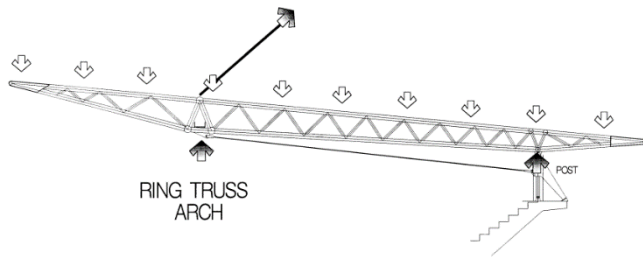
Arch (Dome)



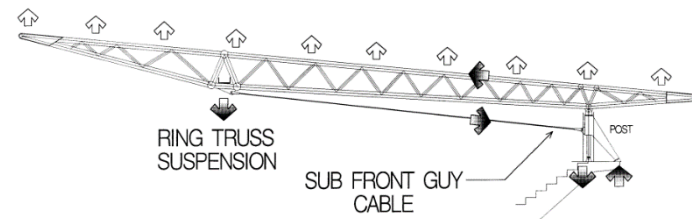
Valley Cable Truss



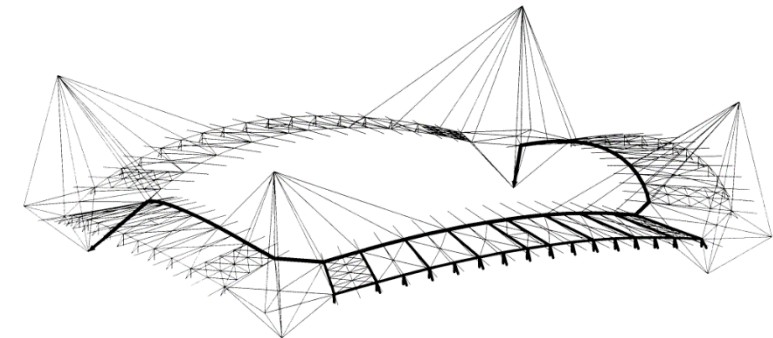
Gravity load (Main truss)



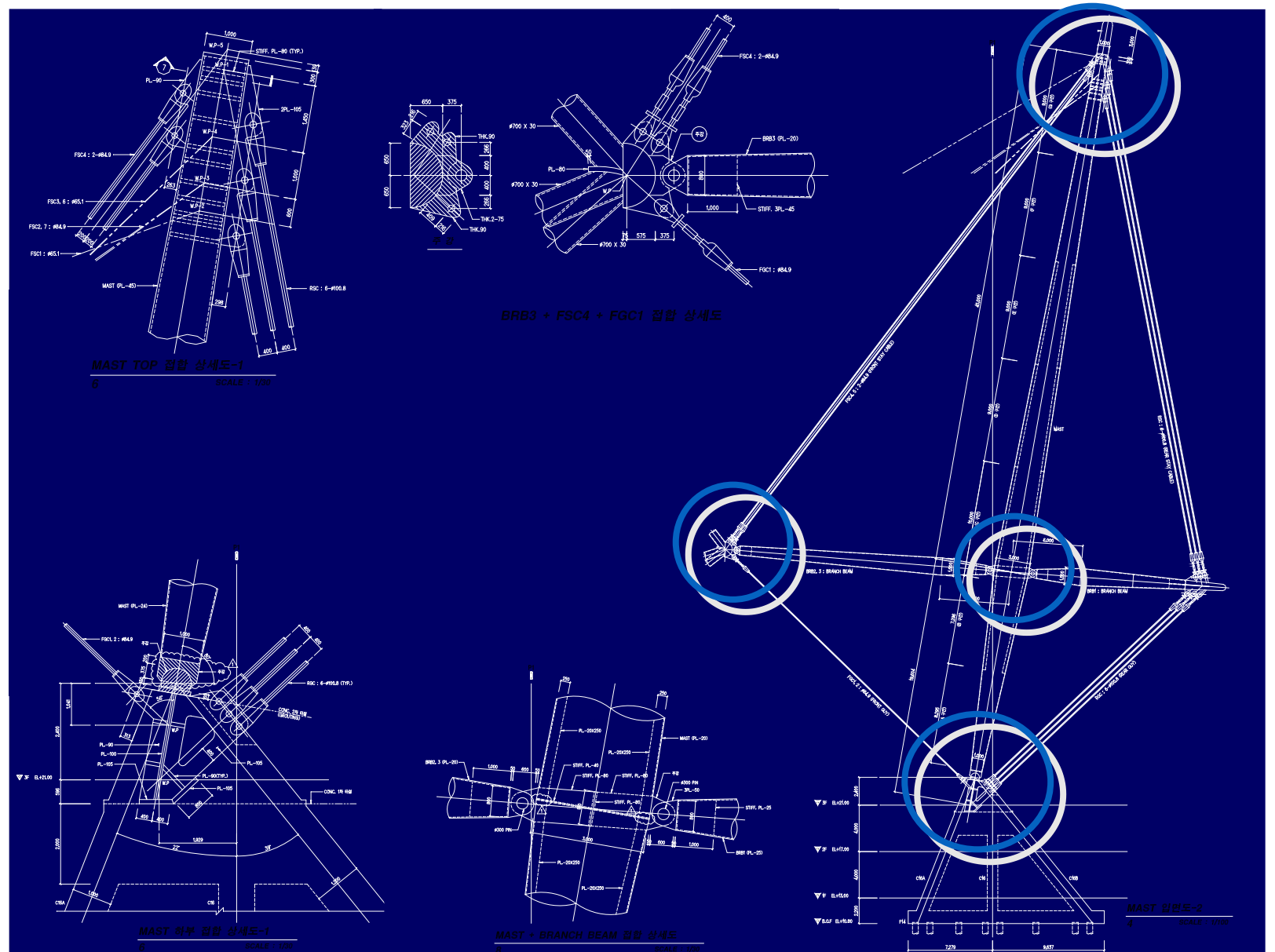
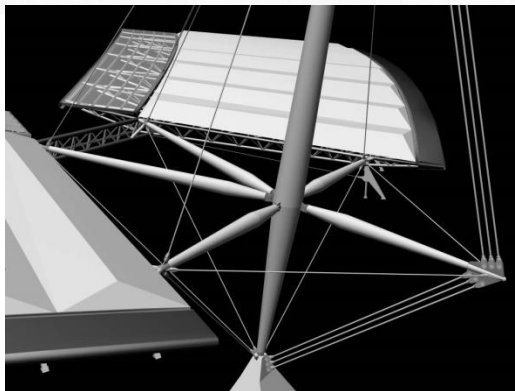
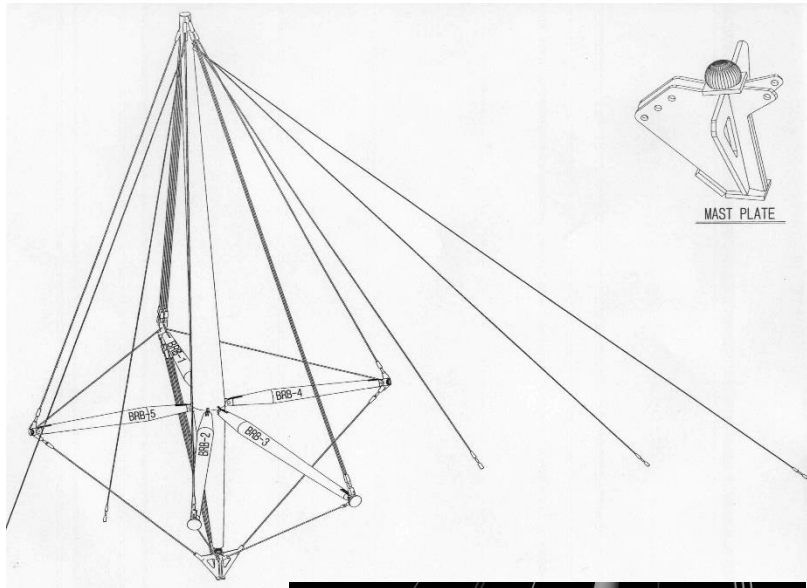
Lateral load (Main truss)



Diaphragm



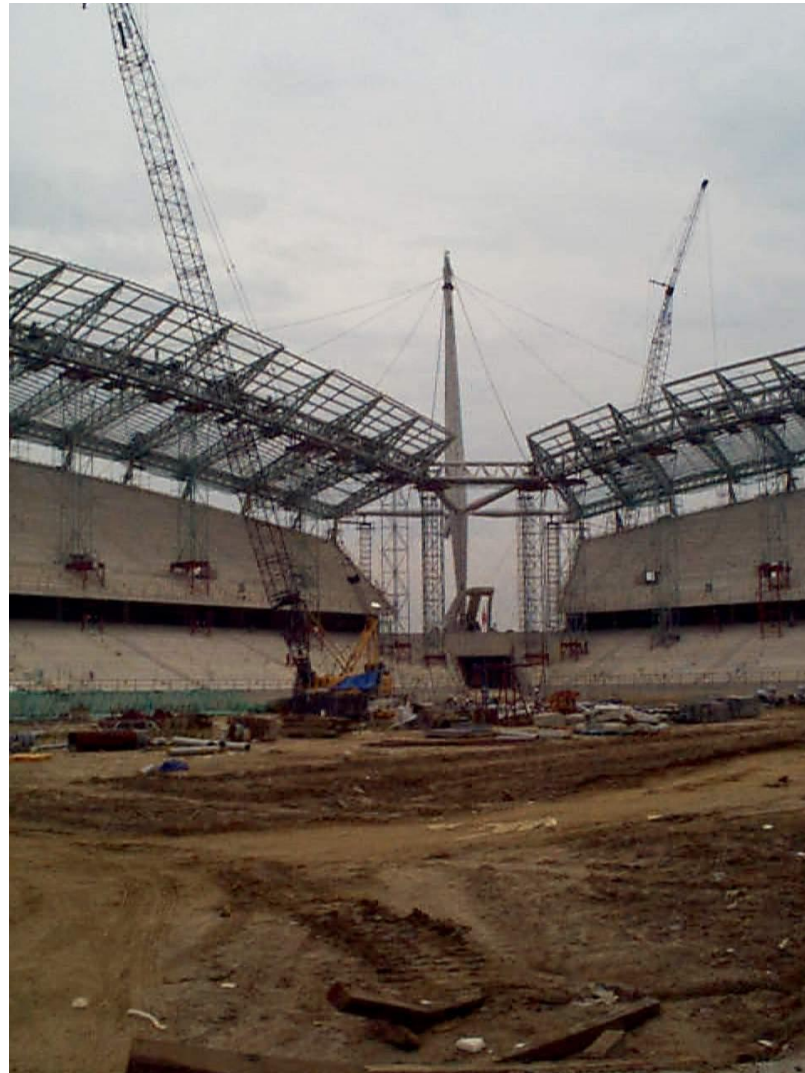
전주 월드컵 경기장



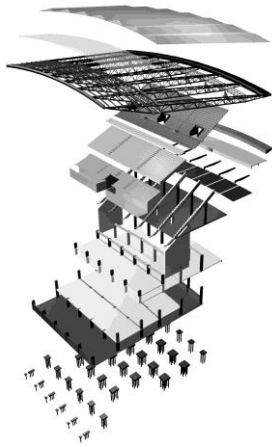
전주 월드컵 경기장



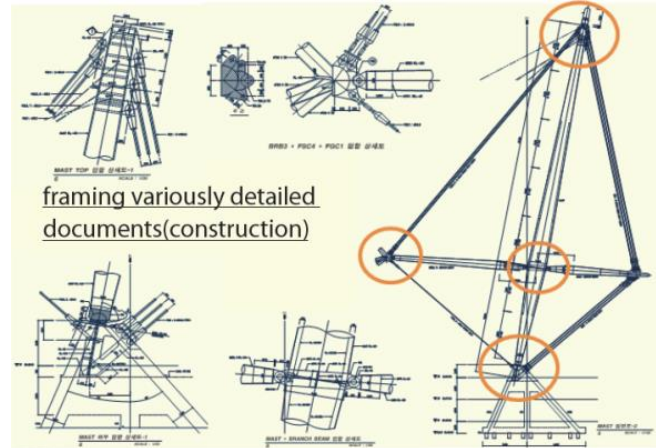
전주 월드컵 경기장 Erection Engineering (Mast)



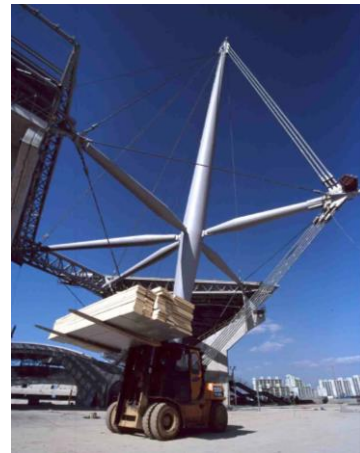
전주 월드컵 경기장 Erection Engineering



Structures

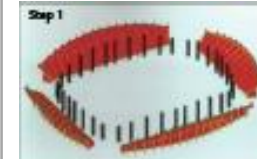


Various Framing Detail Design

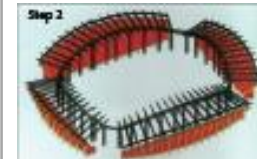


Construction Site

Assembly Sequence



Step 1. A preparatory stage to build the roof structure



Step 2. Installation of the roof truss



Step 3. Installation of the mast



Step 4. Installation of the front stay



Step 5. Installation of the rear stay and rear guy



Step 6. Adjust the length of the roof cable (Introduction of the pretension)

Step 7. Jack down the temporary shore

Step 8. Installation front guy

Step 9. Completion controlling cable pretention

Step 10. Complete erection

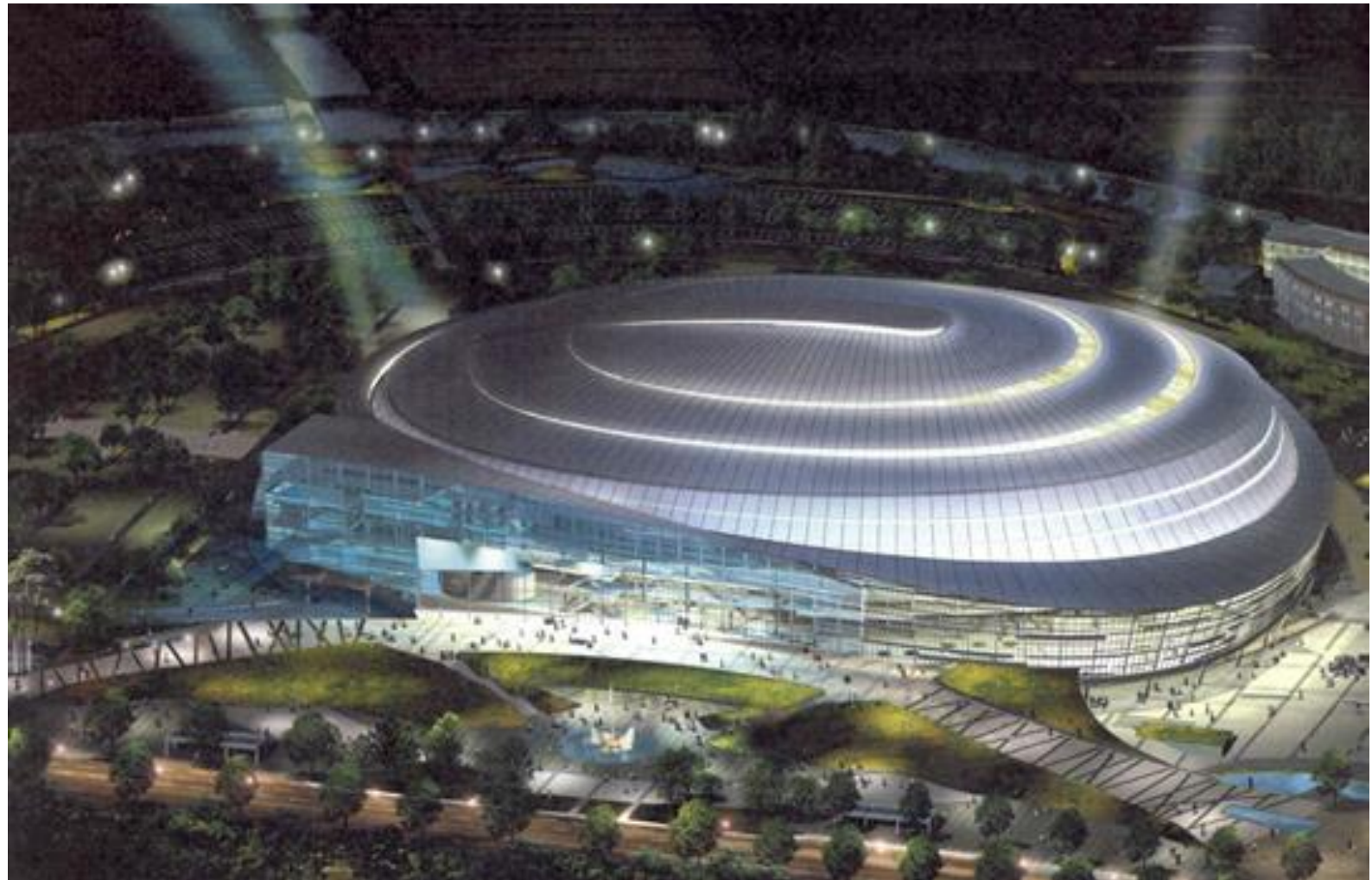
전주 월드컵 경기장 Erection Engineering (Mast)



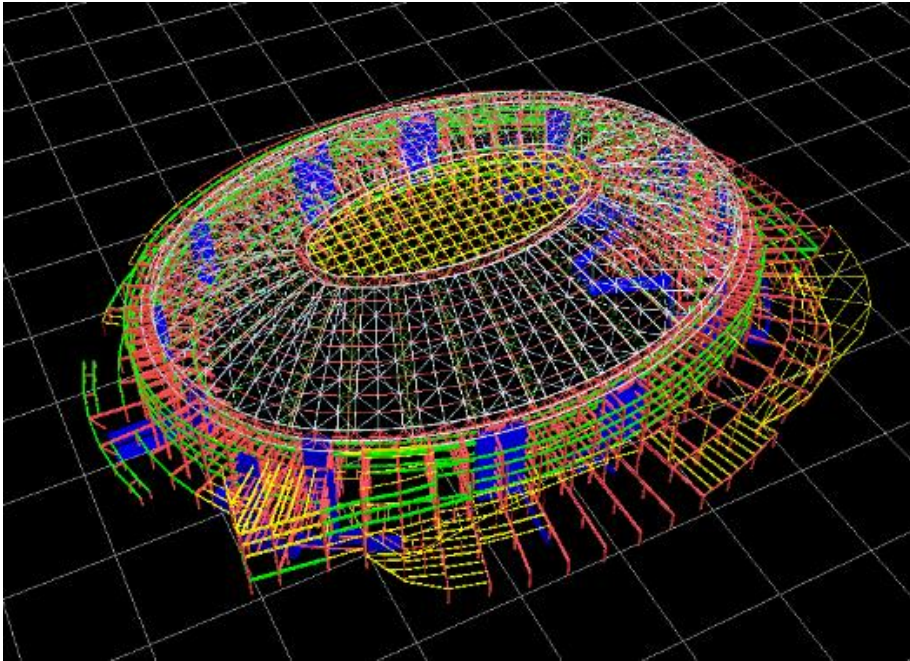
광명 돔 경륜장

광명 돔 경륜장

광명시, 2002년



광명 돔 경륜장



Size of roof : 143.6 x 183.5 x 21.0

Number of seats : 10,896seats

Architect : The Space Architects

Structural Engineer : CS Structural Engineers Inc.

Contractor : Daewoo + Samsung Construction Co. Ltd.

Structural System : Flow truss dome above

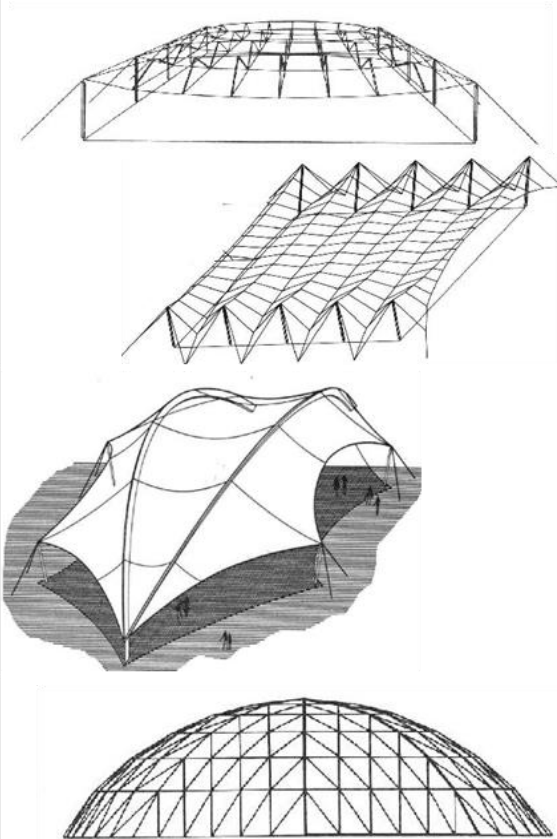
Precast and reinforced concrete frame

광명 돔 경륜장

Define process of the shape of roof

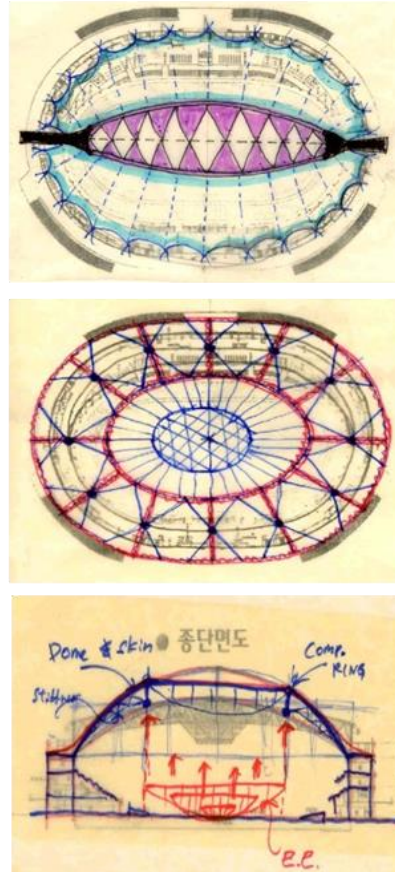
•STEP 1

Search what kind of structural system is available



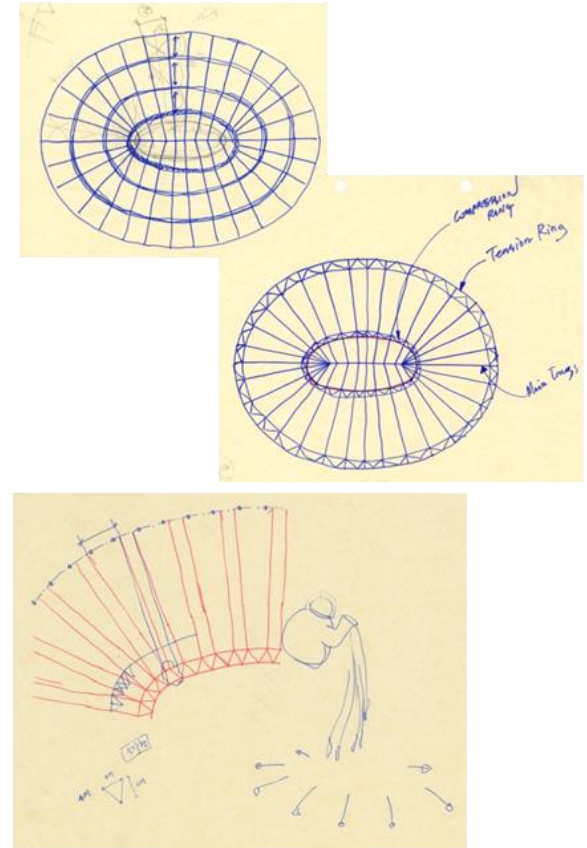
•STEP 2

Create alternatives for the stadium through on each case



•STEP 3

Define the effective roof system with architects

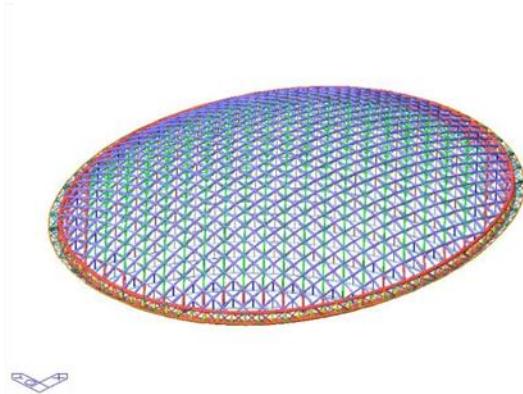


광명 돔 경륜장

Define process of the shape of roof

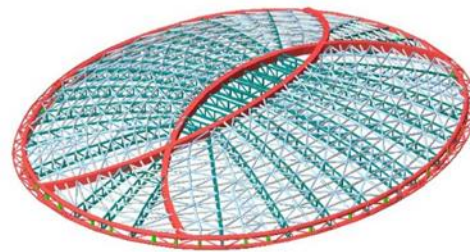
ALT 1

Double Layer Grid Dome



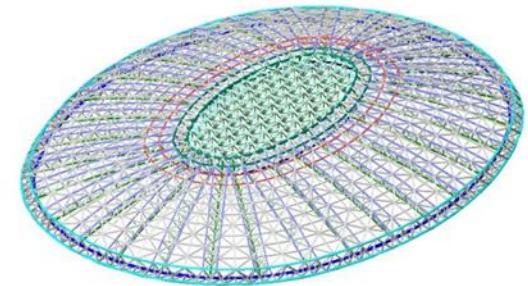
ALT 2

Super Truss Dome



ALT 3

Flow Truss Dome

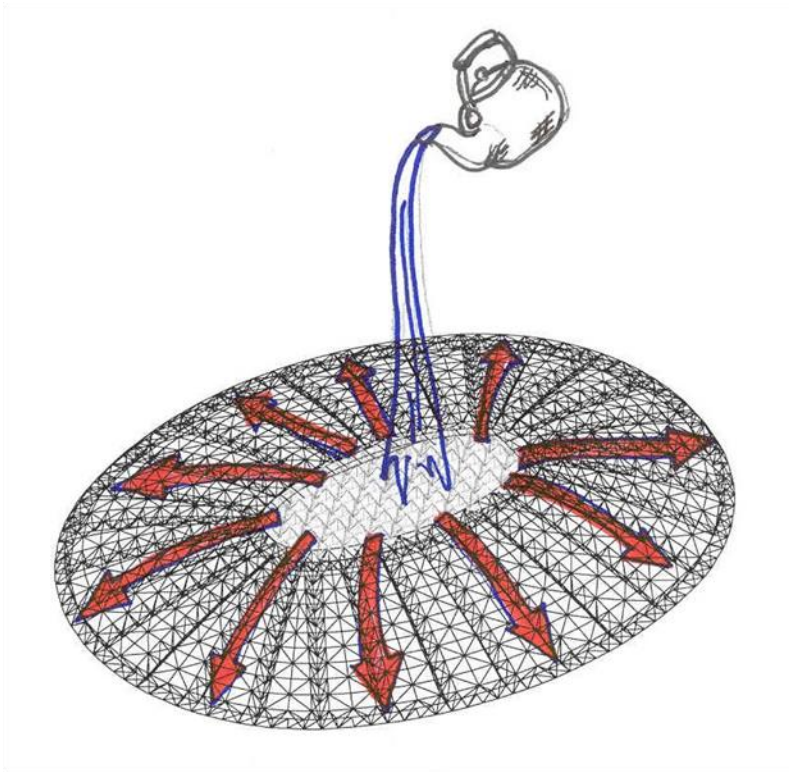


광명 돔 경륜장

Define process of the shape of roof

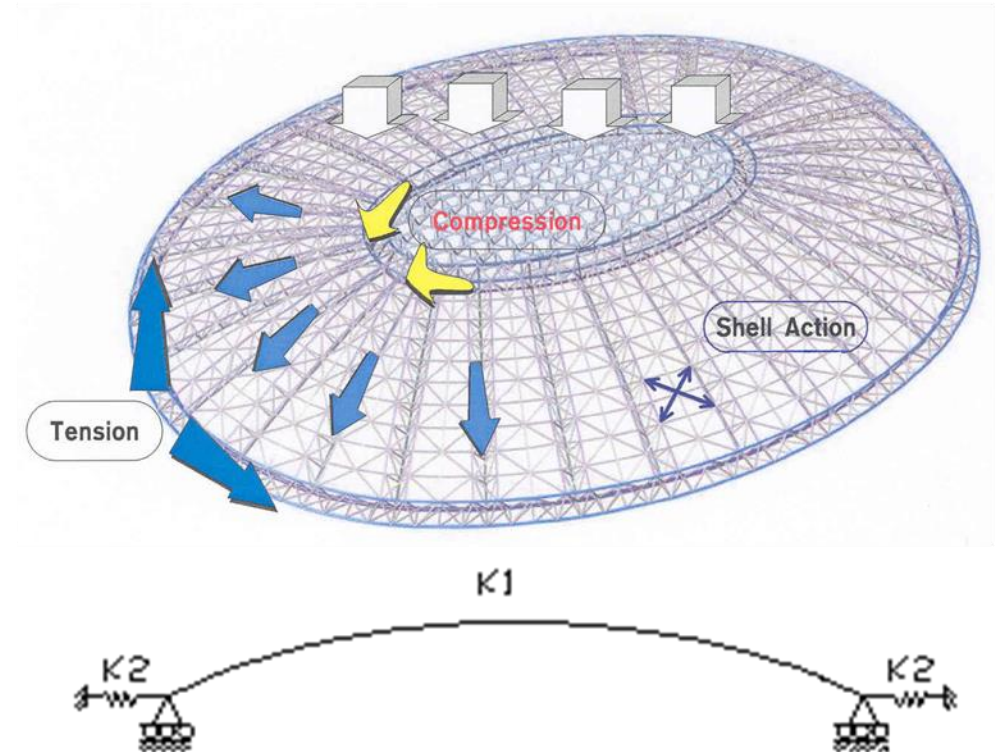
•Flow truss

- Guiding forces flowing as water spread



•Types of resisting mechanism of roof

- Dome Action

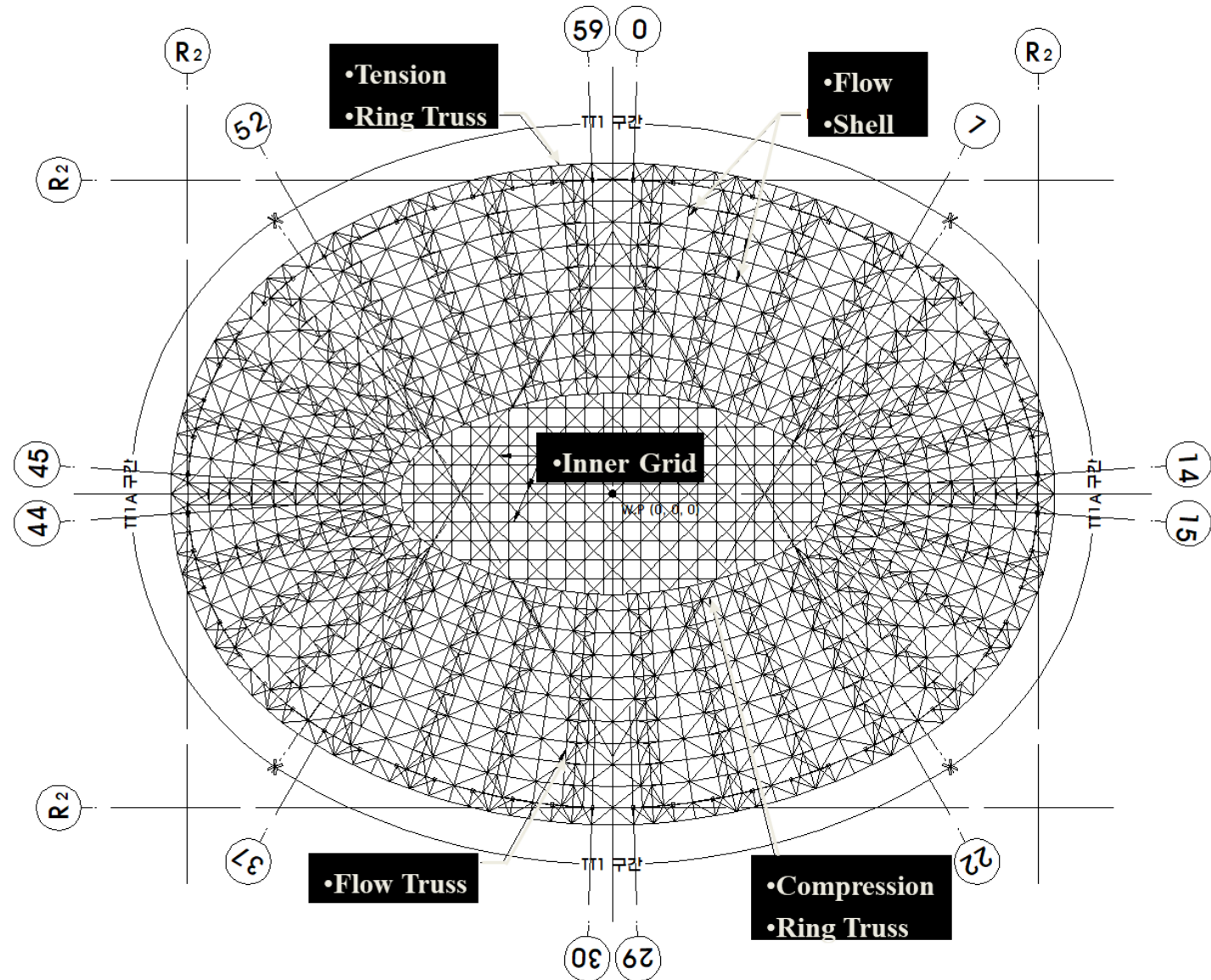


•K1 : Roof Truss Stiffness

•K2 : Tension Ring Truss Stiffness

광명 돔 경륜장

Roof Frame Plan



광명 돔 경륜장

Overall snapping stability check of domed roof

Collapse mechanism consists of

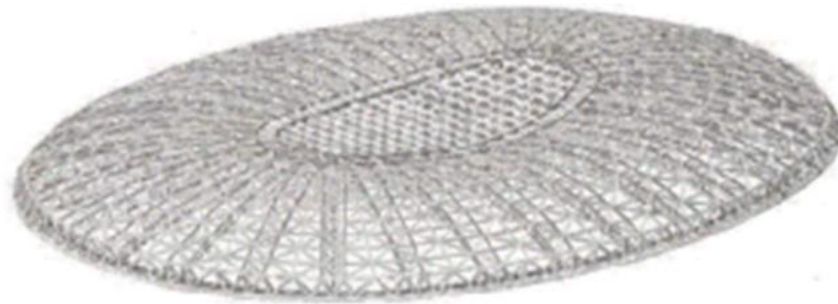
- rise span ratio
- element stiffness
- mode of loads



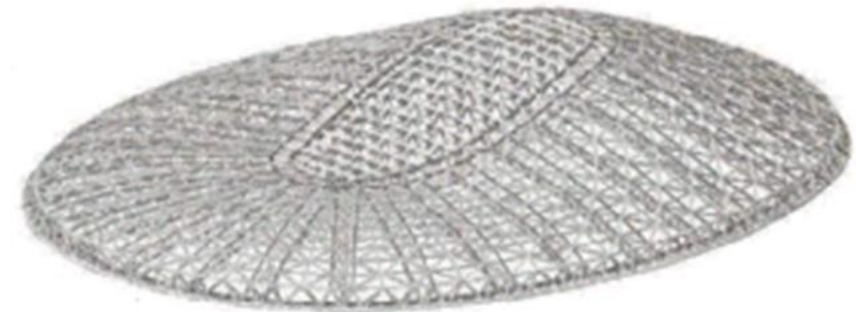
Shallow dome : Snap through

High height dome : Bifurcation

check by nonlinear analysis



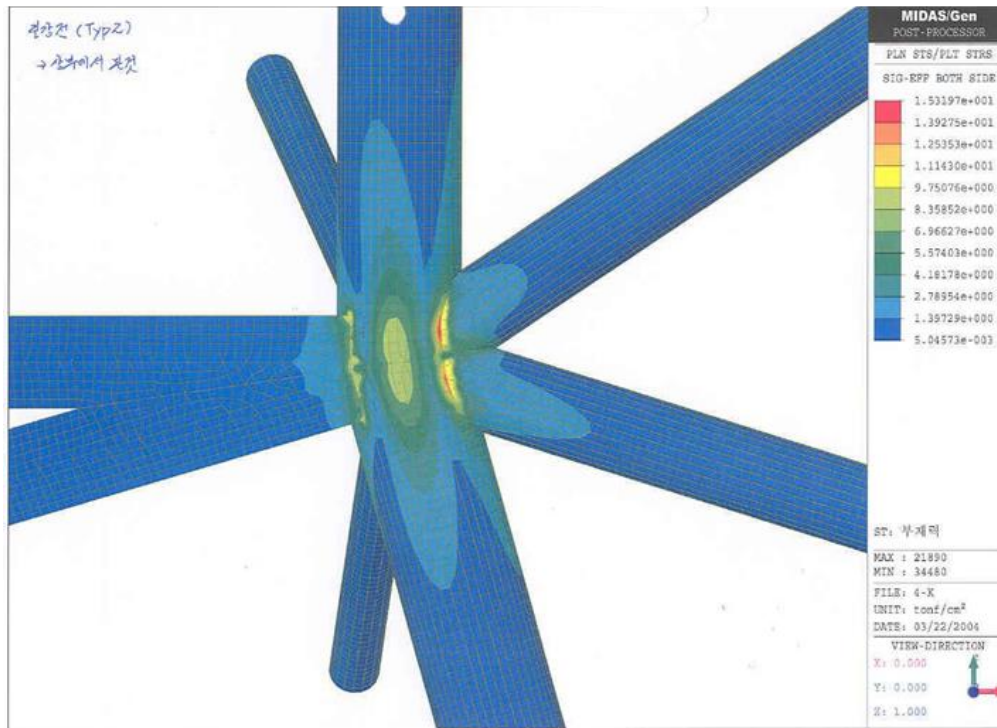
Snap-through



Bifurcation

광명 돔 경륜장

Detailed FEM Analysis of Steel Pipe Connection



•Stresses before reinforcing



•After reinforcing

광명 돔 경륜장

Erection Engineering

STEP 1



Install temporary support
(comp. and tens. Ring)

STEP 2



Install inner grid structure

STEP 3

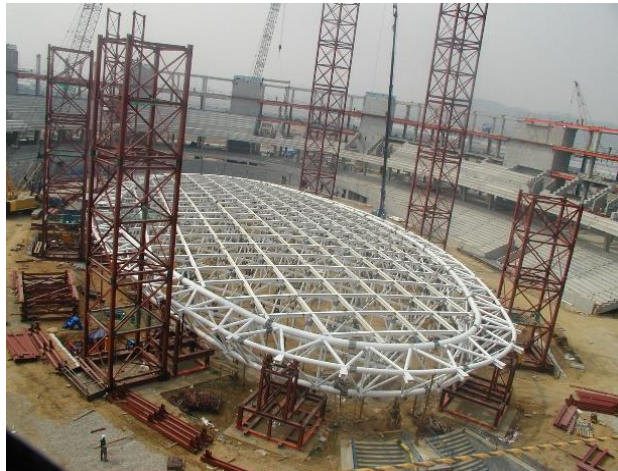


Install flow truss and flow
shell structure

STEP 4

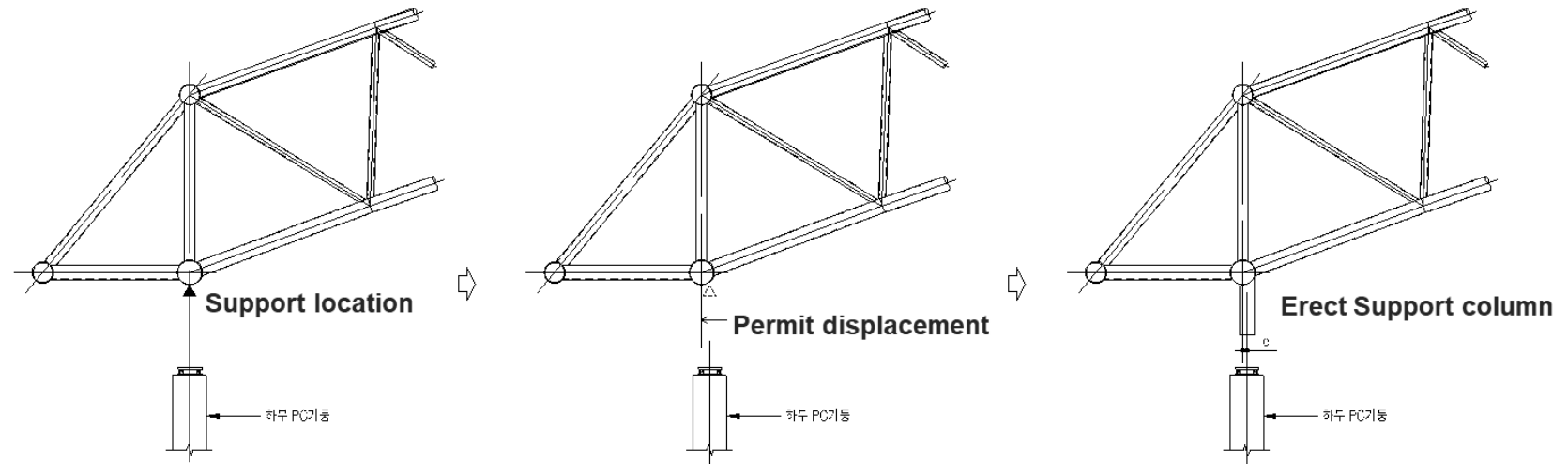


Complete construction

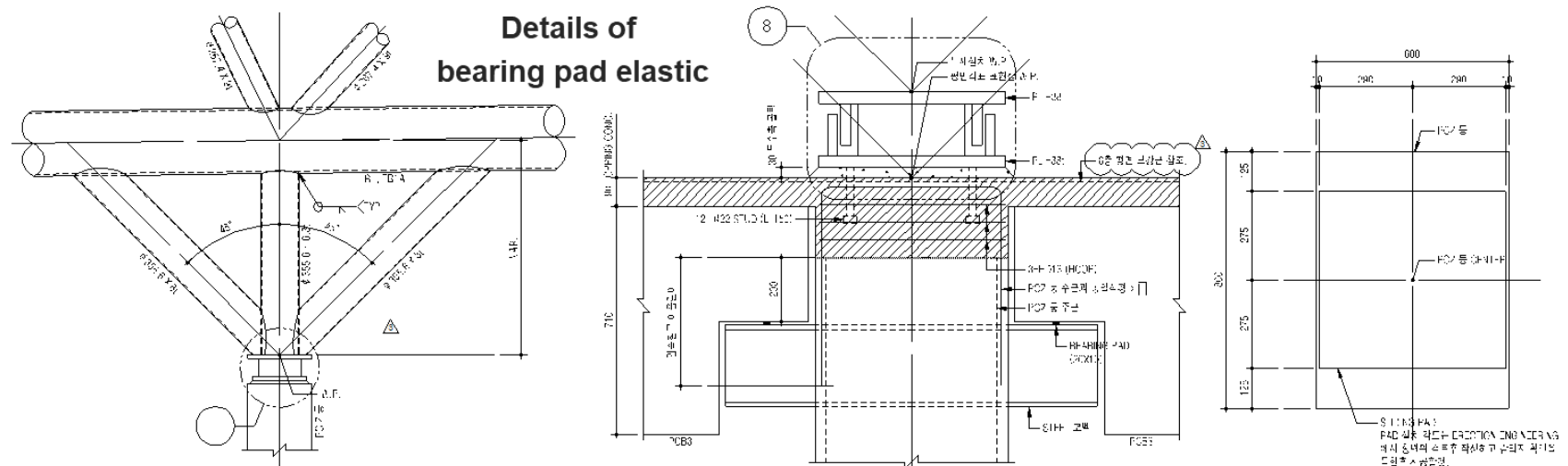


광명 돔 경륜장

Erection Engineering



- Erection sequence for support column -



고척 스카이드롬

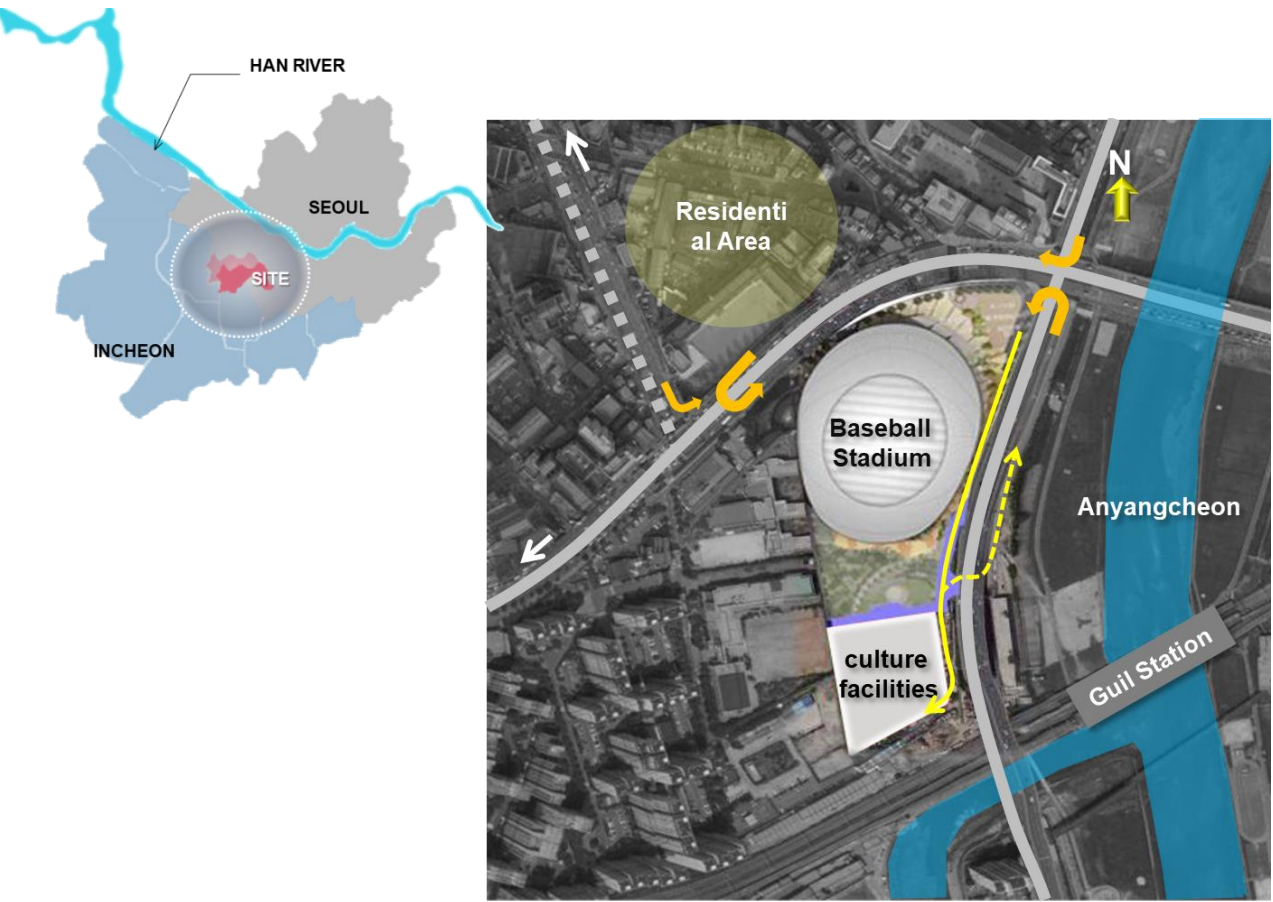
고척 스카이드롬

고척동, 2009년



고척 스카이드롬

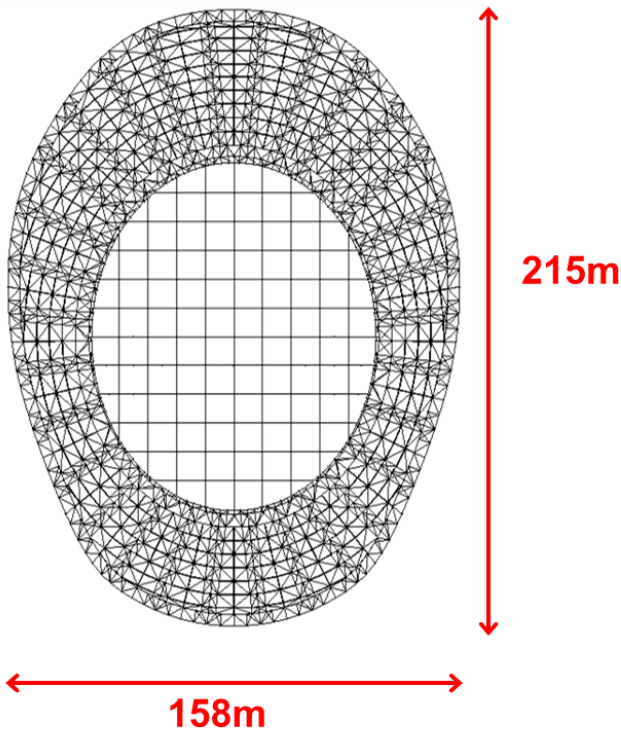
서울시 구로구, 2009년



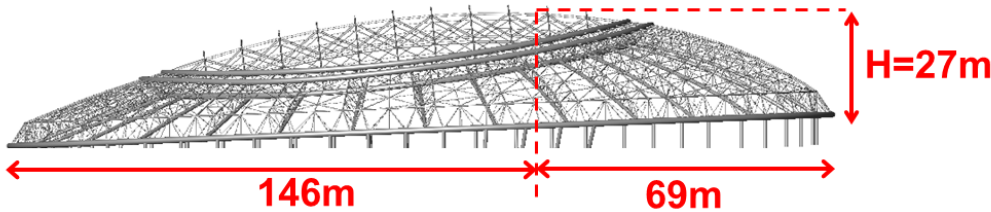
Project	South-Western Baseball Stadium
Site	Gocheok-dong, Guro-gu, Seoul, Korea
Gross Area	62,443 m ²
Floors	Above ground 4F (Underground 2F)
Structure	RC Frame / PC Stand Roof : Space Frame + Membrane
Seats	22,258

고척 스카이드롬

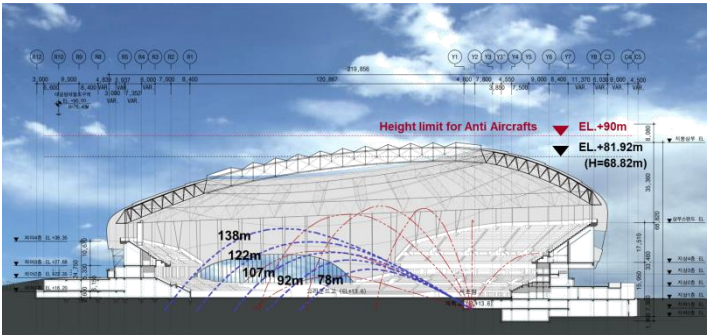
Dome Diameter (Plan)



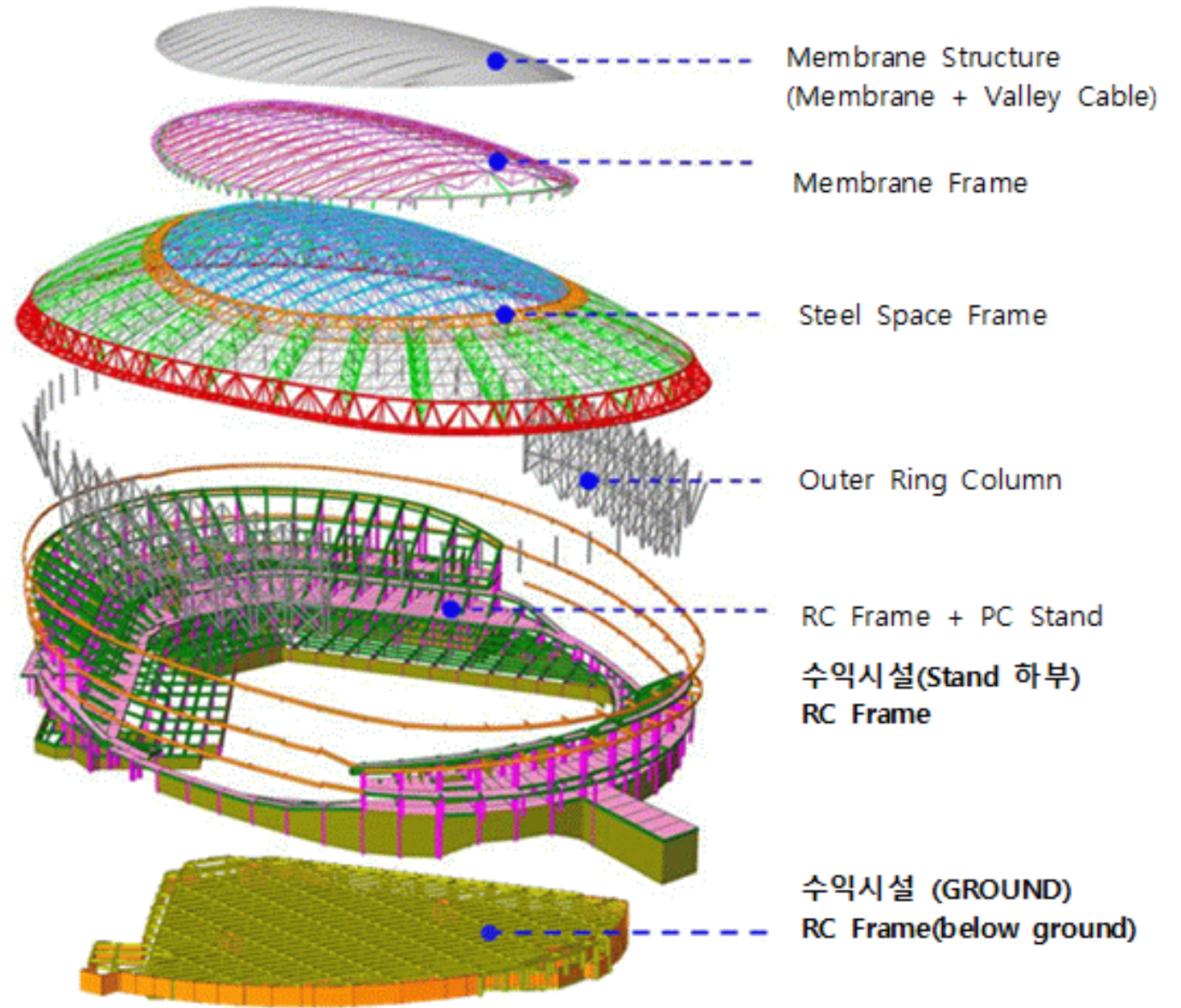
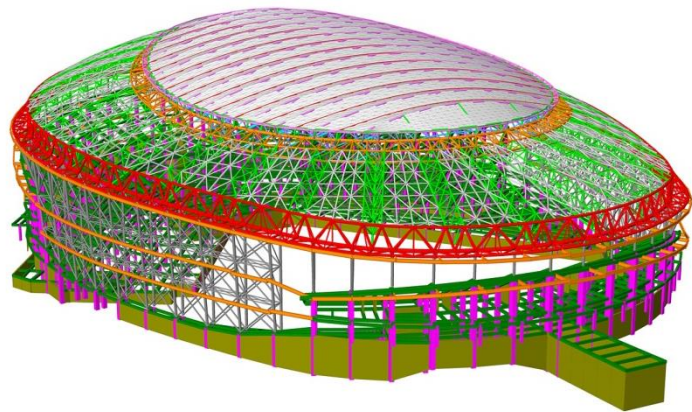
Dome height (Elevation)



Span-Rise Ratio	Minor axis	$\frac{27}{2 \times 146} = 0.09$
	Major axis	$\frac{27}{158} = 0.17$



고척 스카이드롬



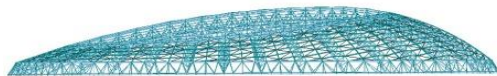
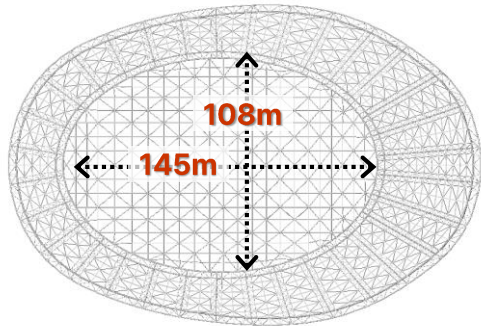
고척 스카이드롬

Alternative Structural System Study

ALT 0

(Rib + Grid Dome -original)

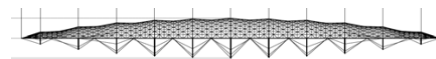
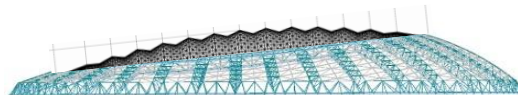
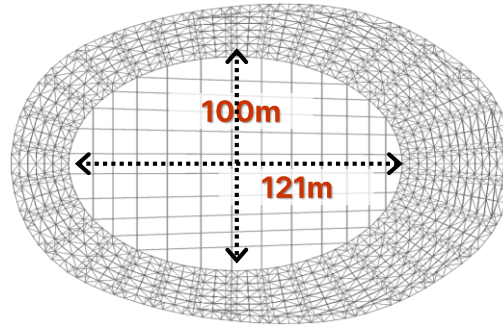
Steel truss dome system composed with rib truss and inner grid



ALT 1

(Rib + Cable Truss Dome)

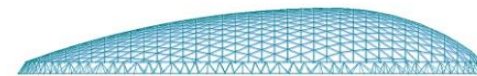
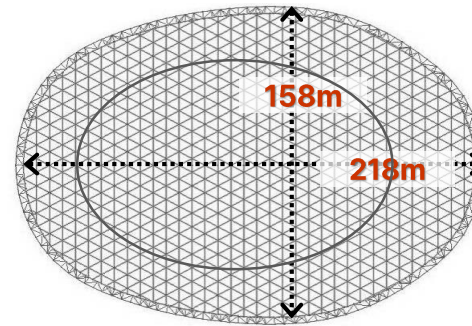
Hybrid system composed with rib truss and under-tension cable truss



ALT 2

(Grid Dome)

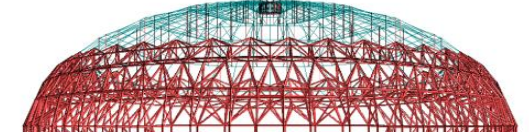
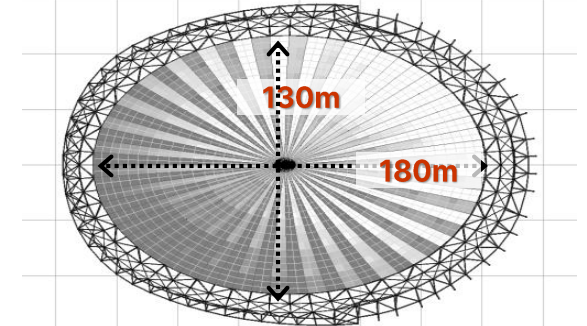
Hybrid system composed with double layer grid and single layer grid shaped structural membrane



ALT 3

(Cable Dome)

Tensegrity system using radial cable structure



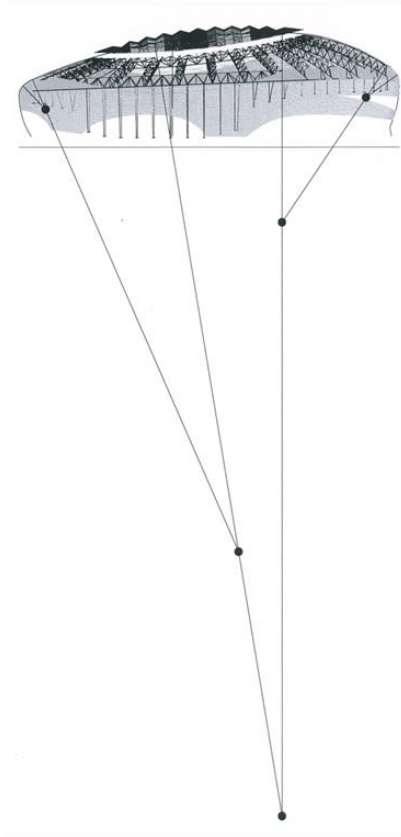
고척 스카이드롬

Structural Design Concept

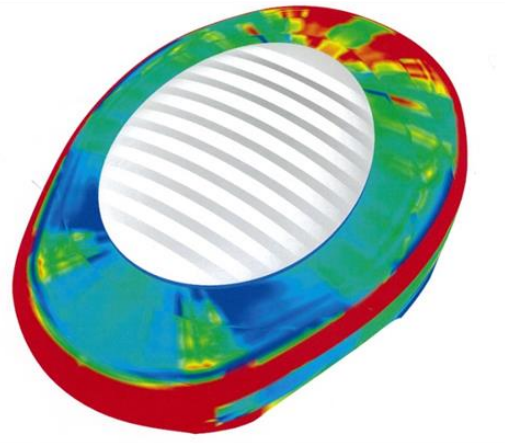
- Curvature analysis



The curvature of the Dome is too complex



Curvature analysis on long axis



Gaussian curvature analysis
($-9.8e-12 \sim +9.8e-11$)



Gaussian curvature analysis
($-2.65e-12 \sim 2.65e-11$)

고척 스카이드롬

Structural Design Concept

- Model 1 : regularized in entire structure

➡ Maximum clearance, heavy secondary members

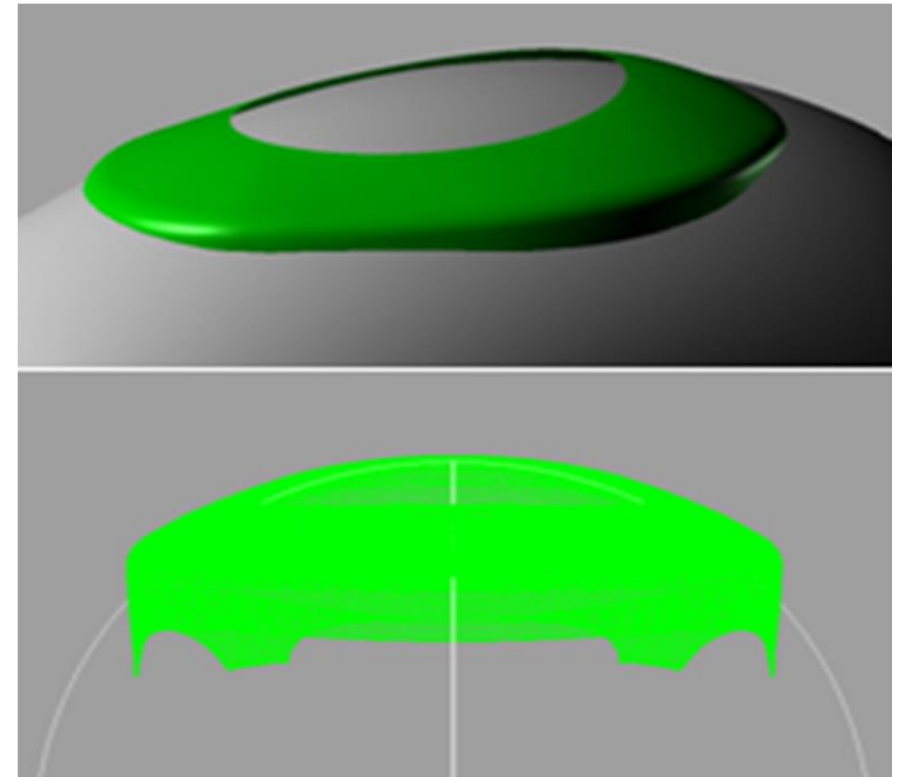
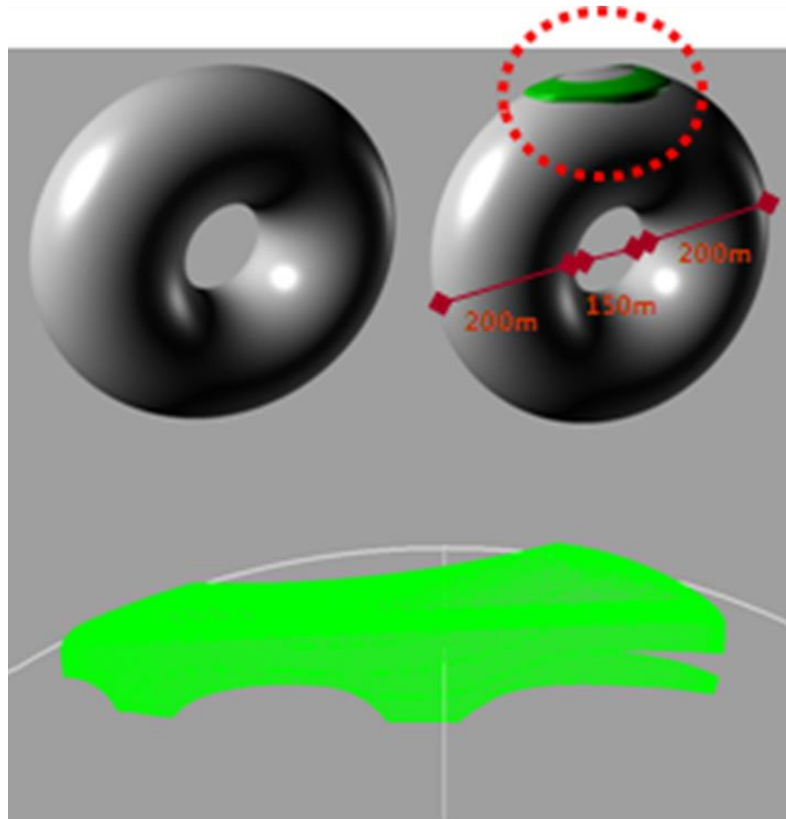


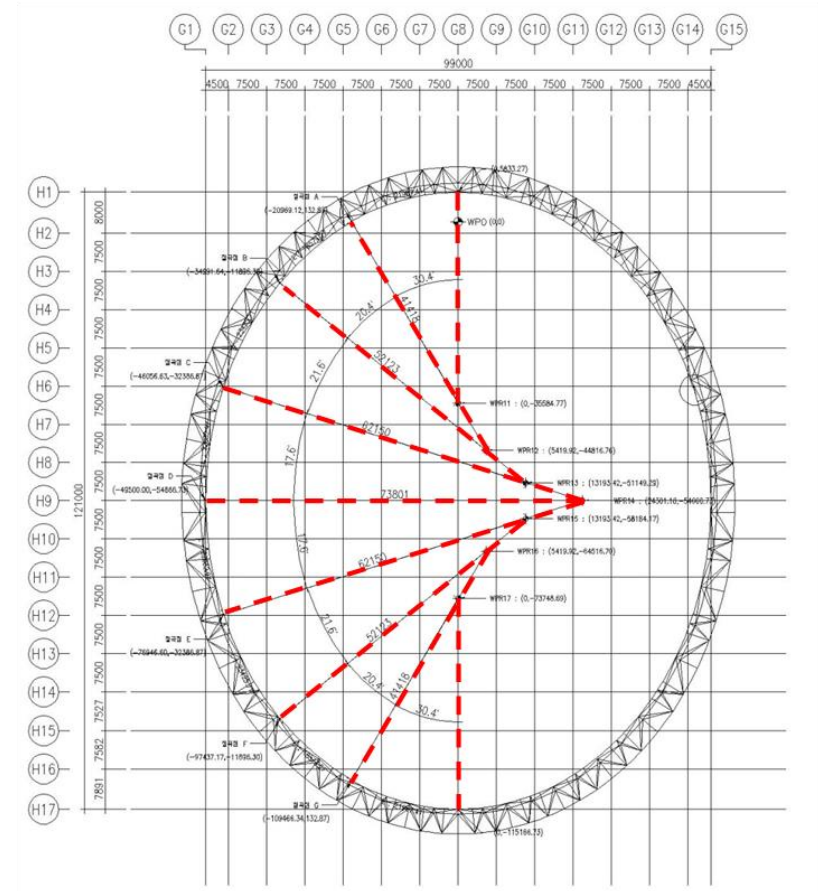
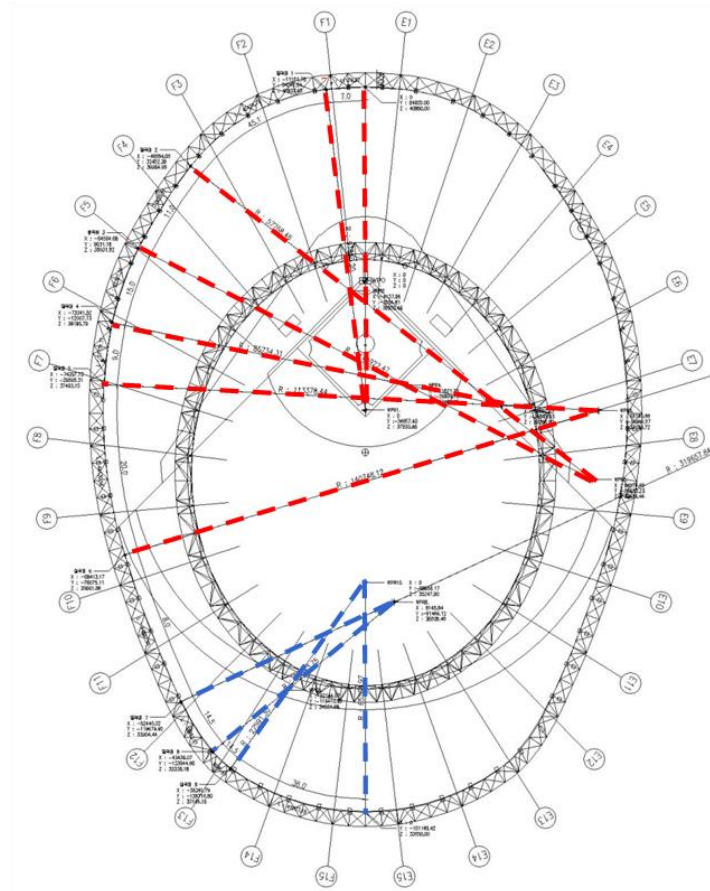
Image search of structure through Torus

고척 스카이드롬

Structural Design Concept

- Model 2 : regularized in each major members

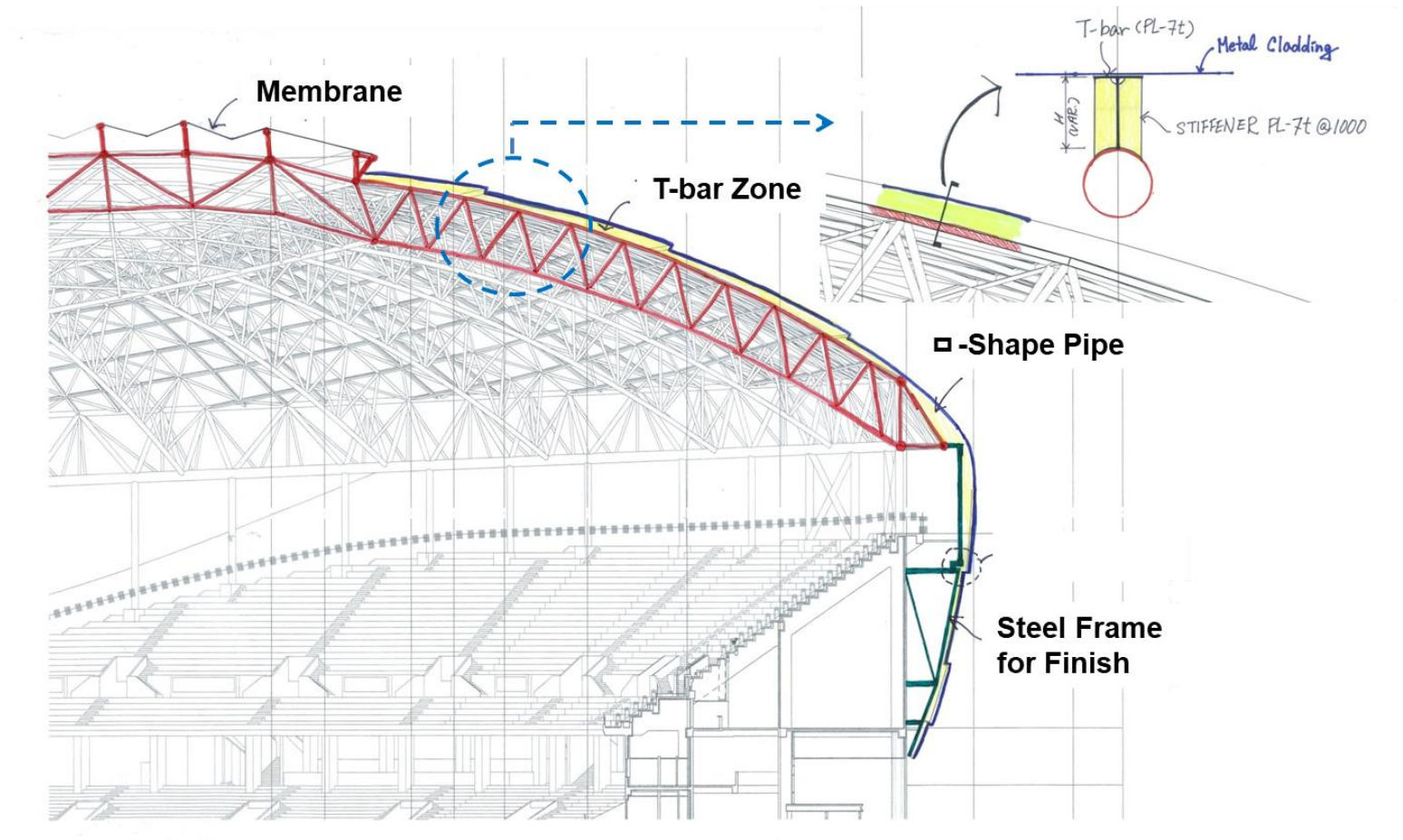
➡ minimum clearance



고척 스카이드롬

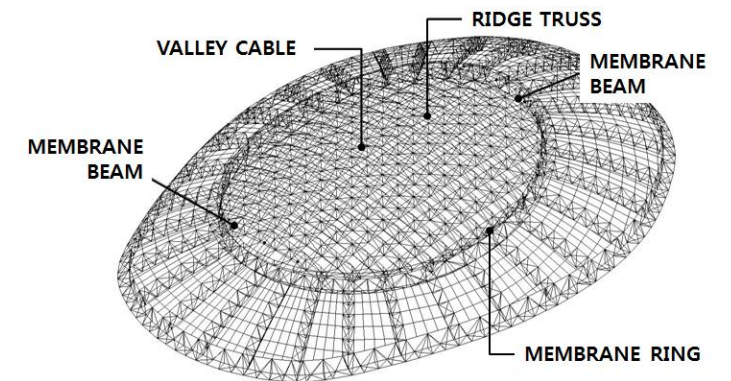
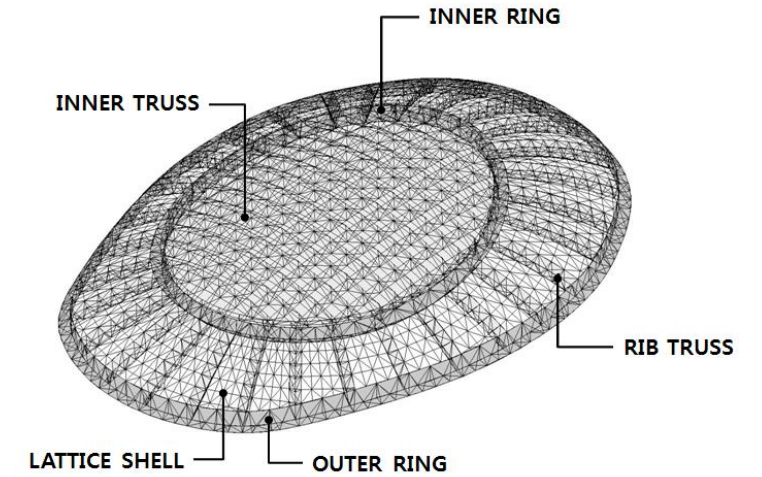
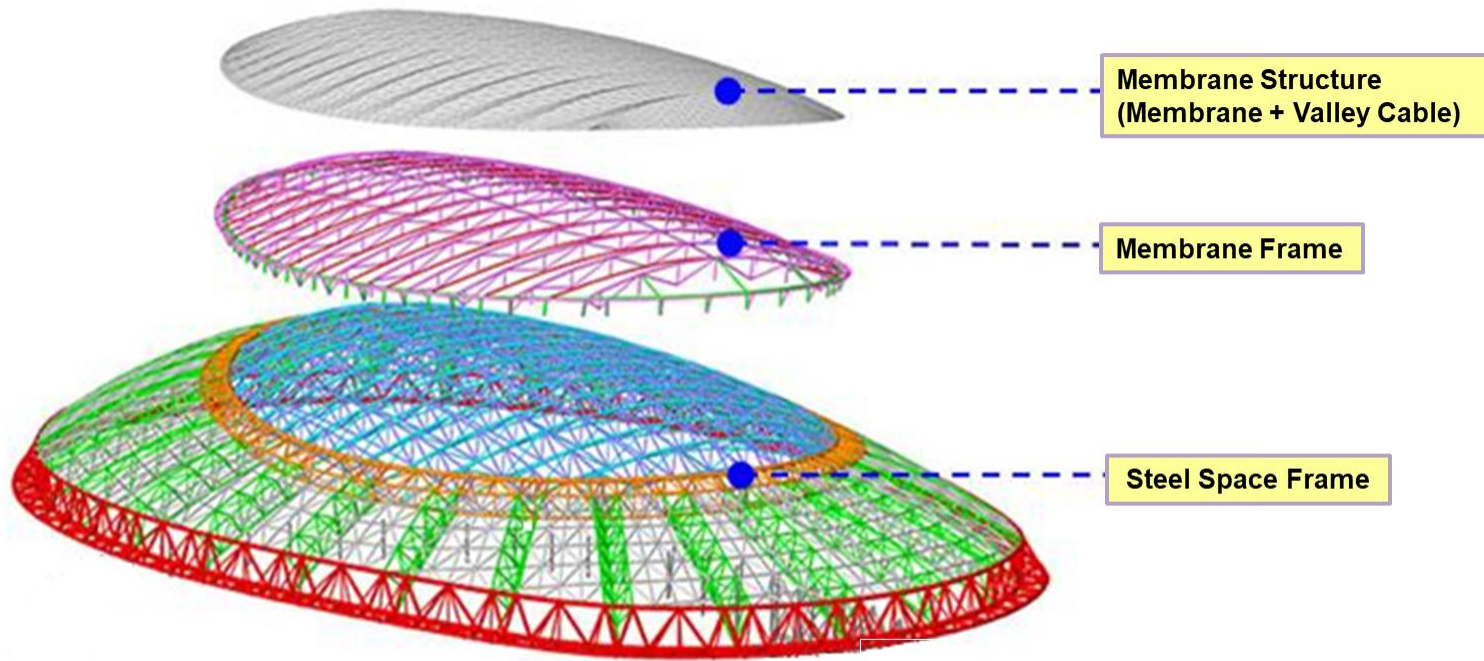
Structural Design Concept

- Secondary members between major member and shape



고척 스카이드롬

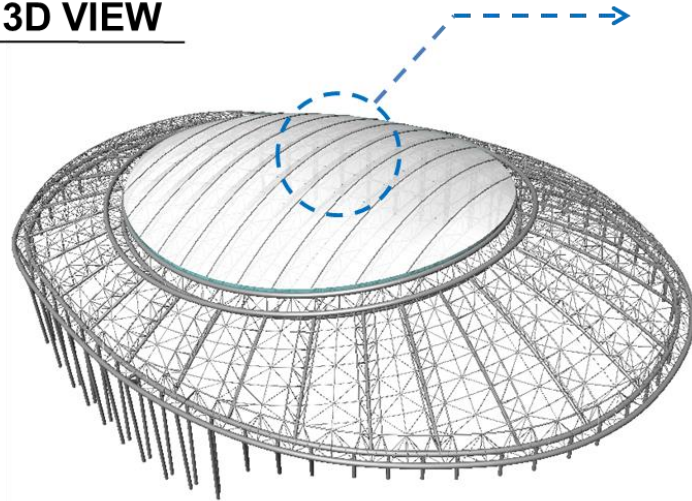
Roof Structural System



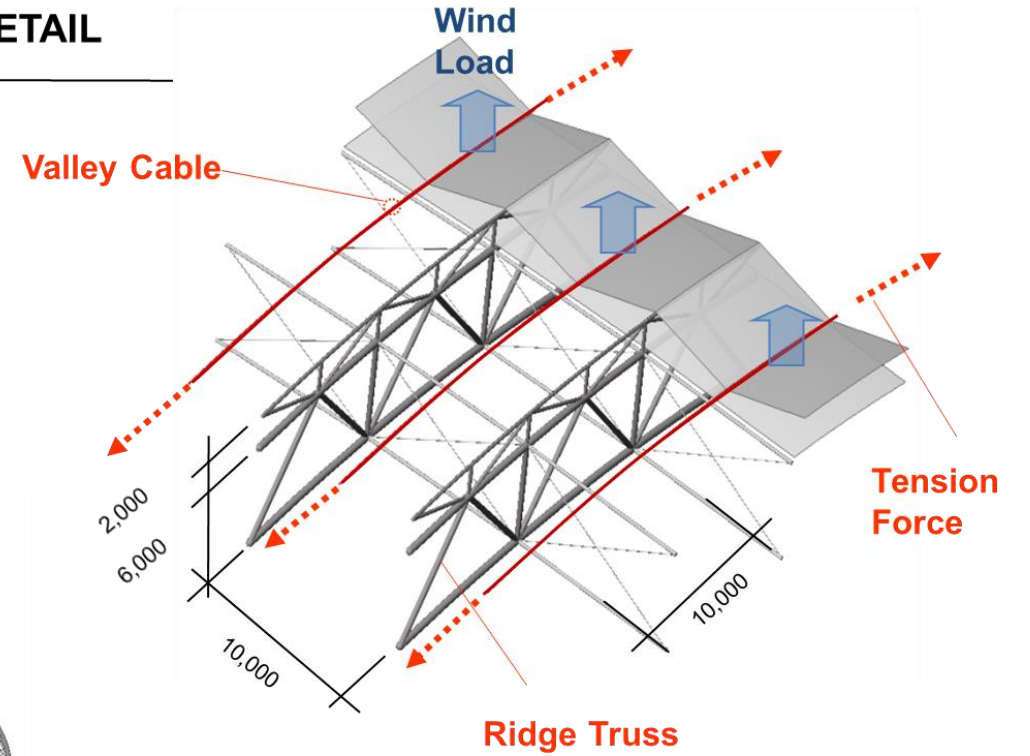
고척 스카이드롬

Roof Structural System

3D VIEW



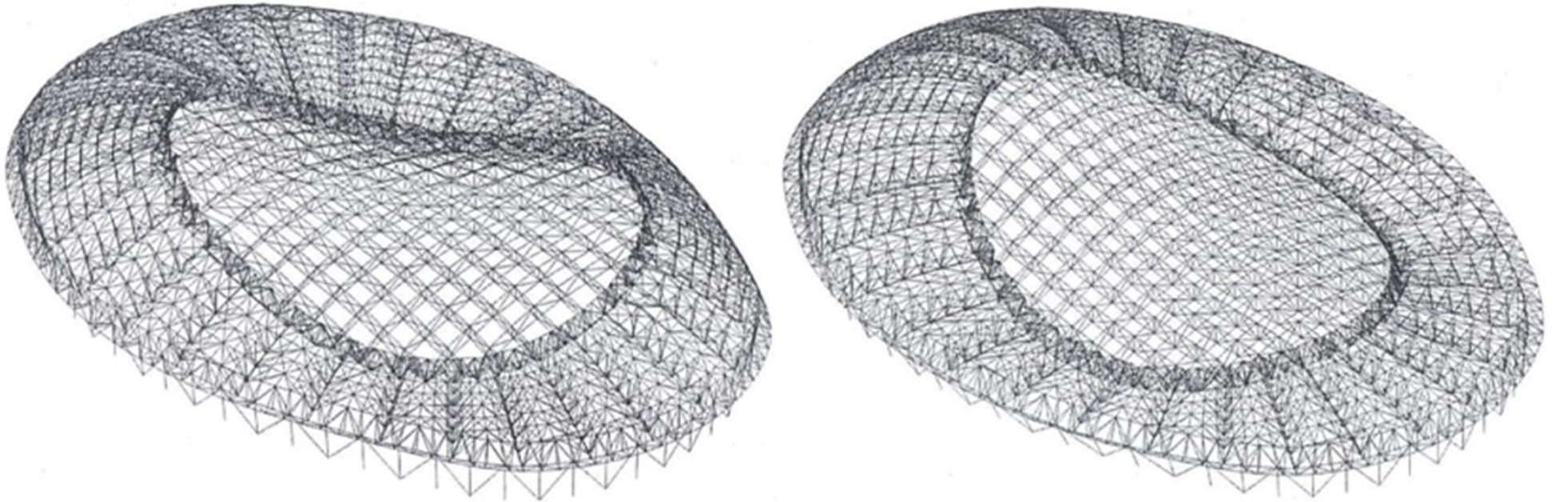
DETAIL



고척 스카이드롬

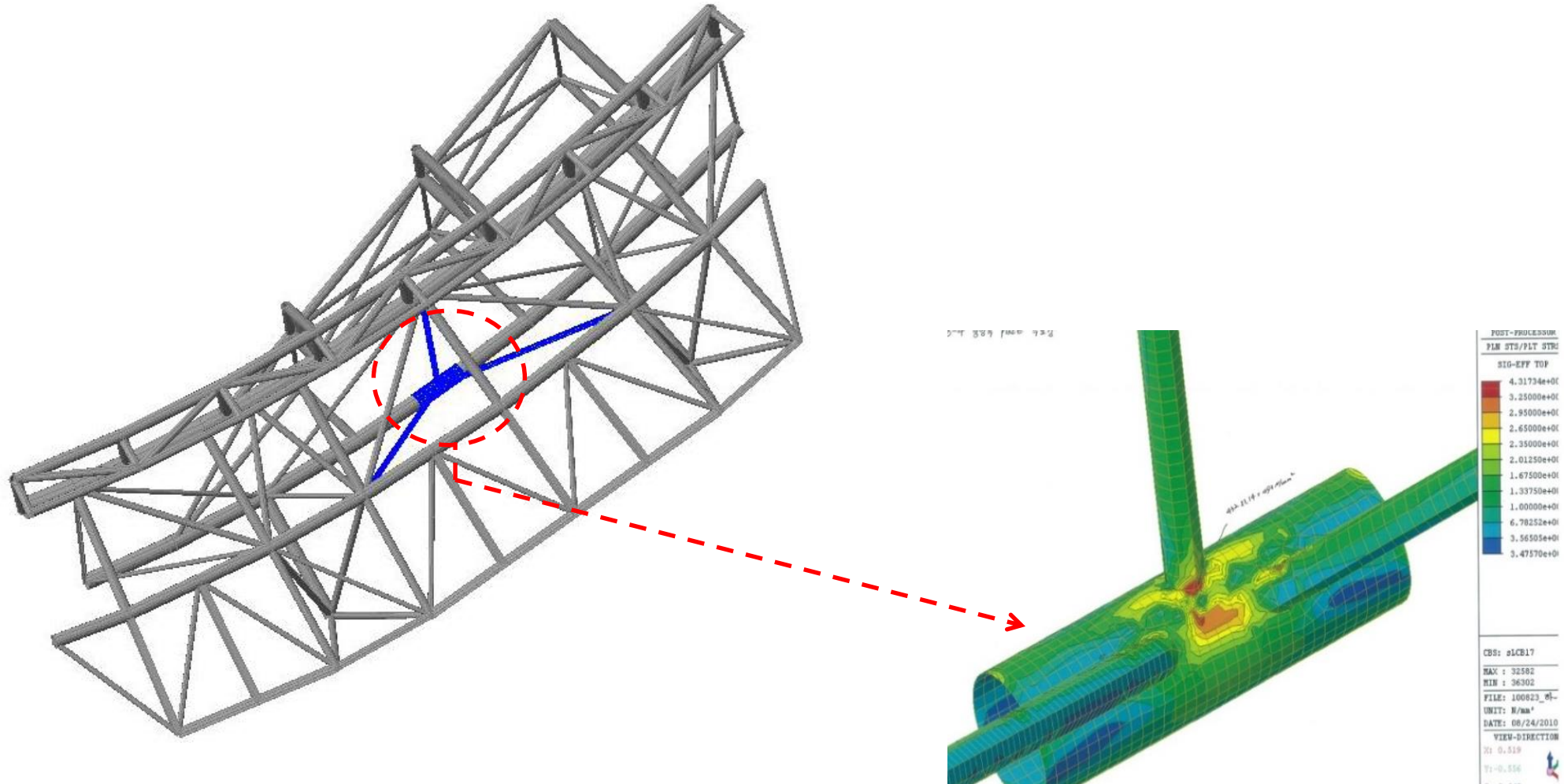
Nonlinear Snapping Analysis

- Dome structure is a form-resisting structure
- 'Snapping' could be a serious problem on dome structure
- Nonlinear Snapping Analysis was conducted to confirm its stability



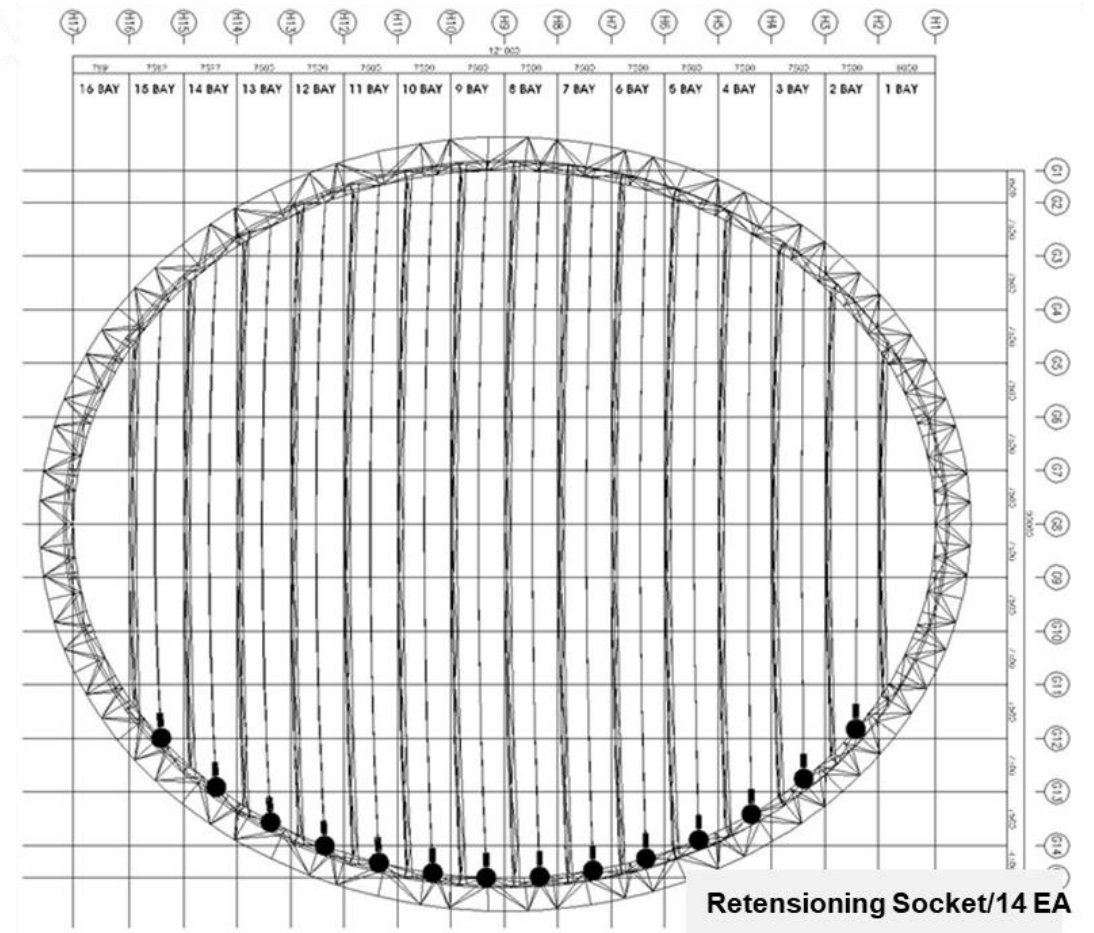
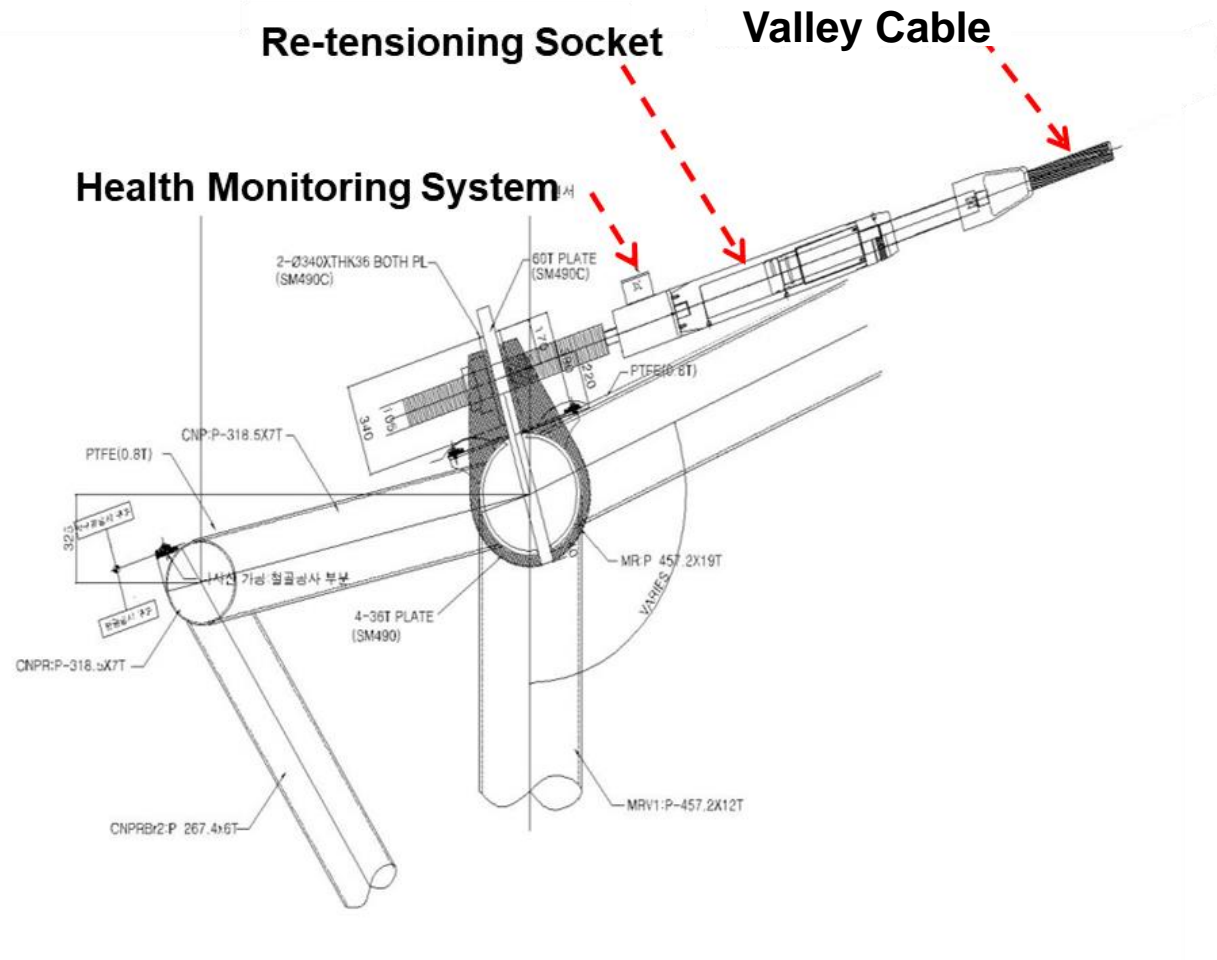
고척 스카이드롬

Pipe Connection Analysis



고척 스카이드롬

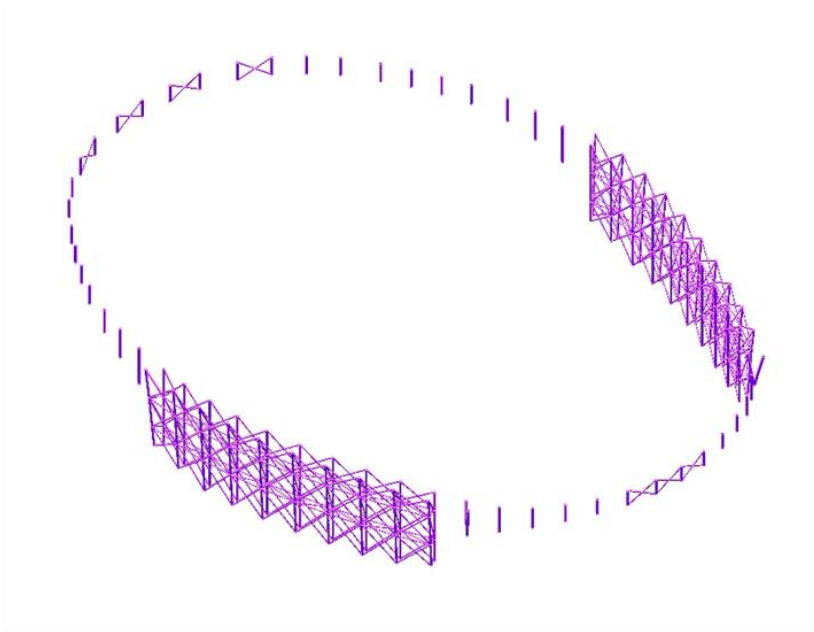
Monitoring, re-tensioning system



고척 스카이드롬

On-site installation plan

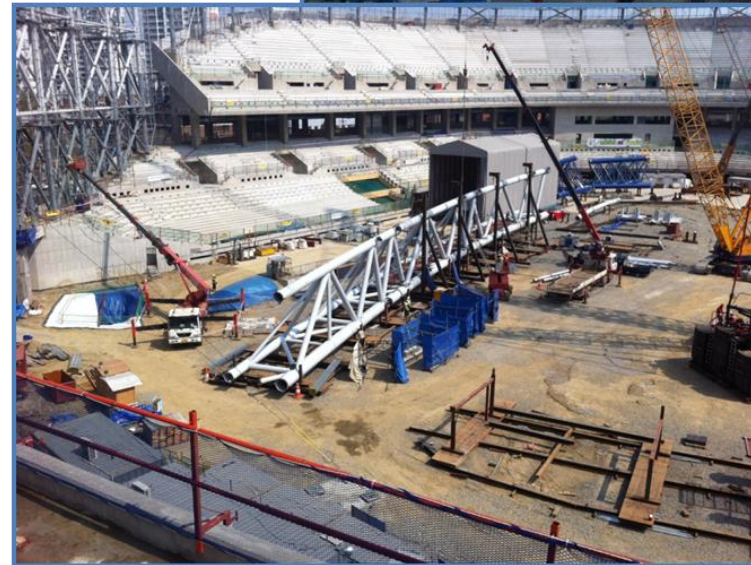
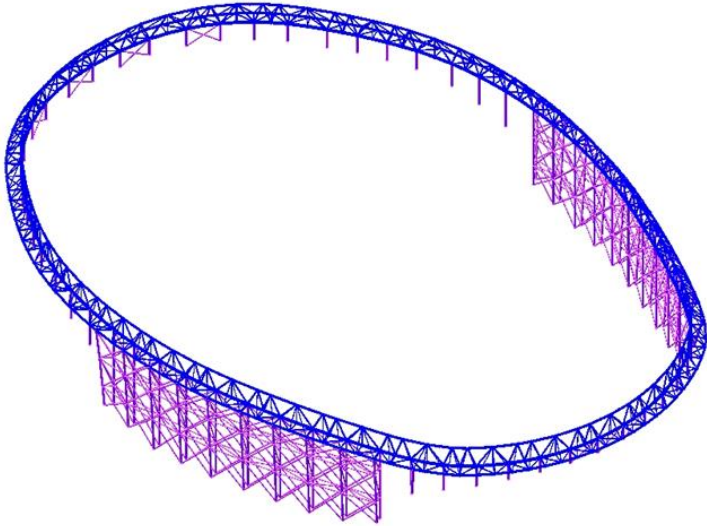
STEP 1 : Columns / Exterior steel 설치



고척 스카이드롬

On-site installation plan

STEP 2 : Outer Ring 설치

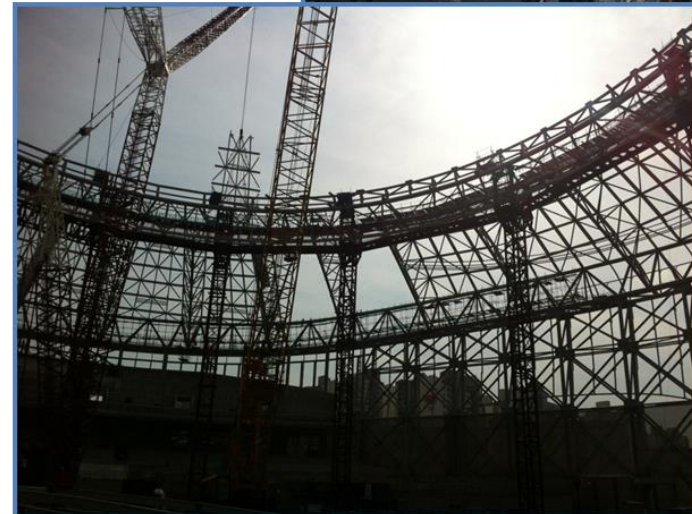
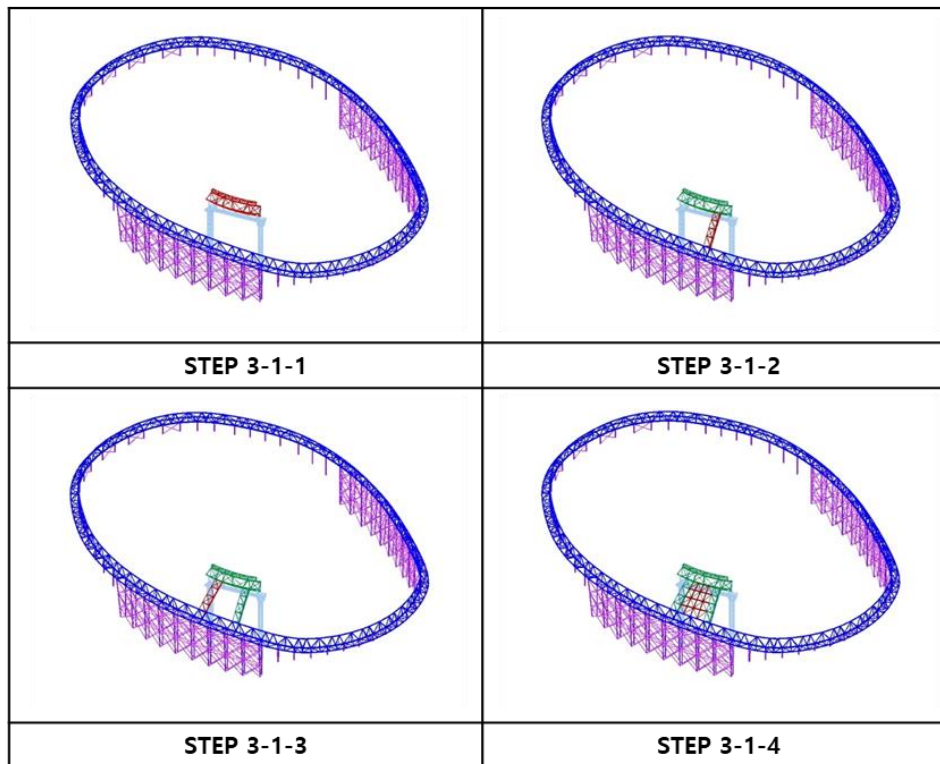


고척 스카이드롬

On-site installation plan

■ STEP 3 : Inner Ring Truss / Rib Truss / Lattice Shell 설치

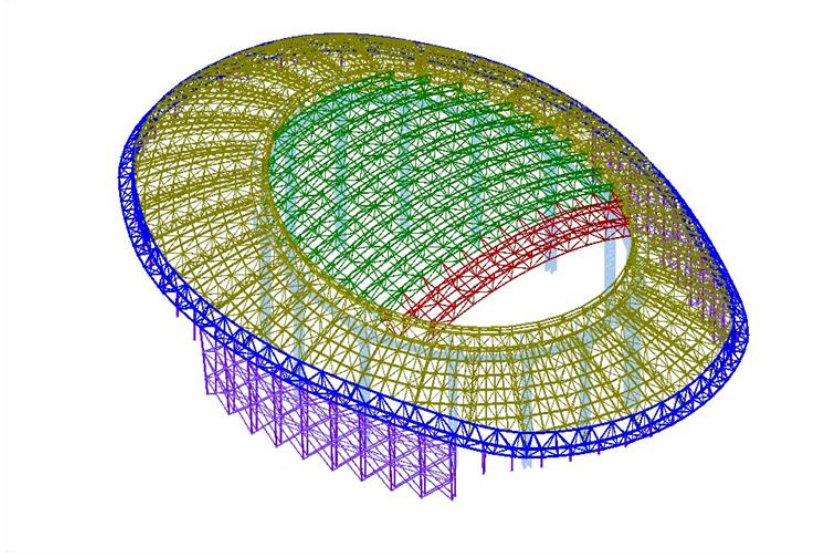
• STEP 3-1



고척 스카이드롬

On-site installation plan

STEP 4 : Inner Truss / Ridge Truss 설치

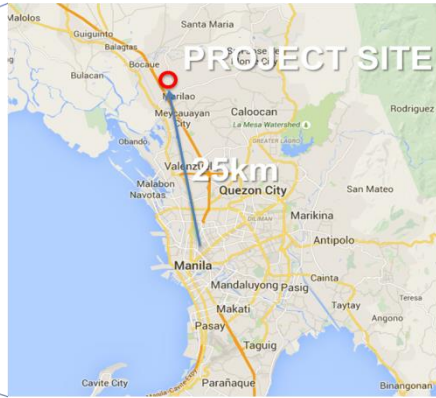


필리핀 아레나

필리핀 아레나

Philippines, 2012년

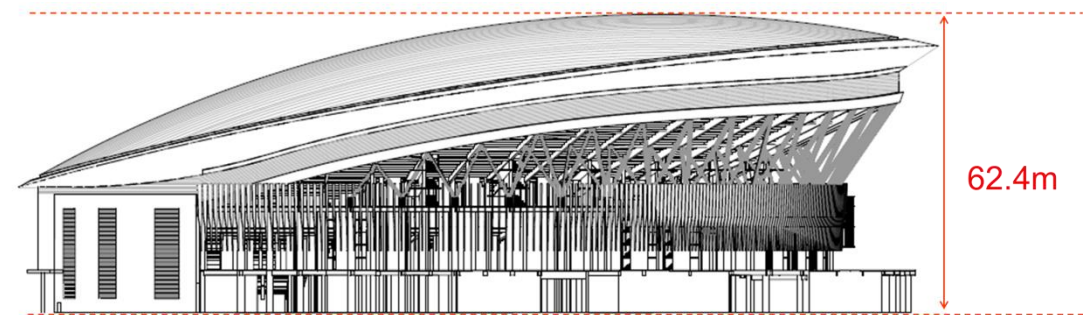
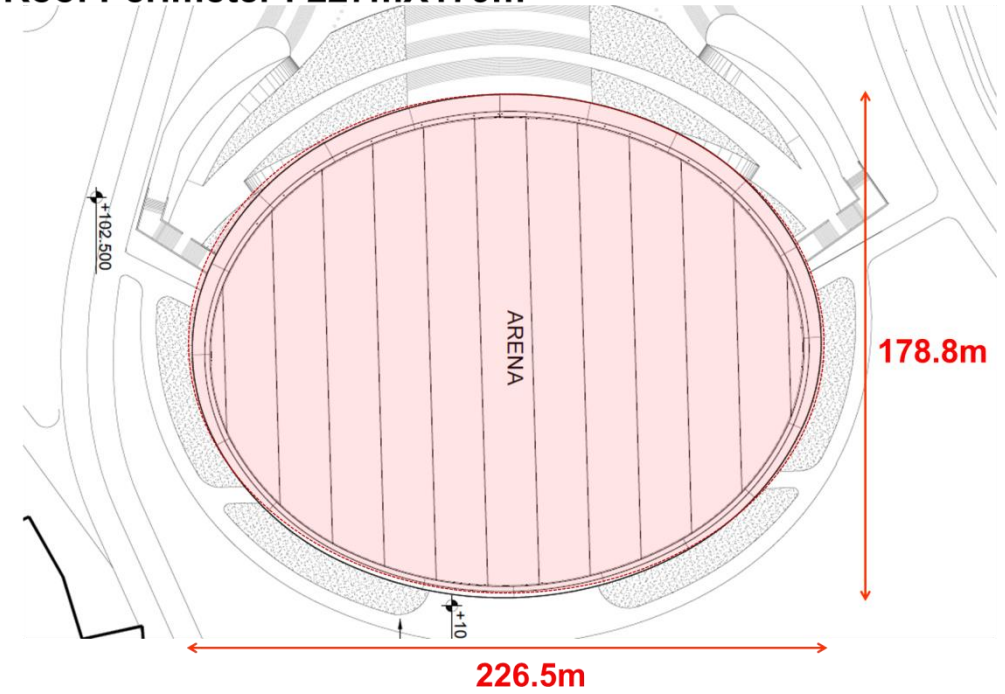




- **Barangay Duhat, Bocaue, Bulancan in the Philippines.**
(North-West Side of Manila)
- **Seismic Area : Zone 4**

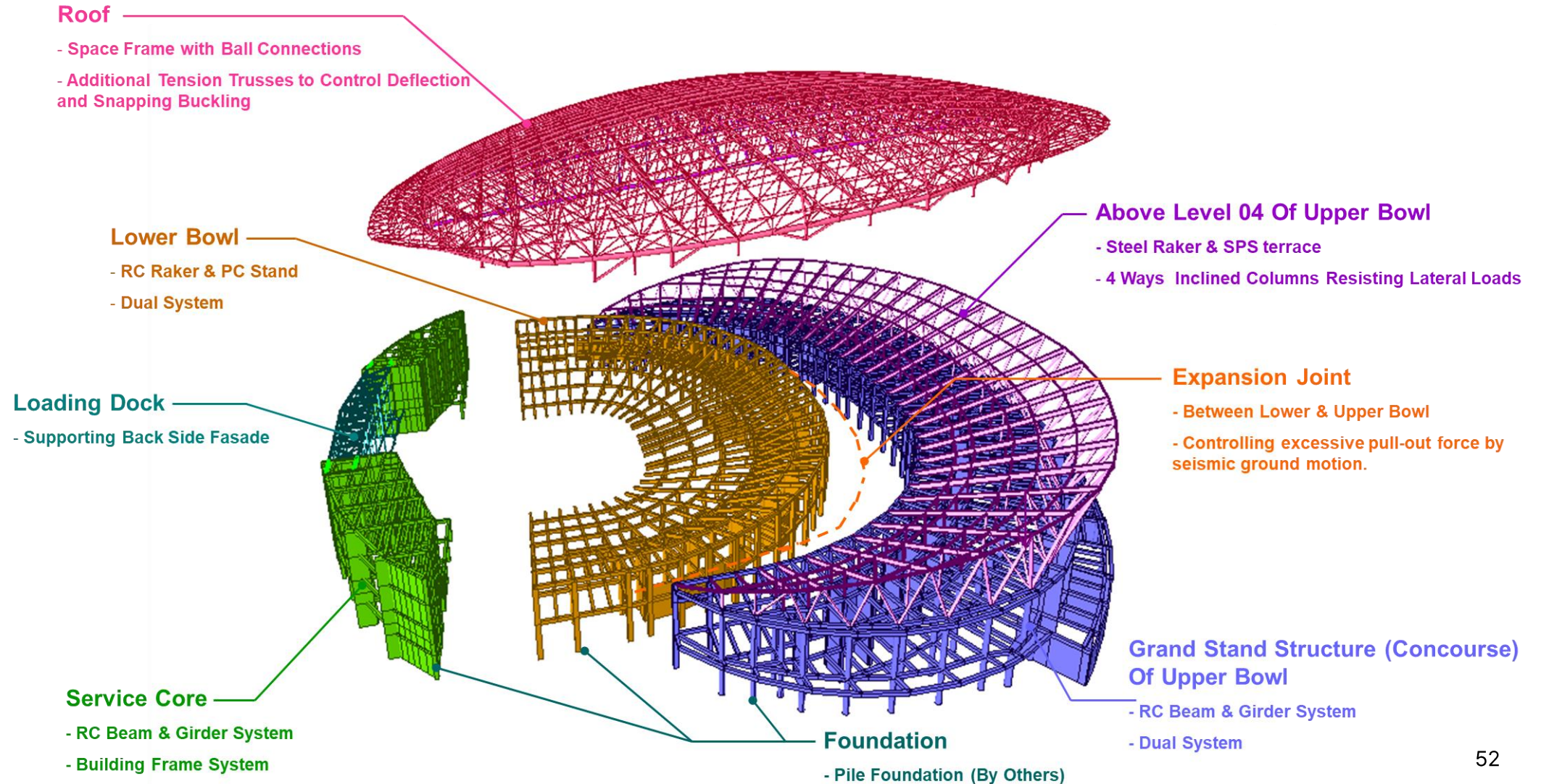
Section	Description
Project name	Philippine Arena
Site Location	Barangay Duhat, Bocaue, Bulancan in the Philippines
Occupancy or Use	Religious Rally, Concert Hall, Gymnasium
Size	1F~5F, Roof Area 36,000m ² , Roof Perimeter 227mX179m
Foundation System	Pile Foundation (Owner's Supply Item)

- **Roof Area : 36,000m²**
- **Roof Perimeter : 227mX179m**



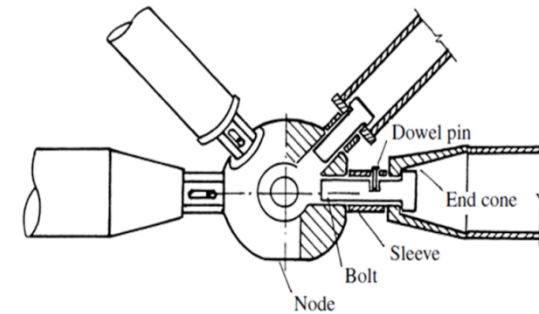
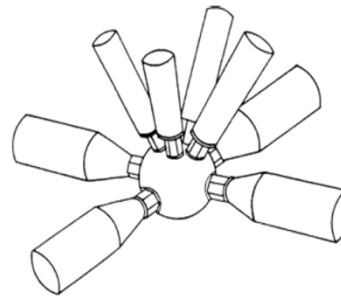
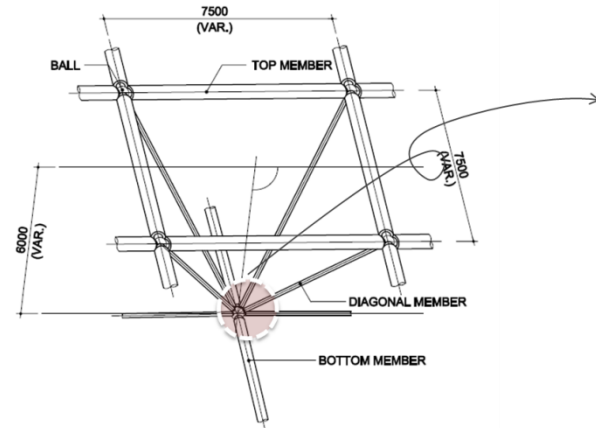
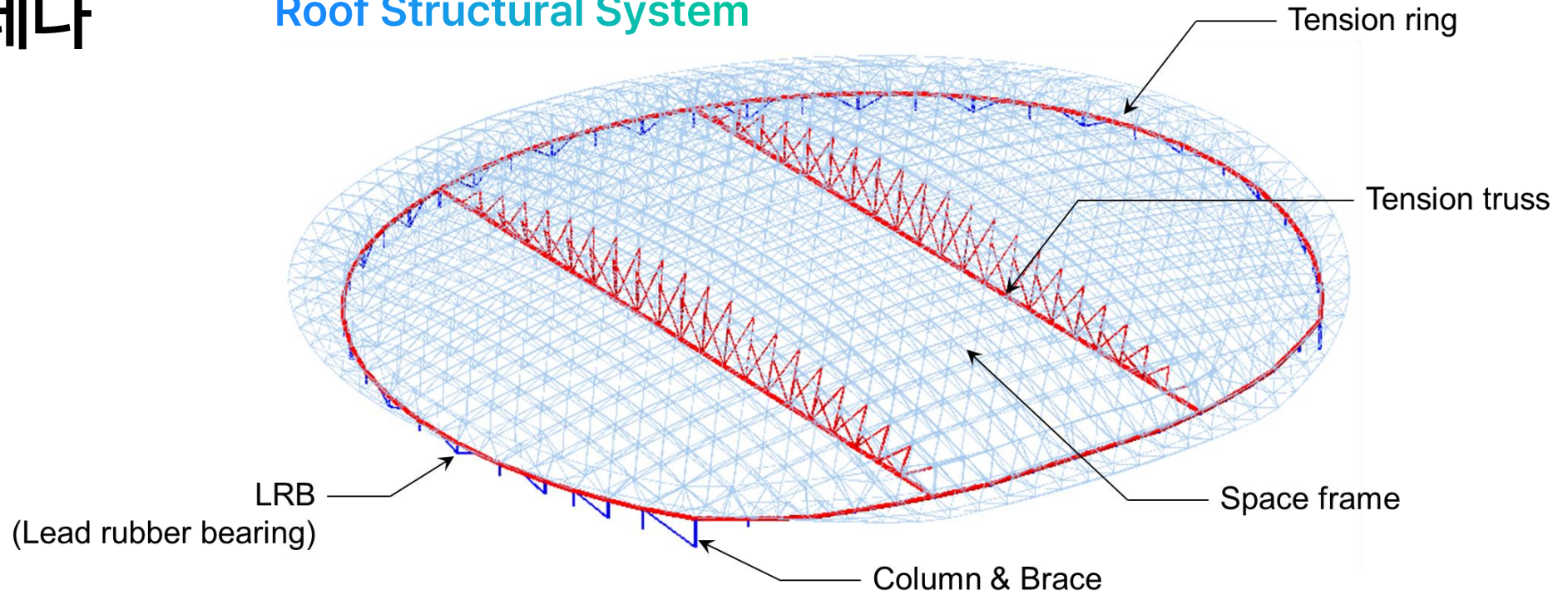
필리핀 아레나

Structural System



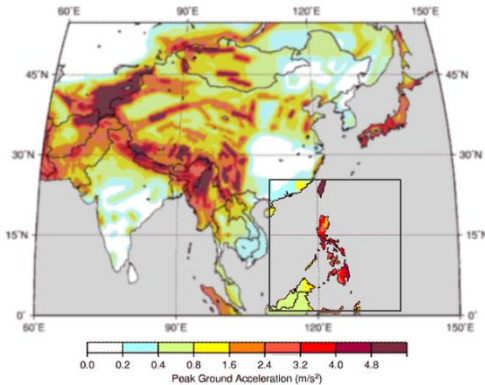
필리핀 아레나

Roof Structural System

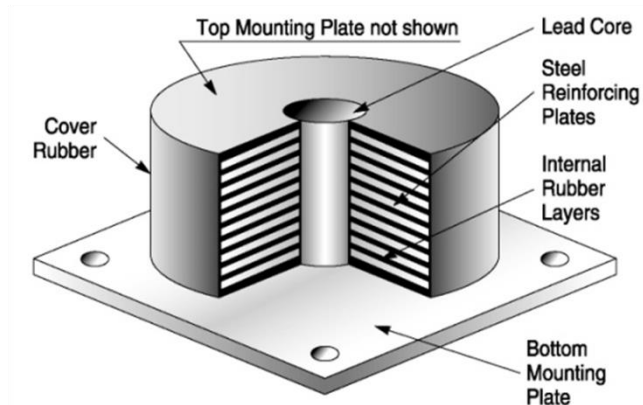
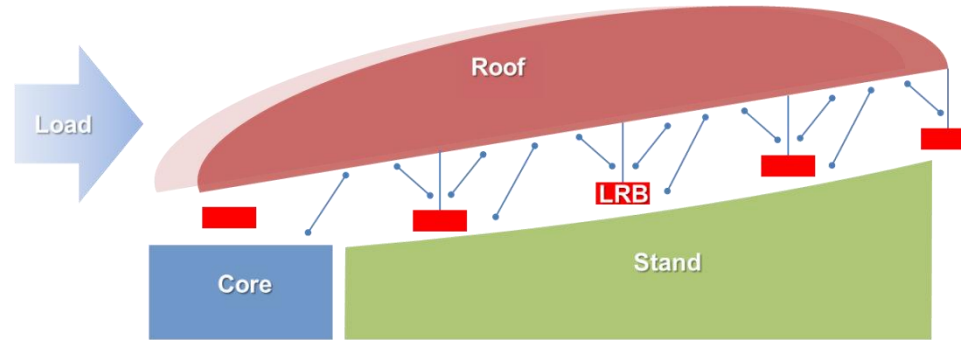


필리핀 아레나

Isolator System of Roof



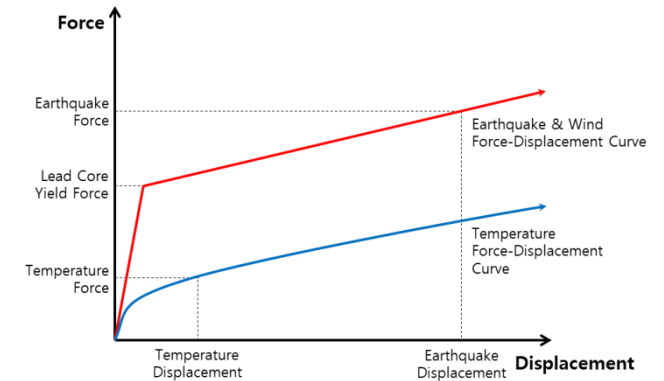
<Seismic hazard map>



<Lead Rubber Bearing : LRB>

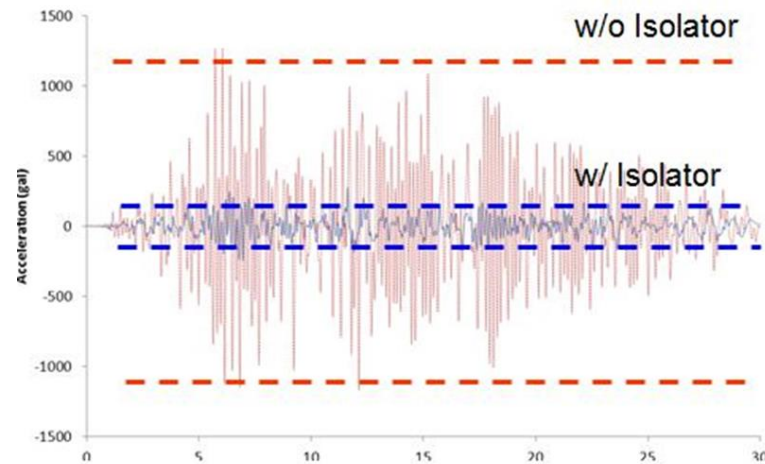
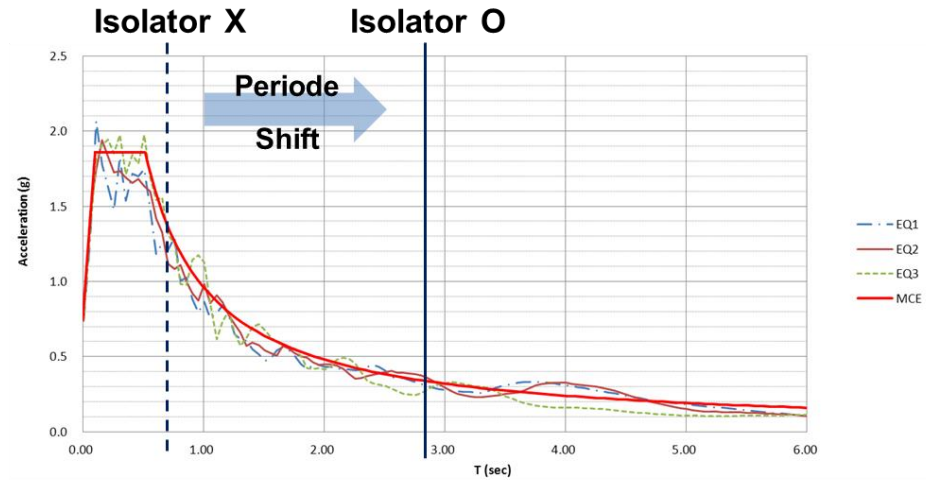


<LRB8000 Maximum displacement pre-test>

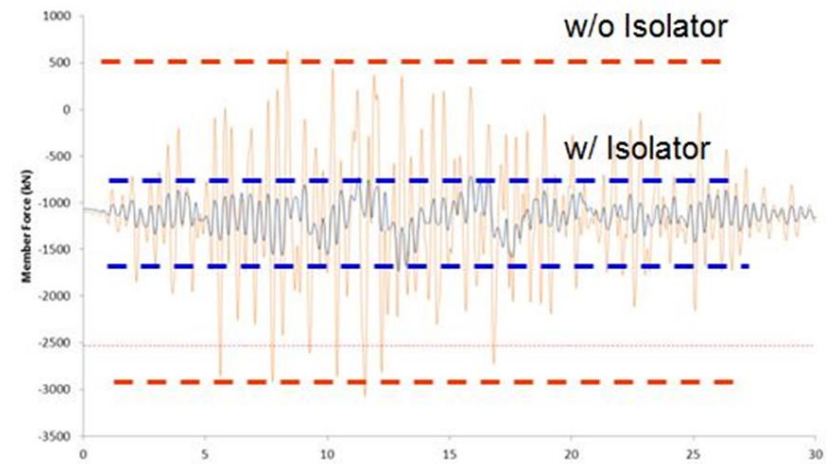


필리핀 아레나

Isolator System of Roof



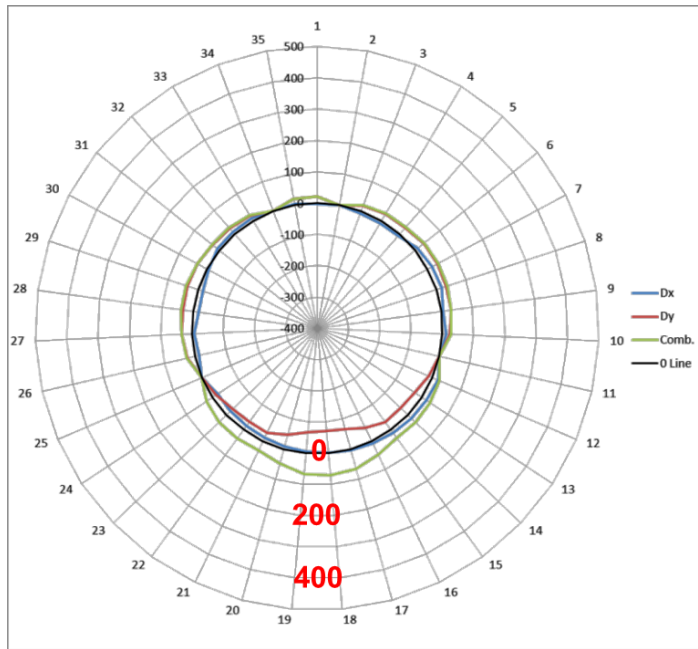
[Response Acceleration Comparison]



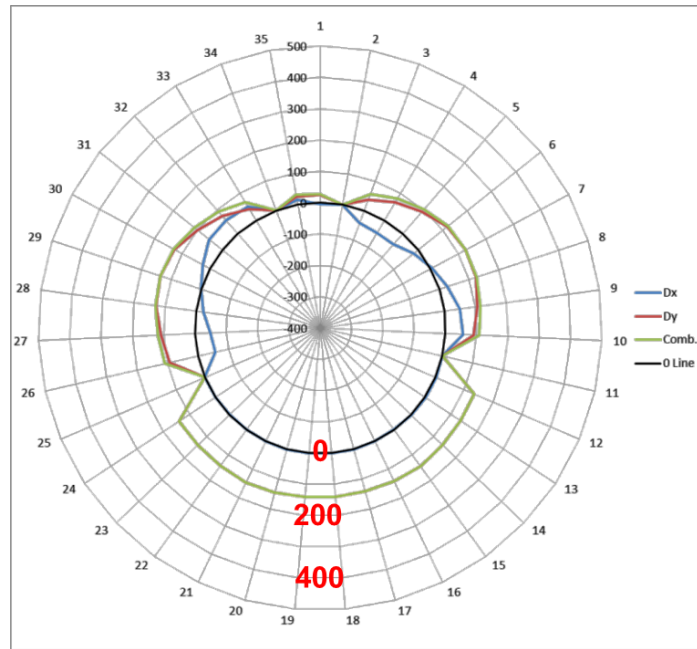
[Member Force Comparison]

필리핀 아레나

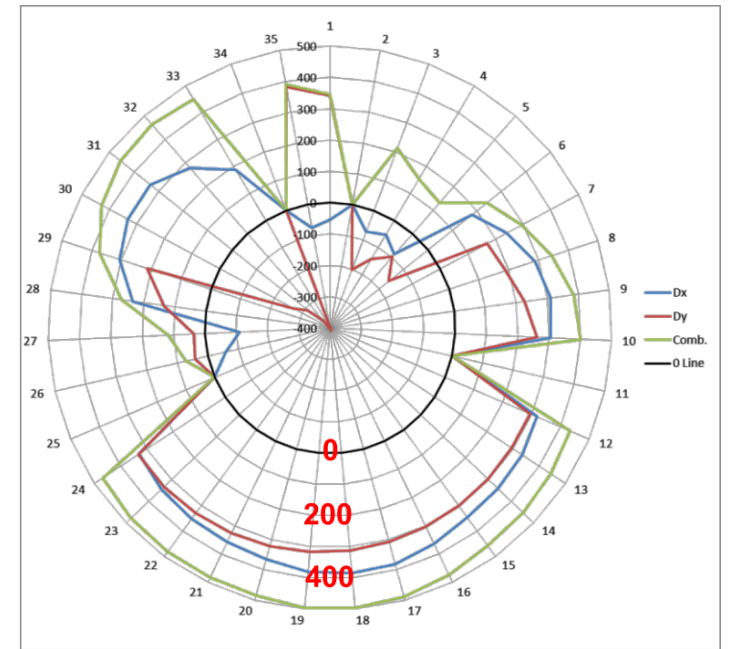
LRB Displacement



(a) Dead Load



(b) Wind Load

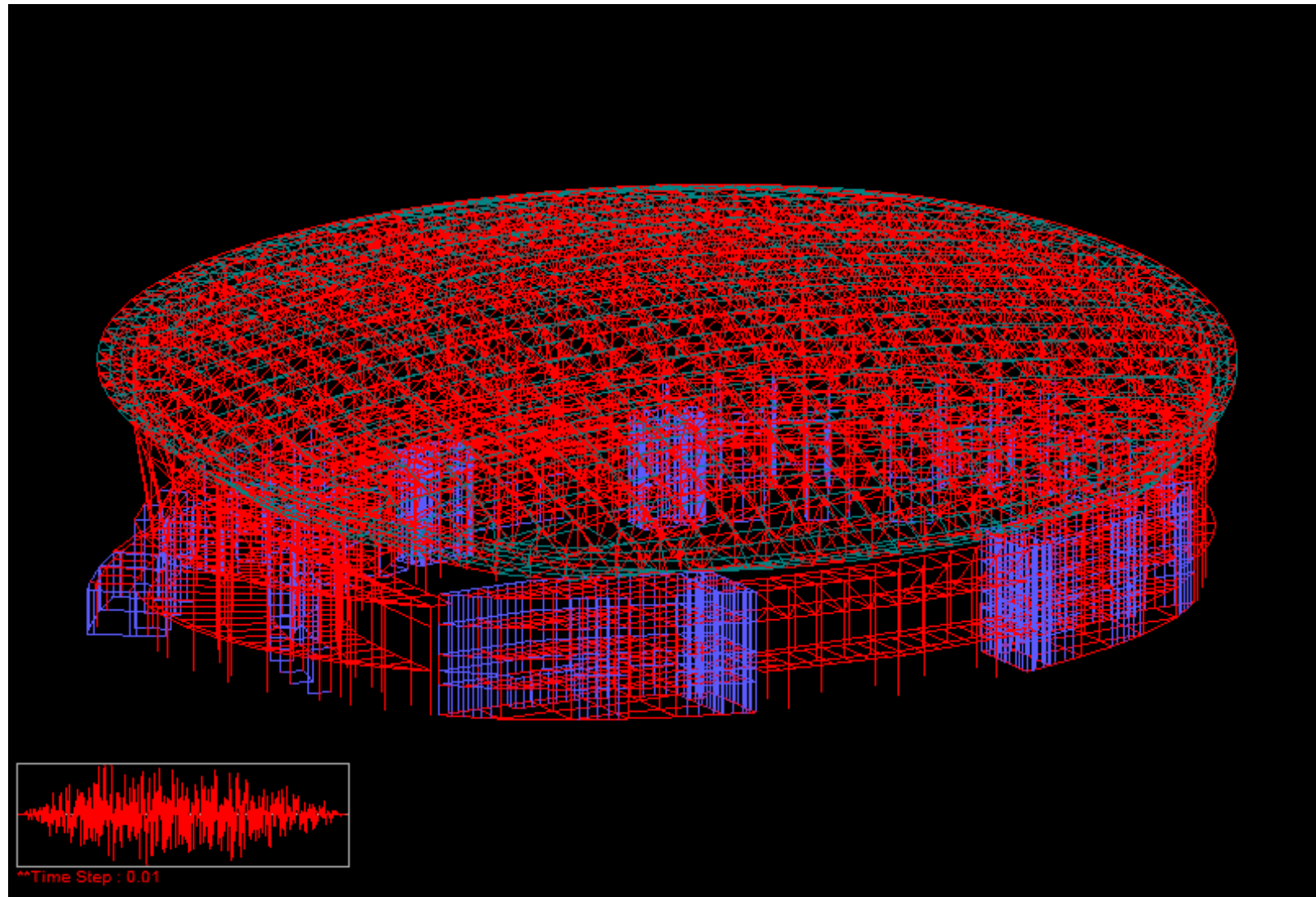


(c) Earthquake Load

< LRB Displacement >

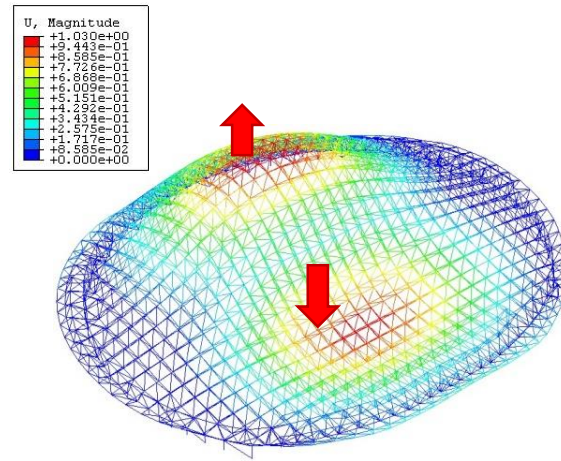
필리핀 아레나

Time History Analysis by MIDAS

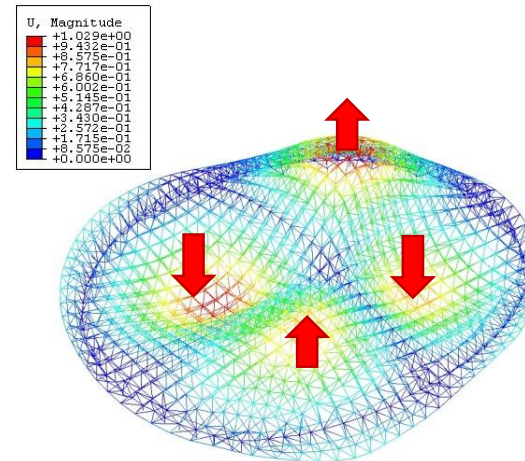


필리핀 아레나

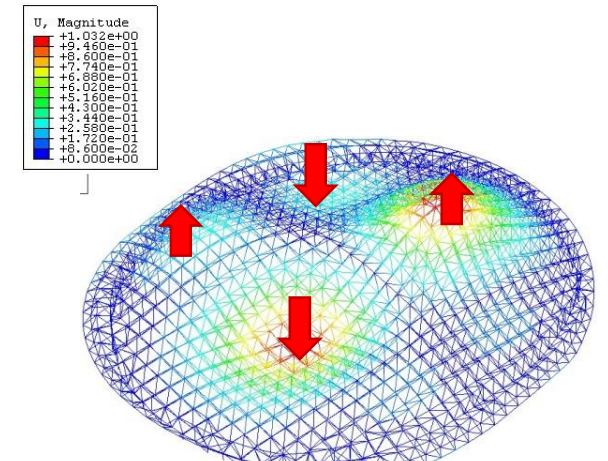
Nonlinear Snapping Analysis



(a) 1st Mode



(b) 2nd Mode

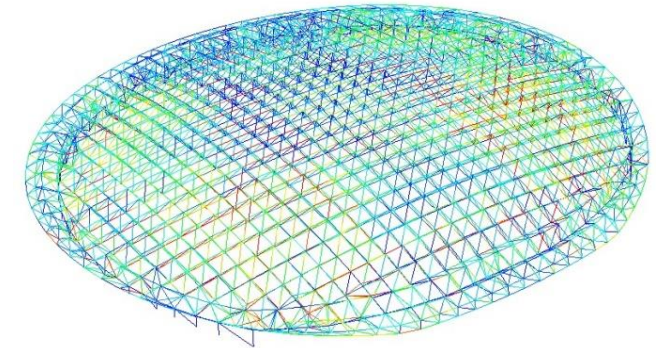
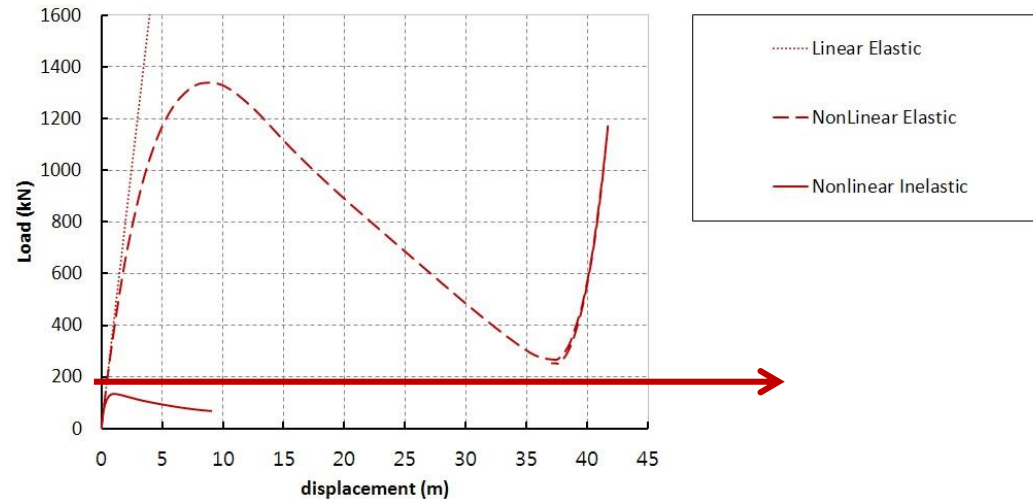


(c) 4th Mode

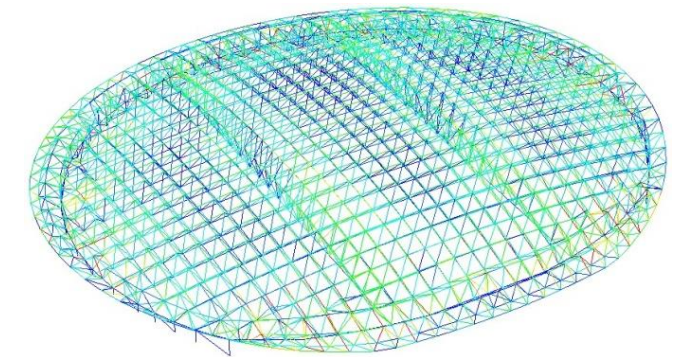
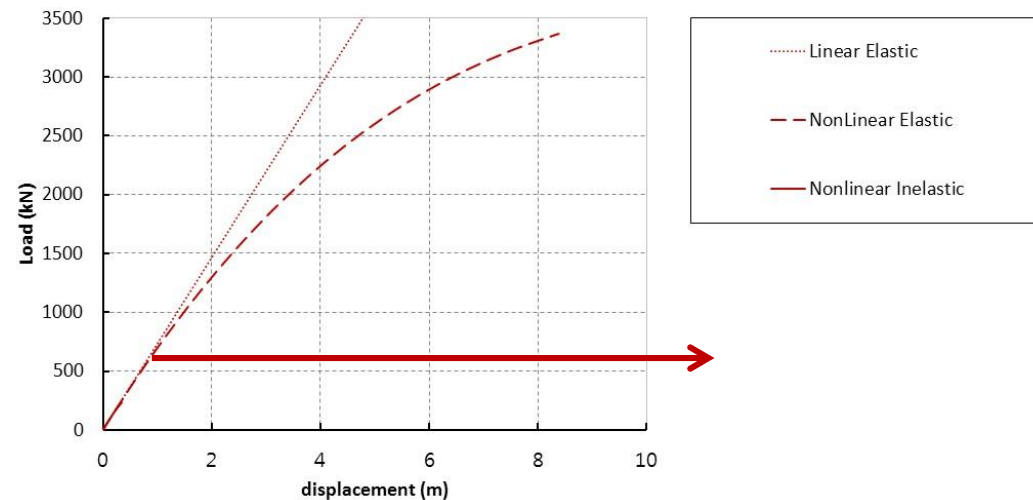
	Buckling Load (kN)	Design Load/ Buckling Load
1 st Mode	2,374	0.08
2 nd Mode	3,202	0.06
4 th Mode	3,923	0.05

필리핀 아레나

Nonlinear Snapping Analysis



<Result of Nonlinear Analysis _ w/o Tension Truss>



<Result of Nonlinear Analysis _ w/ Tension Truss>

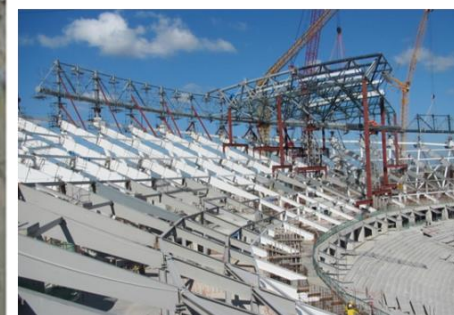
필리핀 아레나

2012.12.



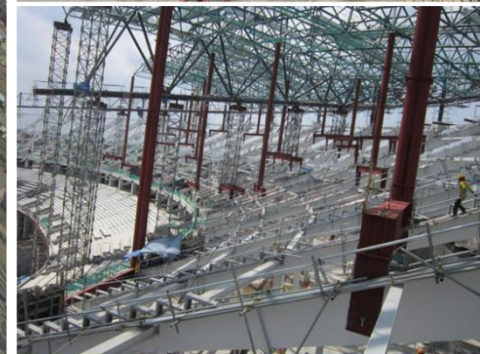
필리핀 아레나

2013.01.



필리핀 아레나

2013.04.



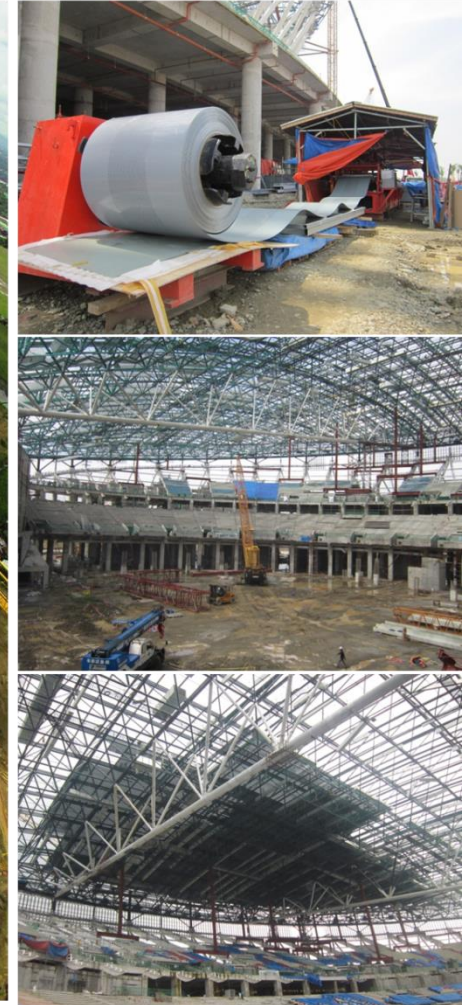
필리핀 아레나

2013.06.



필리핀 아레나

2013.08.



필리핀 아레나

2014.01.



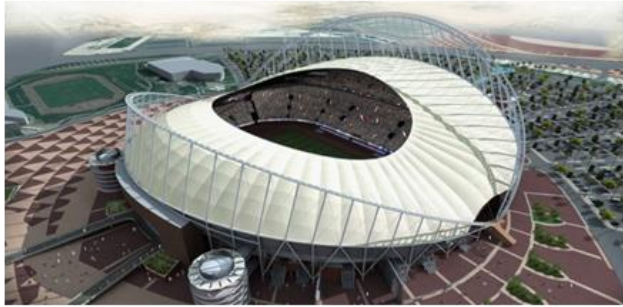
카타르월드컵경기장

칼리파 스타디움

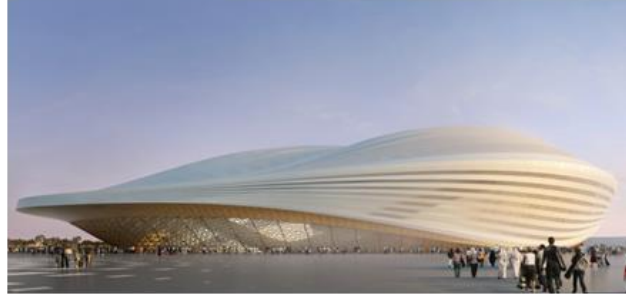
알와크라 스타디움

알바이트 스타디움

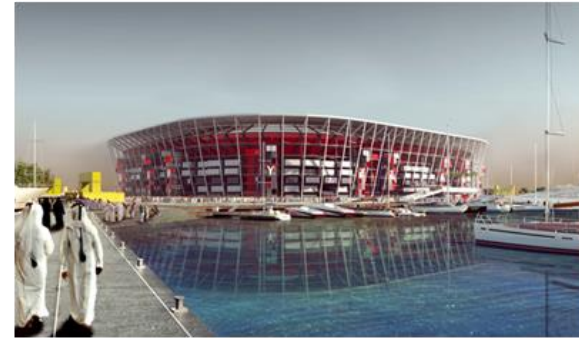
가.. 칼리파 스타디움



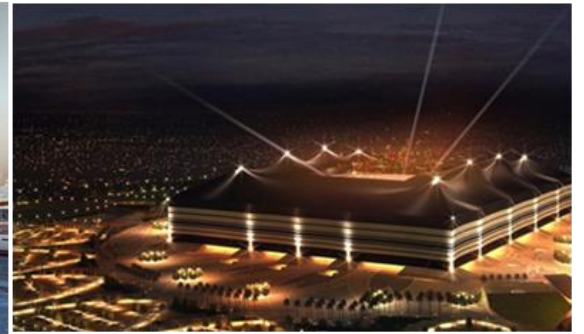
나. 알와크라(알자누브) 스타디움



다. 스타디움 974 (라스 아부 아부드 스타디움)



라. 알바이트 스타디움



마. 알투마마 스타디움



바. 루사일 아이코닉 스타디움



사. 에듀케이션 시티 스타디움



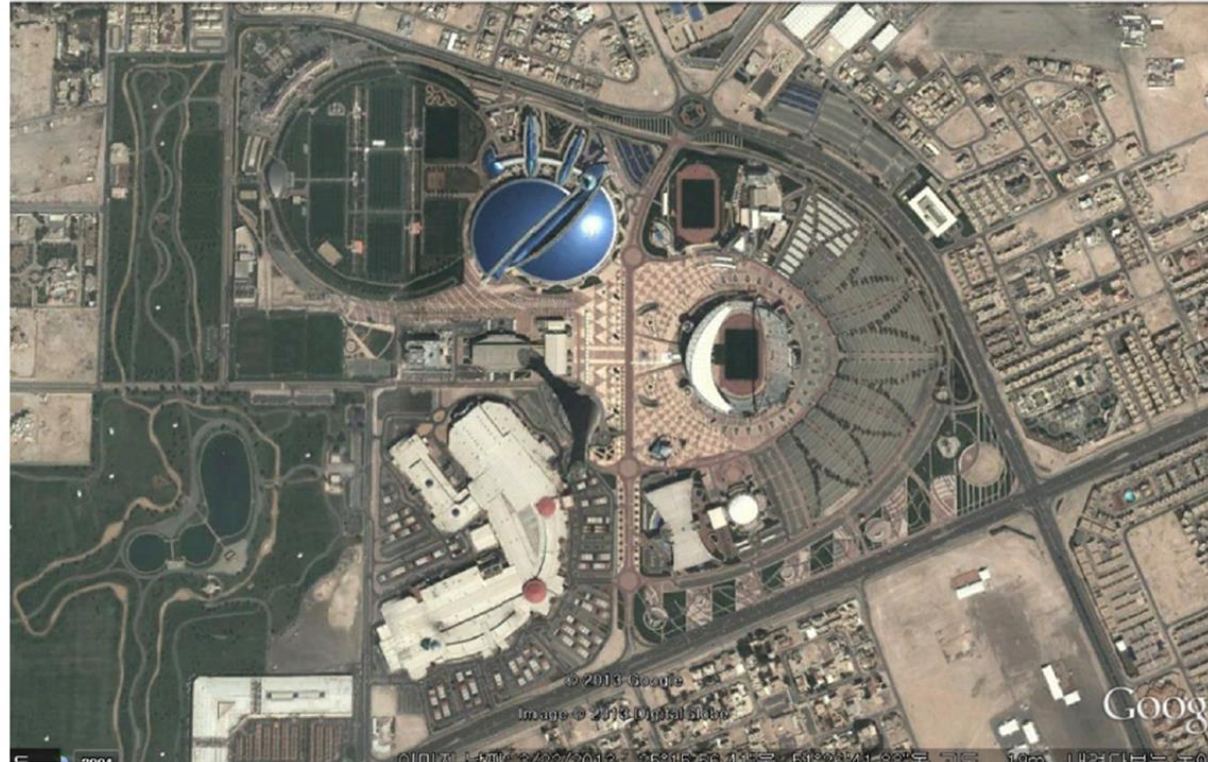
마. 아트마드 빈 알리 스타디움



칼리파 스타디움

칼리파 스타디움

카타르, 2013년



< Figure - Site Location >

Location : ASPIRE Zone Doha Sports City, In Al Waab District of Doha
(도하 알 와브 지역의 ASPIRE 존 도하 스포츠 시티)

History : 1976년에 개장했지만, 2006년 아시안 게임을 앞두고 20,000명에서 40,000명으로 수용 인원을 늘리기 위해 2005년에 구장을 개조함.
축구장 및 종합체육시설로 사용

칼리파 스타디움

카타르, 2013년



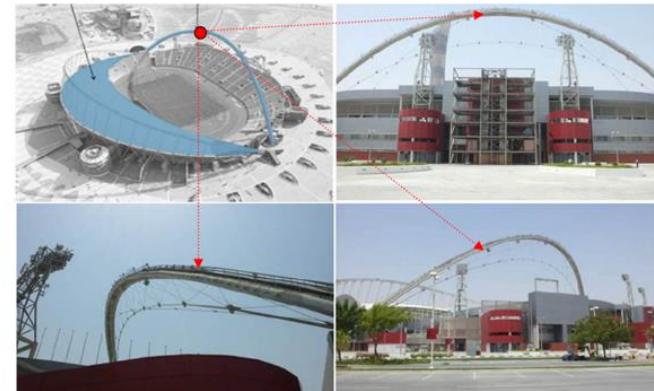
< Before >



< After >

■ Dismantle elements

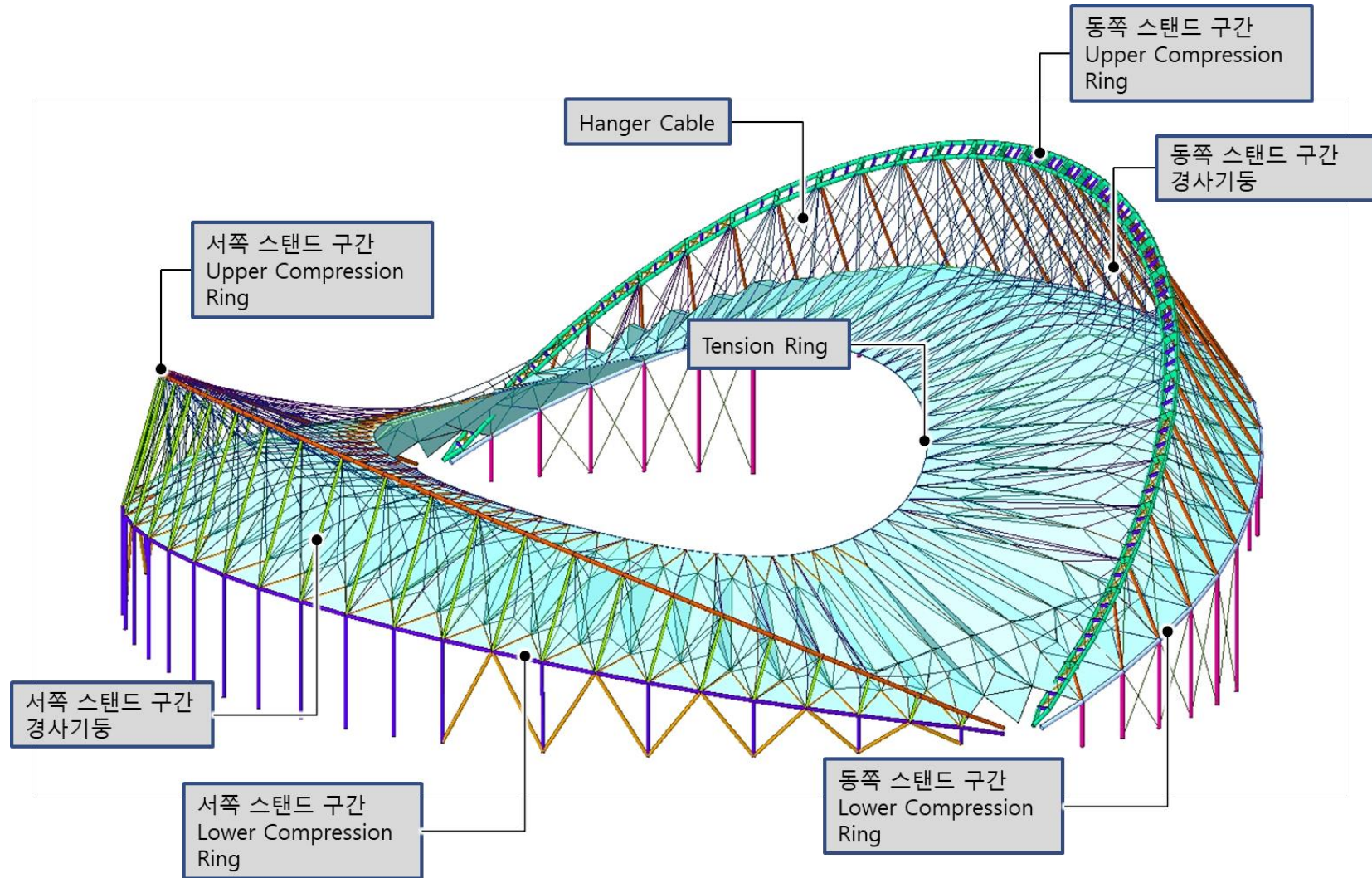
: Lighting Arch, Cable, Catwalk, Lights, CCTV, Camera, Speaker, etc..



카타르 경기장 중 유일한 리모델링하는 경기장

칼리파 스타디움

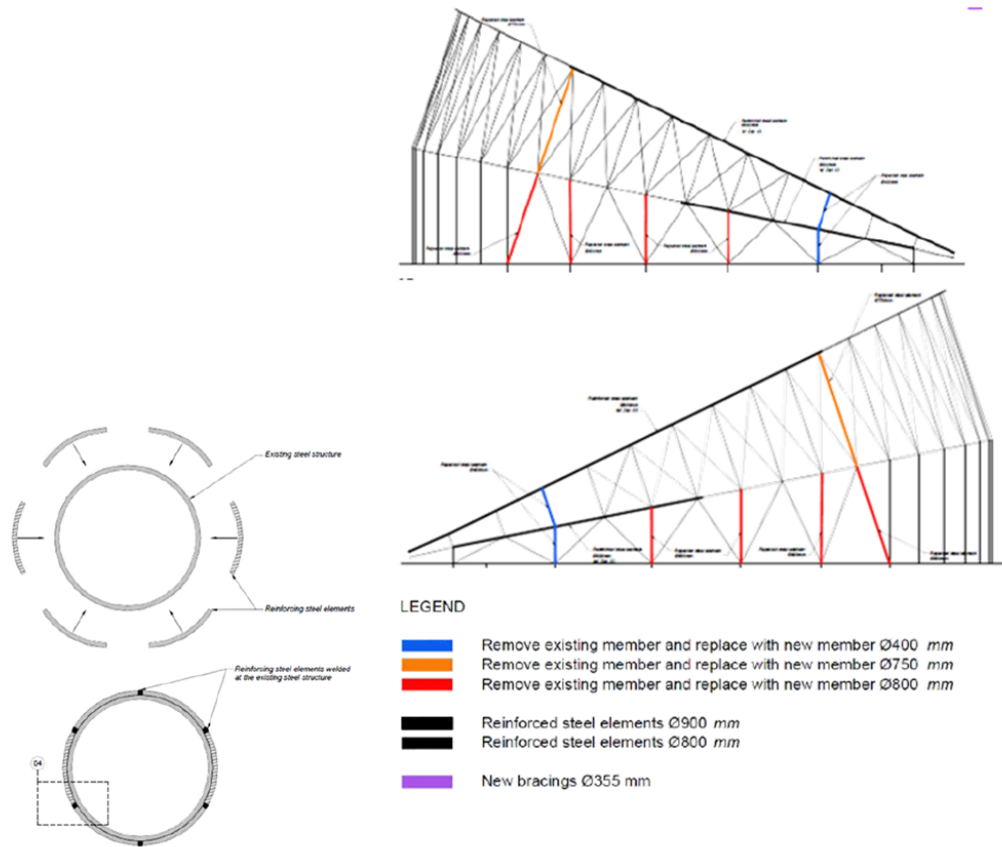
카타르, 2013년



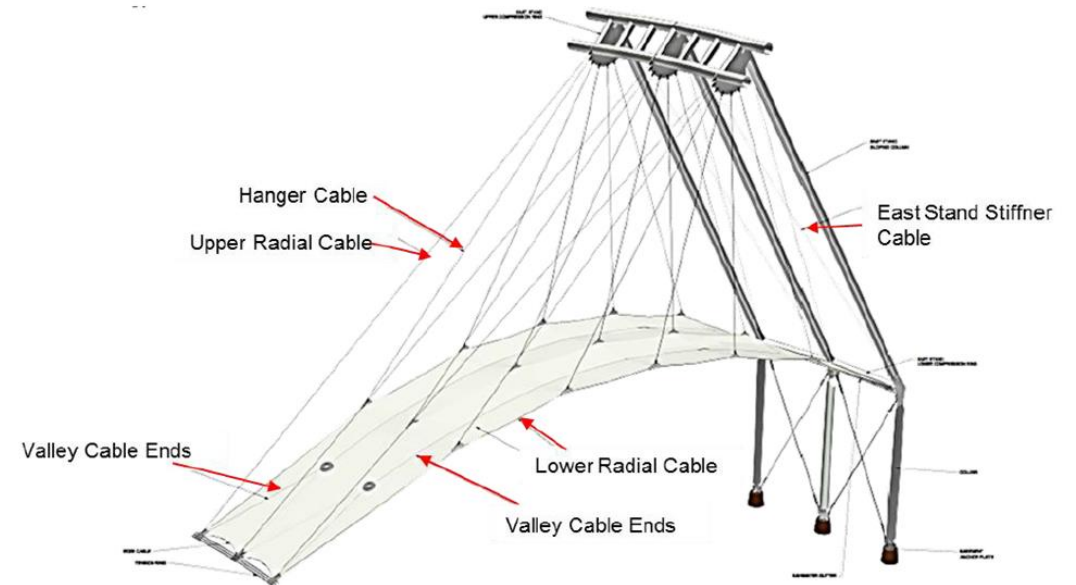
칼리파 스타디움

카타르, 2013년

■ West Stand Steel structure



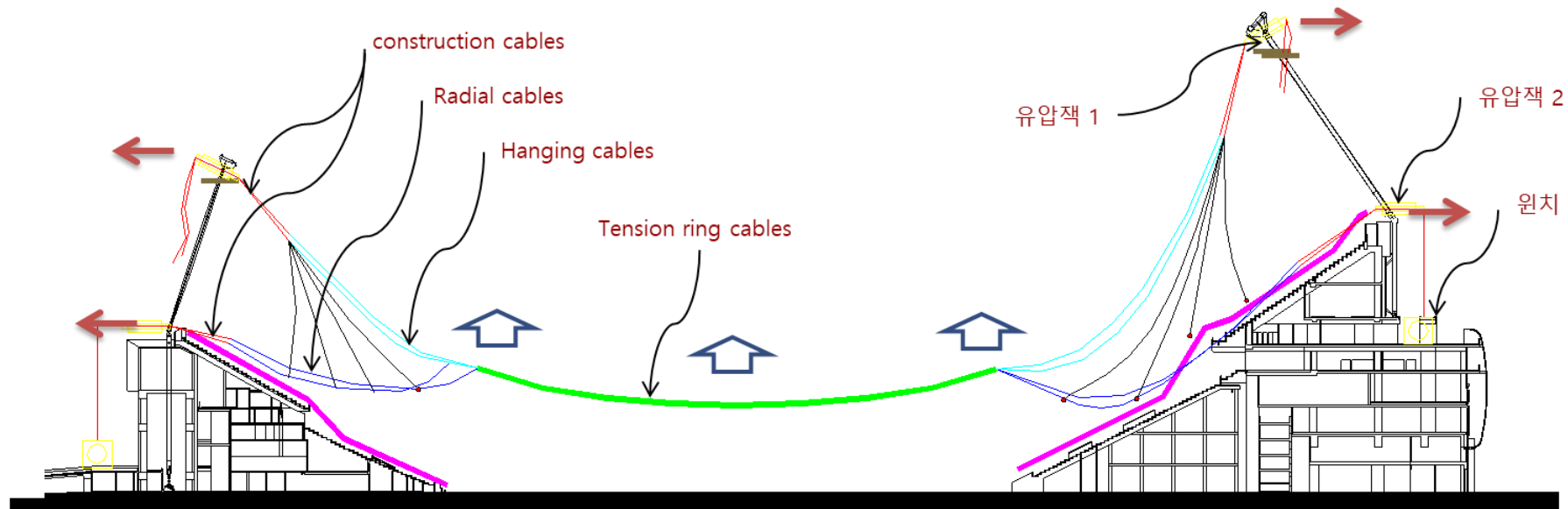
■ Cable Composition



칼리파 스타디움

카타르, 2013년

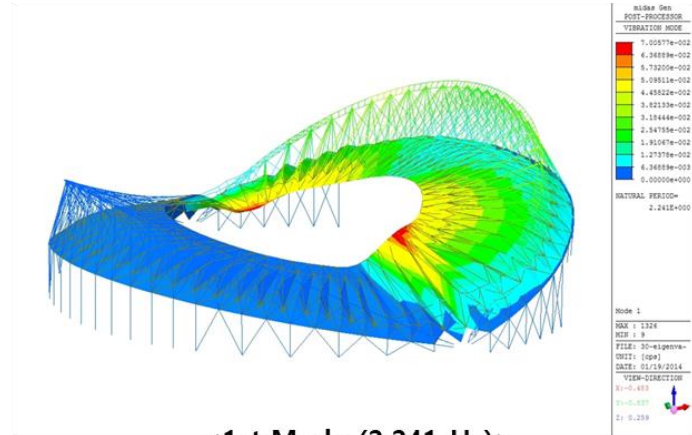
1. Tension ring cable 바닥에 배치
2. Tension ring cable 가장자리로 Radial cable 및 Hanging cable 설치
3. Construction cable, 유압잭 및 윈치 설치
4. 유압잭 및 윈치를 이용해서 Hanging cable을 당김으로써 Tension ring 들어올리기
5. 모든 cable들의 위치가 맞춰지면 compression ring에 고정



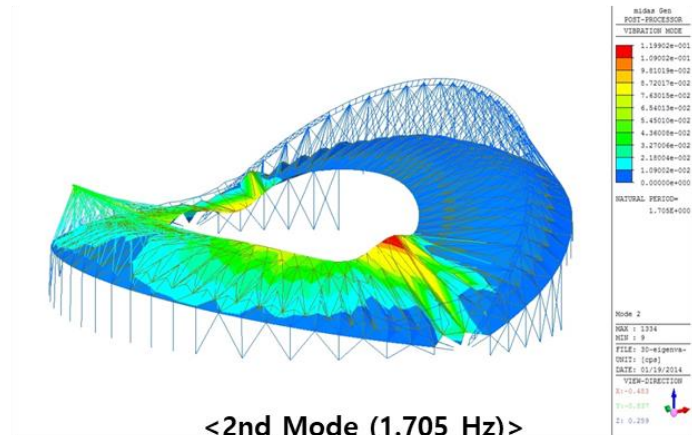
칼리파 스타디움

카타르, 2013년

고유치 해석

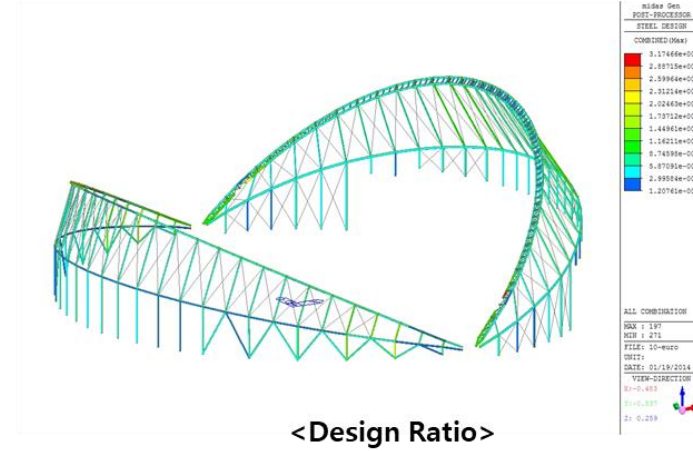


<1st Mode (2.241 Hz)>



<2nd Mode (1.705 Hz)>

부재설계



<Design Ratio>

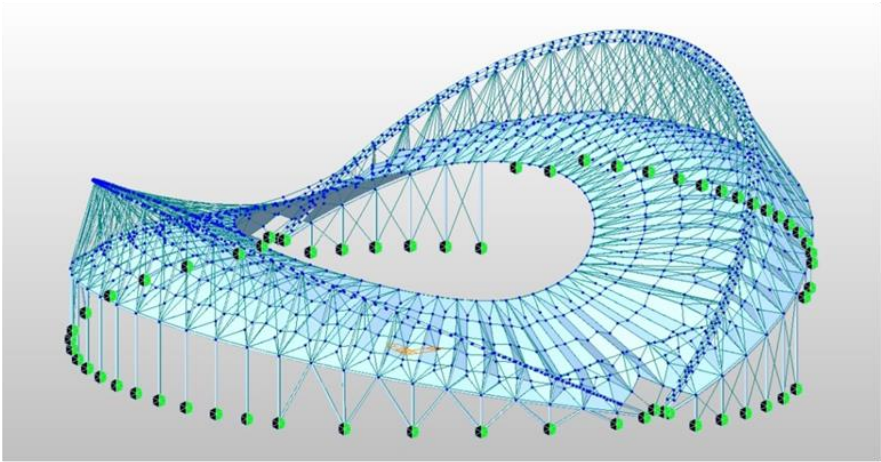
1. Design Information Design Code : Eurocode305 Unit System : kN, m Member No : 410 Material : S355 (No.1) Section Name : Col-2 (No.30701) Member Length : 45.9627		4. Checking Results Slenderness Ratio $\lambda_{y1} = 178.8 < 200.0$ (Web:400, L20: 13) 0.8 Axial Resistance $N_{Ed}/N_{Rd} = 108.22/3066.38 = 0.035 < 1.000$ 0.8 Bending Resistance $M_{Ed}/M_{Rd} = 108.22/5182.19 = 0.021 < 1.000$ 0.8 $M_{Ed}/M_{Rd} = 291.42/5182.19 = 0.056 < 1.000$ 0.8 Combined Resistance $R_{Ed} = N_{Ed}/N_{Rd} + M_{Ed}/M_{Rd}$ $R_{Ed} = 0.035 + 0.021 = 0.056 < 1.000$ 0.8 Shear Resistance $V_{Ed}/V_{Rd} = 0.002 < 1.000$ 0.8 $V_{Ed}/V_{Rd} = 0.017 < 1.000$ 0.8	
2. Member Forces Axial Force : Fx = -1838.2 (LOB: 3, POS:1) Bending Moments : My = -1800.0, Mz = 291.418 End Moments : My1 = -1800.0, My2 = 212.867 (for Lx) : Mz1 = -1800.0, Mz2 = 212.867 (for Lx) Shear Forces : Fy1 = 15.3286 (LOB: 2, POS:1) : Fz2 = -133.70 (LOB: 3, POS:1)		Outer Dia. : 0.80000 Wall Thick : 0.02500 Area : 0.00087 Azl : 0.00043 Qw : 0.10031 Qwz : 0.10031 Iyy : 0.00467 Izz : 0.00467 Wyy : 0.00000 Wzz : 0.00000 Iyy : 0.01144 Izz : 0.01144 Wyy : 0.00000 Wzz : 0.00000	
3. Design Parameters Unbraced Lengths : Ly = 45.9627, Lz = 45.9627, Lb = 45.9627 Effective Length Factors : Ky = 1.00, Kz = 1.00 Equivalent Uniform Moment Factors : Cm1 = 1.00, Cm2 = 1.00, CmLT = 1.00		Slenderness Ratio $\lambda_{y1} = 178.8 < 200.0$ (Web:400, L20: 13) 0.8 Axial Resistance $N_{Ed}/N_{Rd} = 108.22/3066.38 = 0.035 < 1.000$ 0.8 Bending Resistance $M_{Ed}/M_{Rd} = 108.22/5182.19 = 0.021 < 1.000$ 0.8 $M_{Ed}/M_{Rd} = 291.42/5182.19 = 0.056 < 1.000$ 0.8 Combined Resistance $R_{Ed} = N_{Ed}/N_{Rd} + M_{Ed}/M_{Rd}$ $R_{Ed} = 0.035 + 0.021 = 0.056 < 1.000$ 0.8 Shear Resistance $V_{Ed}/V_{Rd} = 0.002 < 1.000$ 0.8 $V_{Ed}/V_{Rd} = 0.017 < 1.000$ 0.8	

<단위부재 설계>

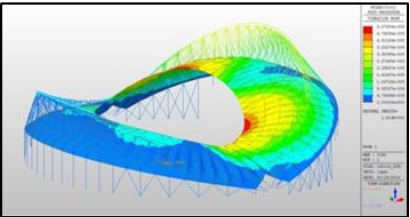
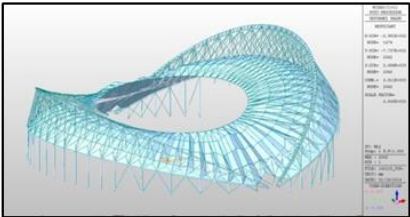
칼리파 스타디움

카타르, 2013년

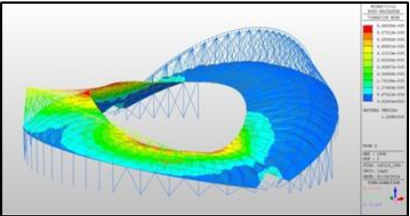
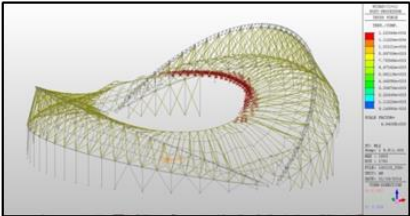
■ 케이블구조 해석



비선형 해석

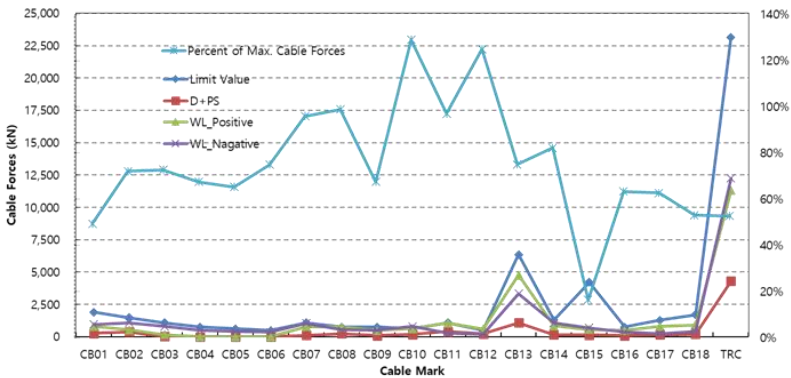


변위 검토



케이블 부재력 검토

고유치 해석

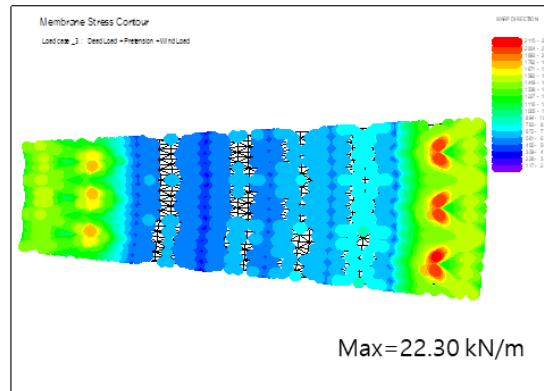


칼리파 스타디움

카타르, 2013년

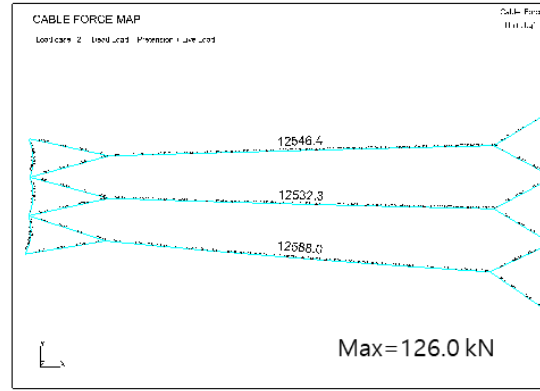
■ 막 해석 결과

Membrane Stress



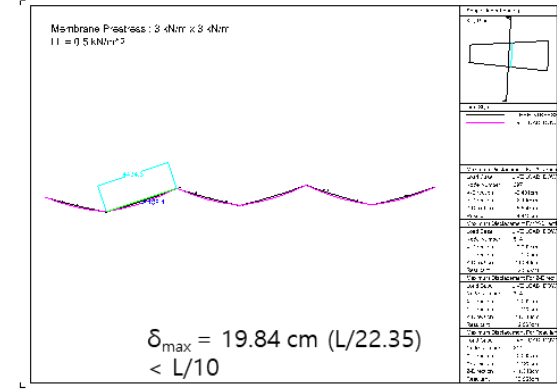
Warp-Direction

Cable Force

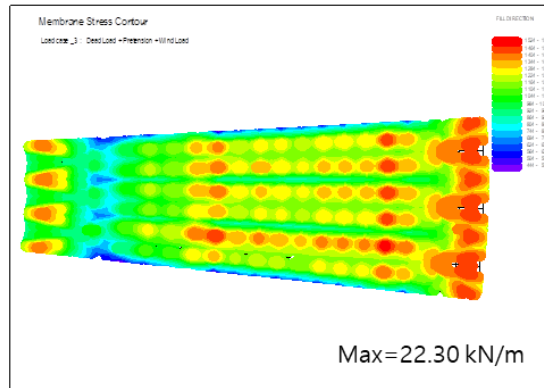


LC2 (D+P+L)

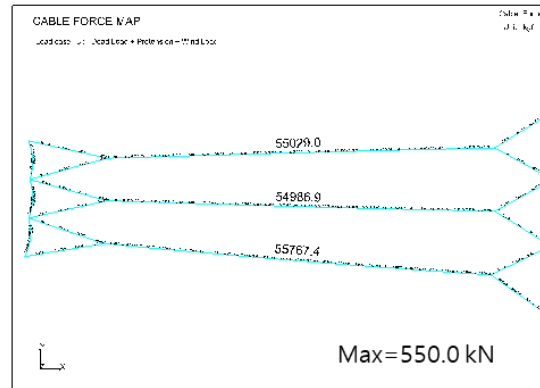
Membrane Displacement



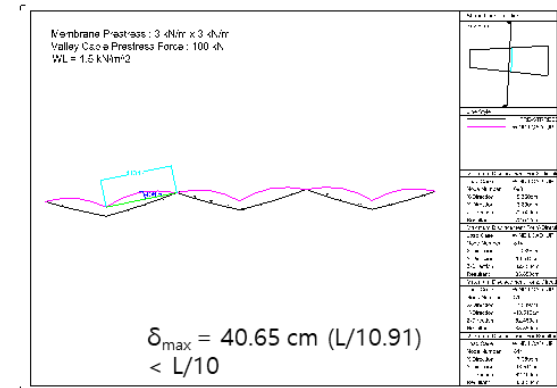
LC2 (D+P+L)



Fill-Direction



LC3 (D+P+W)



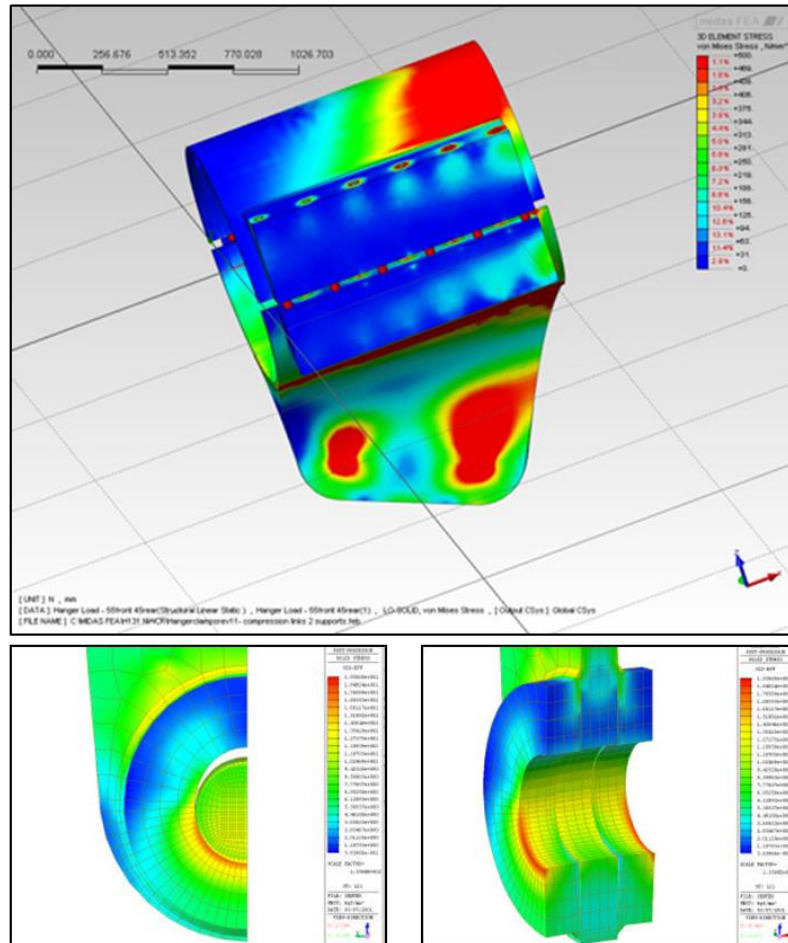
LC3 (D+P+W)

칼리파 스타디움

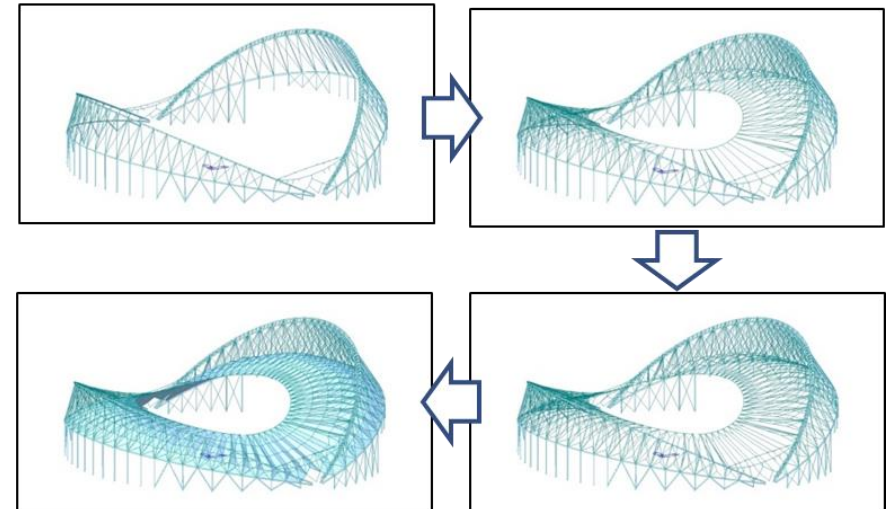
카타르, 2013년

■ 접합부 상세해석

막 구조물/케이블 연결부 유한요소해석

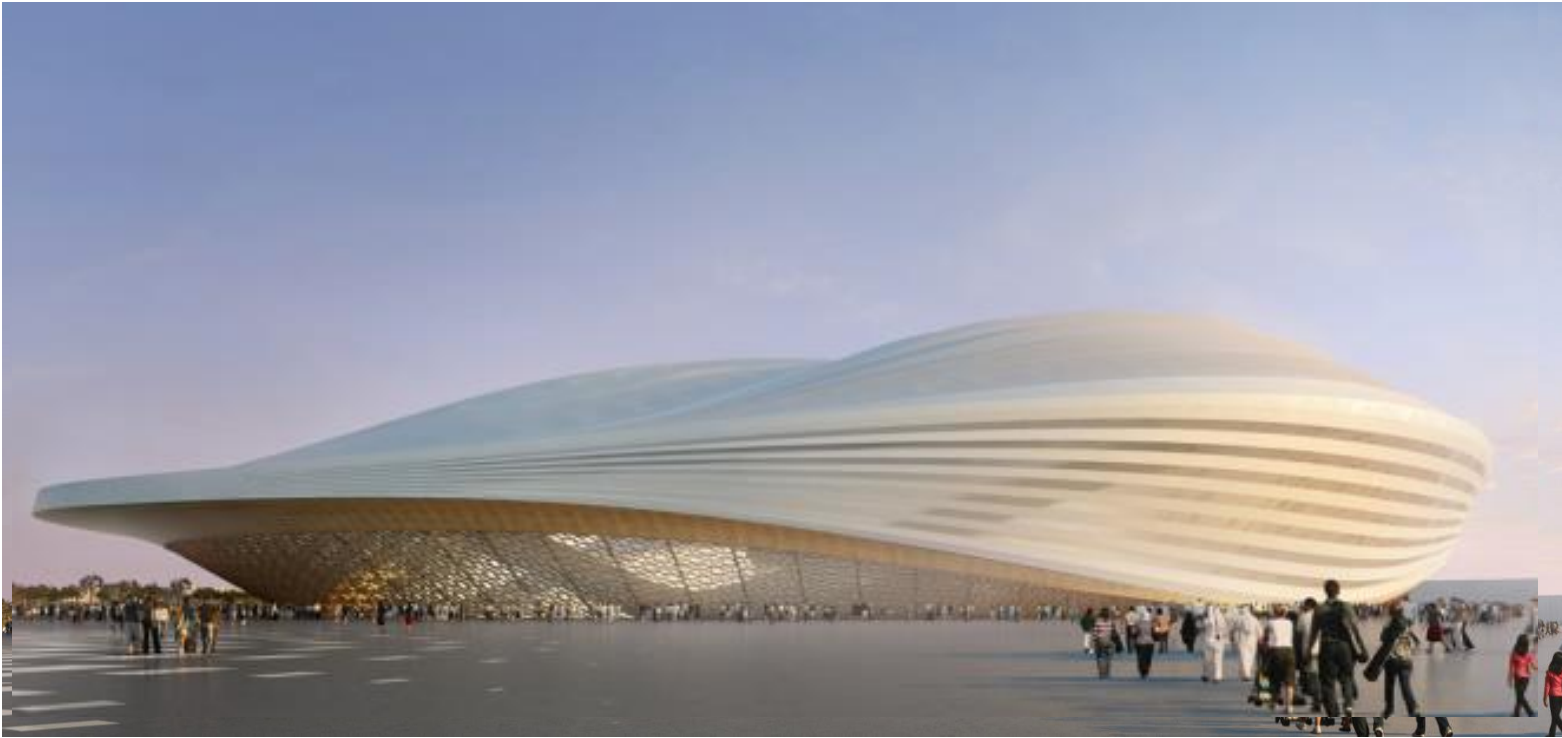


막 구조물 설치에 따른 시공해석



알와크라 스타디움

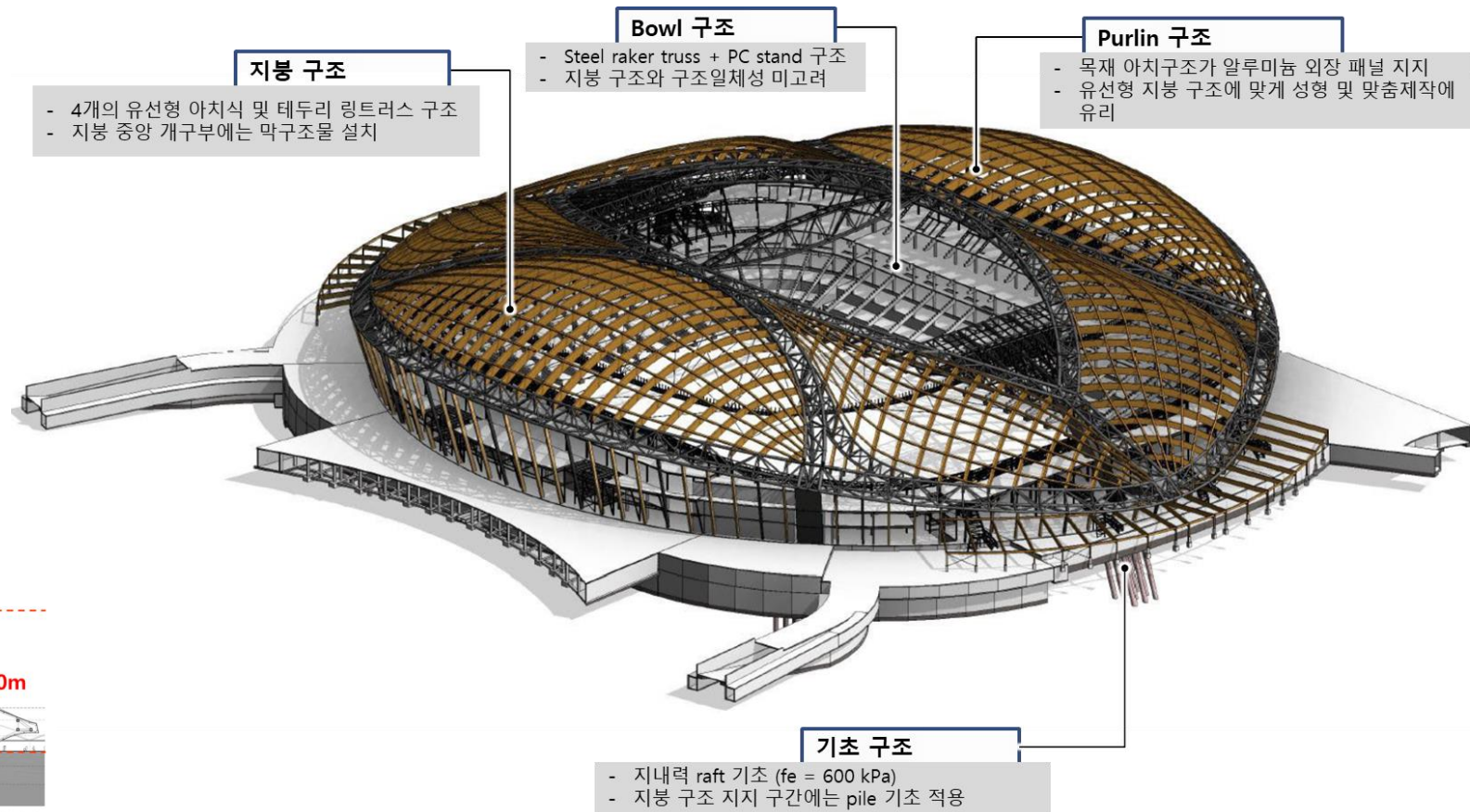
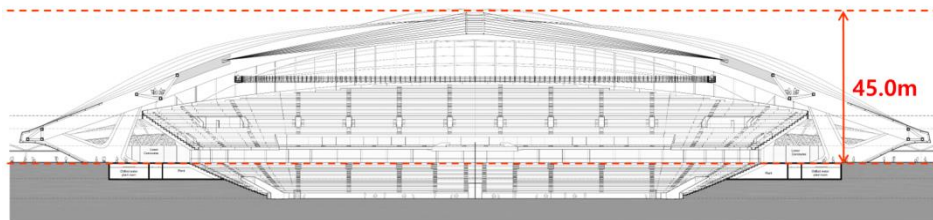
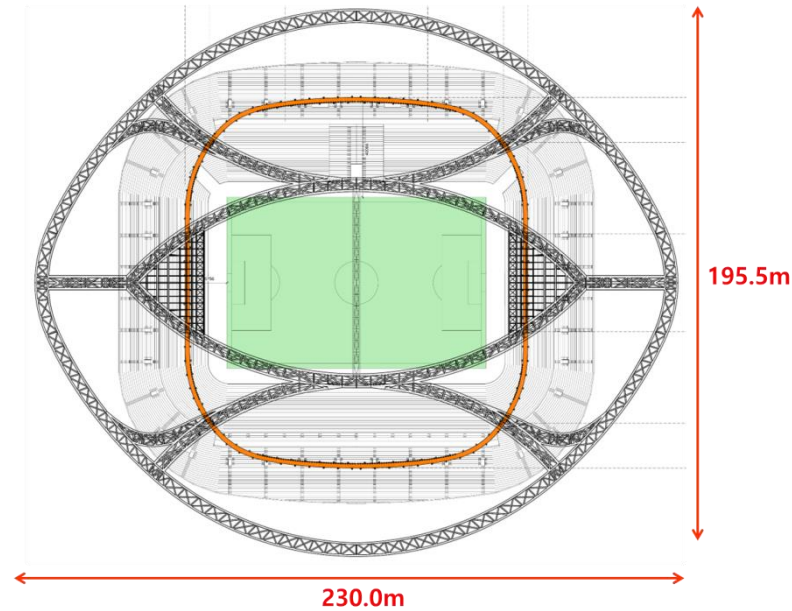
알와크라 스타디움 카타르, 2014년



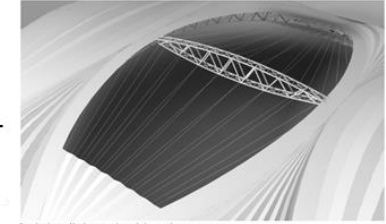
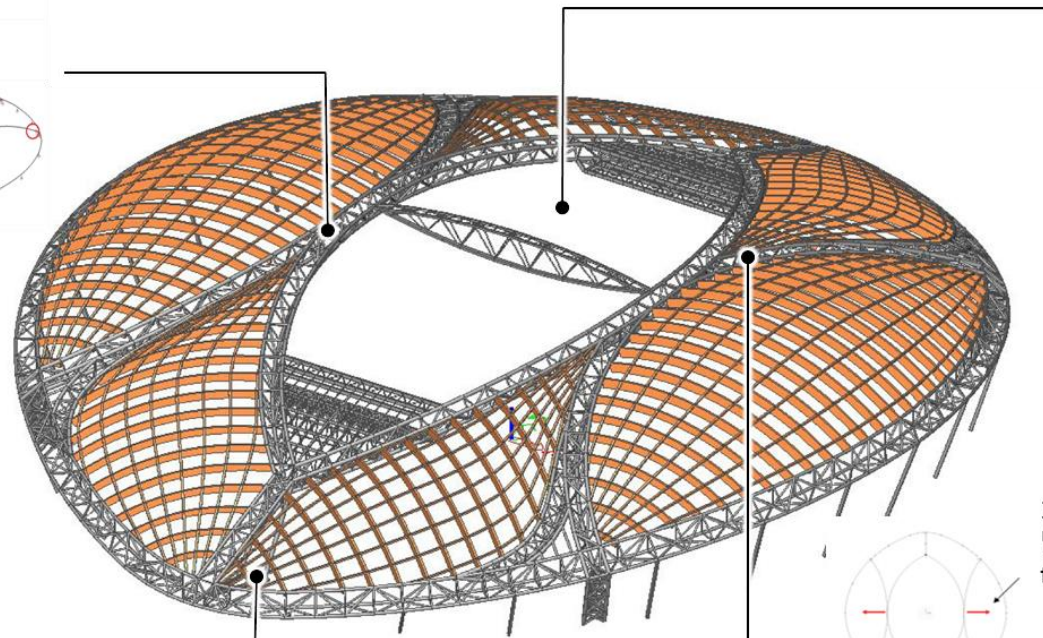
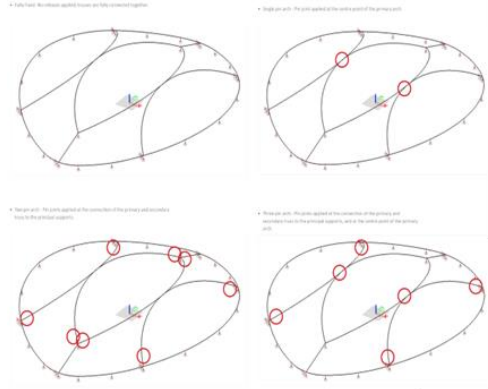
사업명	Al-Wakrah Stadium
사업위치	Al-Wakrah, Qatar
건물용도	문화 및 집회시설, 제1종/2종 근린생활시설
규모	지하1층 / 지상4층
사업면적	586,592 m ²
높이	45.0m
구조형식	지붕 구조물 : 철골 구조시스템 + 목재 구조 Bowl 구조물 : Steel raker truss + PC stand

알와크라 스타디움

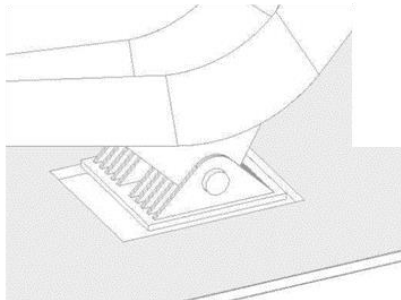
카타르, 2014년



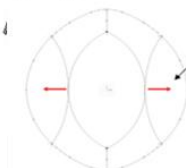
알와크라 스타디움 Roof Structural System



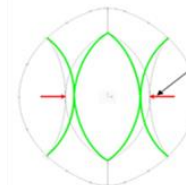
개폐식 막구조물 적용



핀접합 지지 적용
시공오차 및 온도변화에 따른 대응 용이

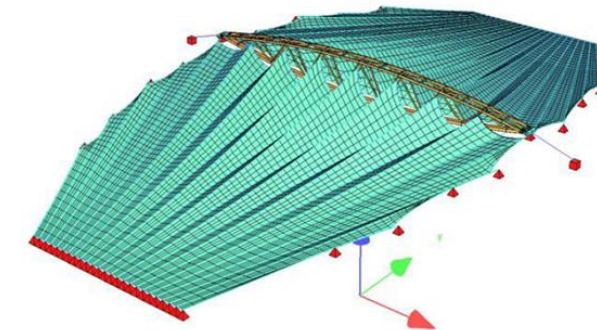
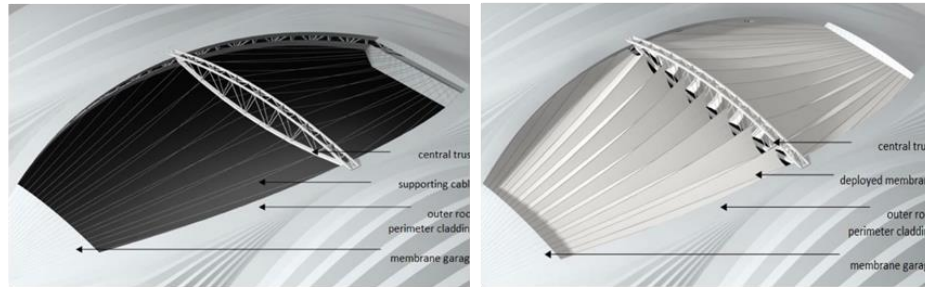


지붕 가장자리 방향으로 횡변위 발생, 그로 인해 트러스 지지점에 torsion 및 목재부재에 압축력 발생



지붕 높이를 낮추고 아치형상을 중앙으로 더 모아서 횡변위 최소화

알와크라 스타디움 Retractable Structure



< 막 구조물 유한요소해석 모델링 >

구동순서	비 고
	평상시에 개구부 양 끝 보관구간에 막구조물 보관
	막구조물 개폐시에 중앙 철골 트러스 까지 설치된 견인줄로 막구조물 개폐
	막 구조물 개폐 후 트러스에 설치된 유압잭으로 인장 및 고정
	막 구조물 접이시에 같은 방식으로 견인줄을 통해 보관구간으로 접이
	접이 후 개구부 양 끝 보관구간에 막구조물 보관

구 분	설 명		비 고
하중조건	고정 하중	<ul style="list-style-type: none">- 30kg/m² (모래하중)- 0.02kN/m² (막구조물자중)- 20kN (구동시스템하중)	<ul style="list-style-type: none">- 사용하중 적용시 안전계수 4.0 적용- 하중 불확실성에 따른 자중의 10% 할증
	활하중	0.3 kPa	<ul style="list-style-type: none">- 안전율 4.0 적용
	풍하중	1.5 kPa (정압)	<ul style="list-style-type: none">- 풍상면에 70%, 풍하면에 100% 풍하중 적용- 하중계수 : 1.3
		-2.0 kPa (부압)	
±0.5 kPa (접선방향)			
사용 프로그램	Sofistik		<ul style="list-style-type: none">- 2차 비선형해석- 케이블, 막, 철골 복합구조- 4 node element

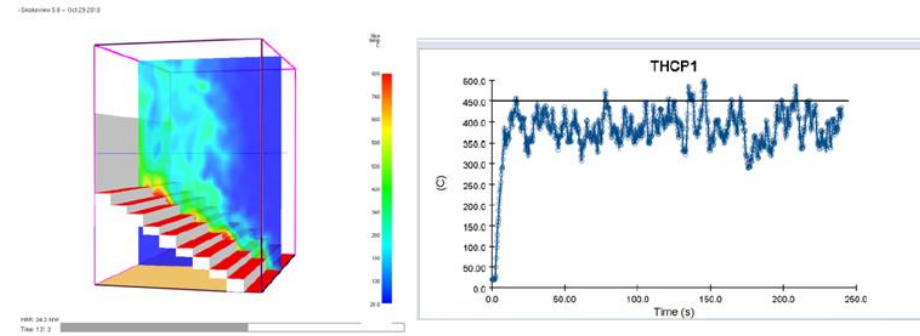
알와크라 스타디움

Timber Structure Overview

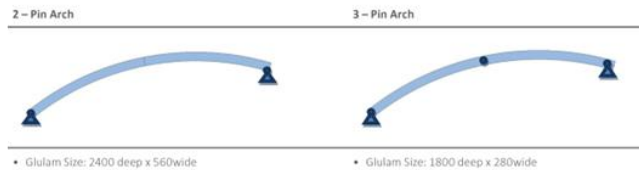
목재 구조	철골 구조
 <ul style="list-style-type: none"> 구조물의 경량화 건축미관 우수 시공성 용이 외부환경에 취약 지역에 따른 자재수급 어려움 	 <ul style="list-style-type: none"> 일반화된 건축재료 외부환경 저항성 높음 자재수급 용이 구조적성질변화 적음



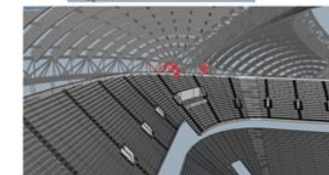
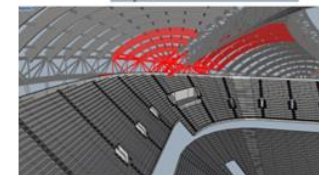
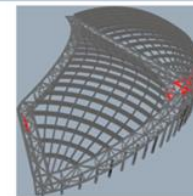
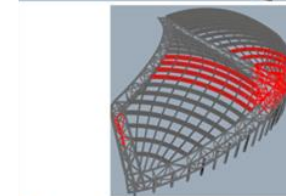
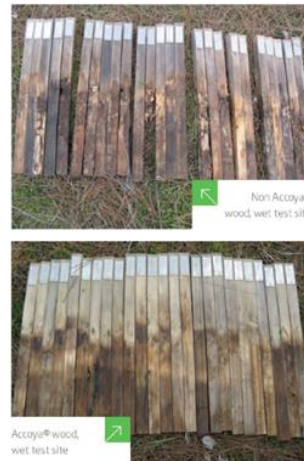
< 목재를 이용한 대공간 구조 사례 >



< 스탠드 최상단 화재상황을 가정한 온도 분포 해석 >



Structural form	% Change in Volume	Mid-span Deflections	% Change in Deflections
2 pin	0	200-300mm	0
3 pin	-63	1200-1500mm	400
2 pin tied	-59	100-200mm	-34
3 pin tied	-63	250-400mm	34
King Post truss	-71	150-200mm	-34

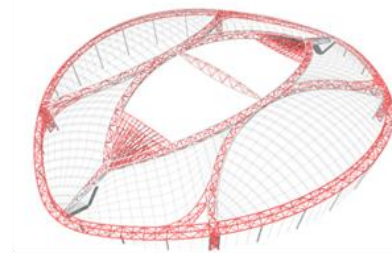


기준에서 제시하는 내화처리 필요구간

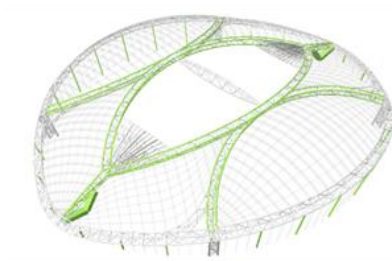
온도 분포 해석 후 내화처리 필요구간

알와크라 스타디움

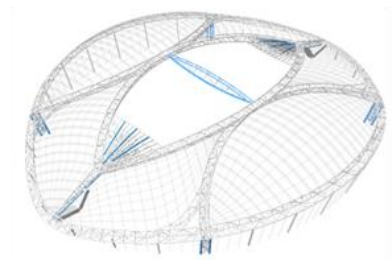
Alternative VE Design – 두께별 분포 및 비율 분석



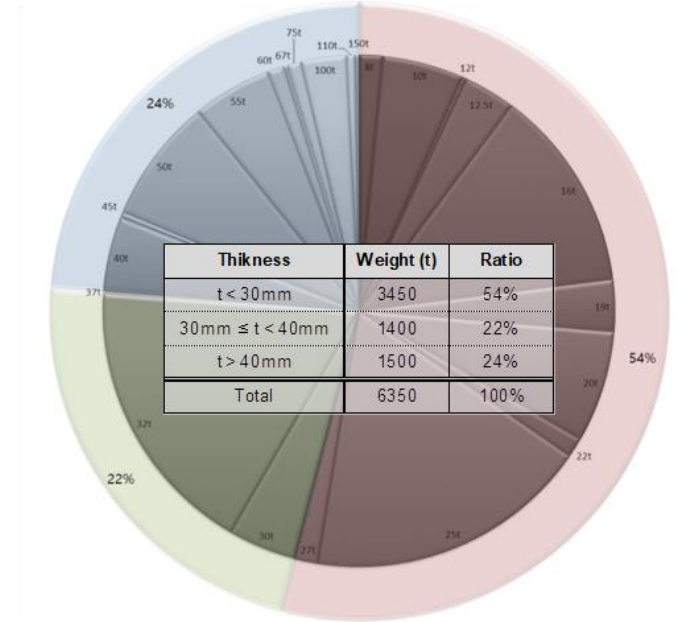
$t < 30\text{mm}$



$30\text{mm} \leq t < 40\text{mm}$



$t > 40\text{mm}$



<두께별 물량비>

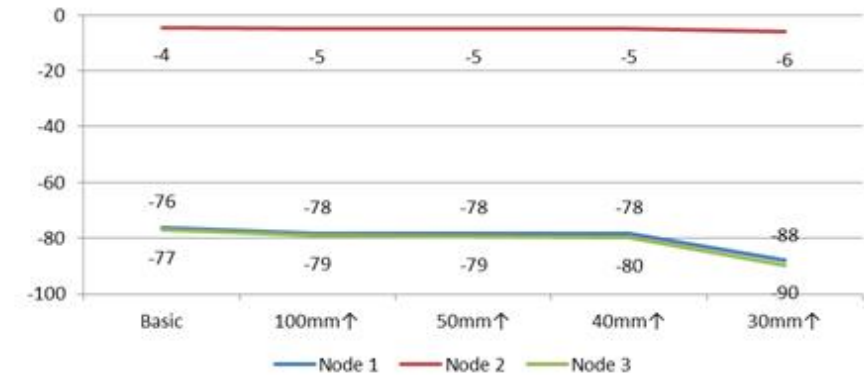
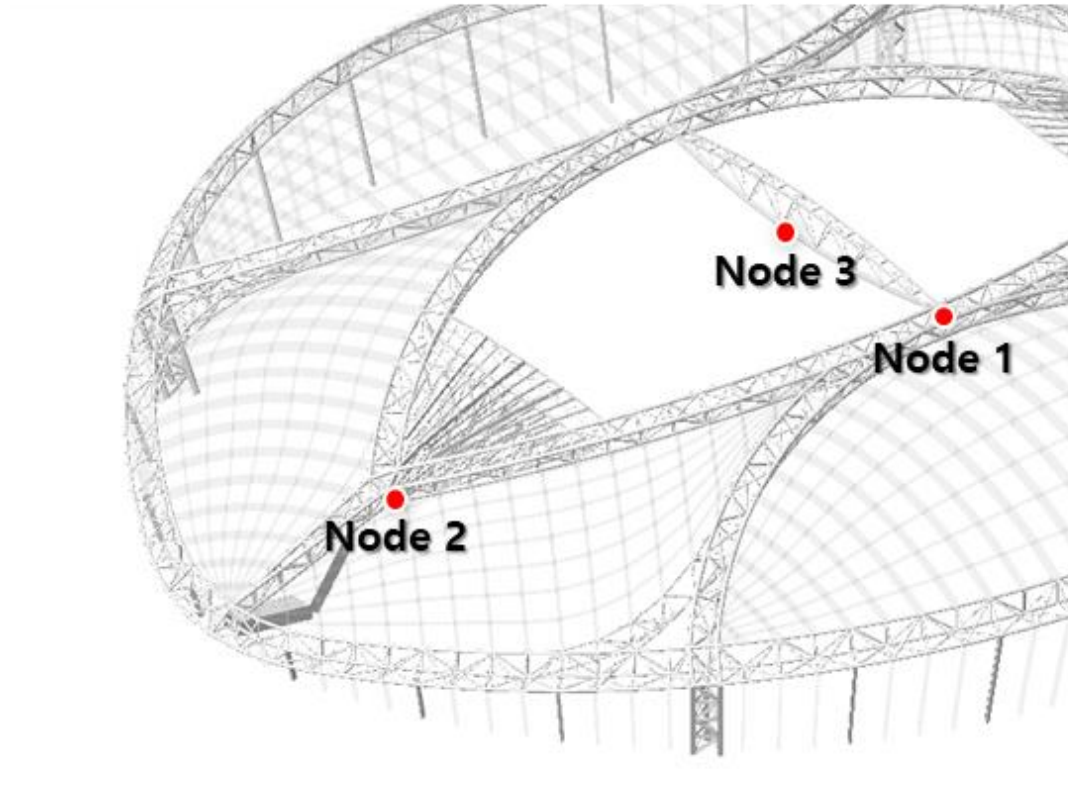
Steel grade	Nominal thickness of element t mm					
	$t \leq 40\text{mm}$		$40\text{mm} < t \leq 80\text{mm}$		-	-
	f_y (MPa)	f_u (MPa)	f_y (MPa)	f_u (MPa)	-	-
S355	355	510	335	470	-	-
S450	440	550	410	550	-	-

Steel grade	Nominal thickness of element t mm					
	$t \leq 50\text{mm}$		$50\text{mm} < t \leq 100\text{mm}$		$100\text{mm} < t \leq 150\text{mm}$	
	f_y (MPa)	f_u (MPa)	f_y (MPa)	f_u (MPa)	f_y (MPa)	f_u (MPa)
S690	690	770	650	760	630	710

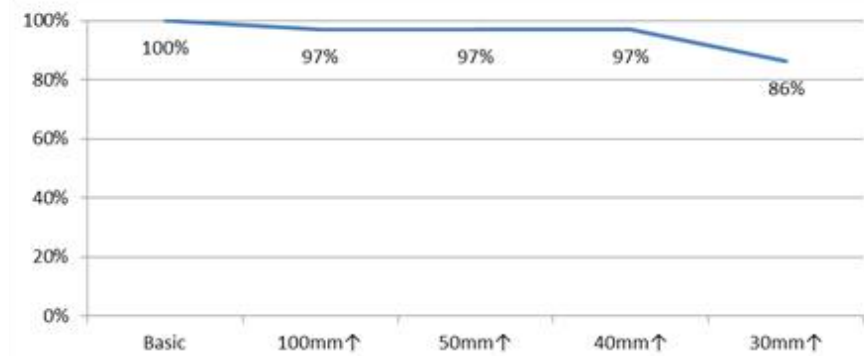
<강종별 항복강도 및 인장강도>

알와크라 스타디움

Alternative VE Design – 물량저감 대비 강성 변화 검토



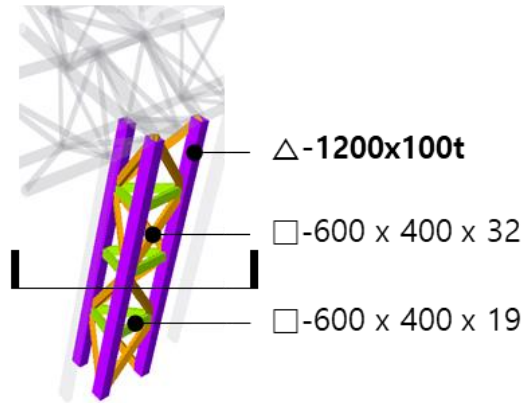
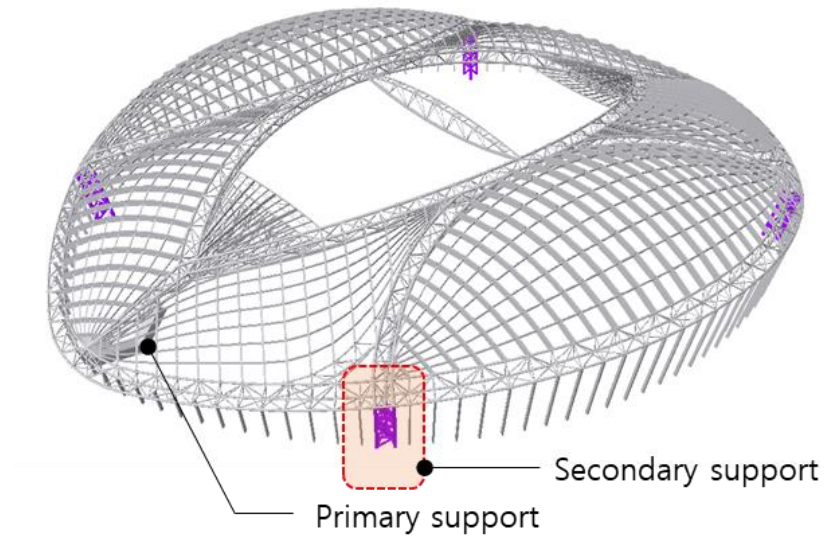
<대안별 활하중 처짐>



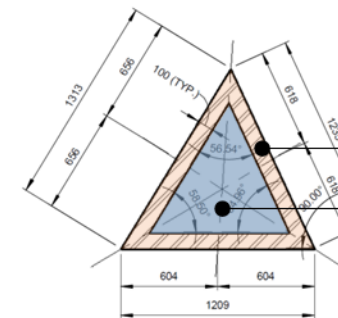
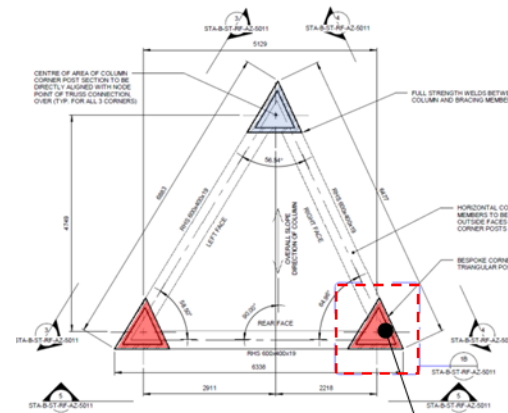
<대안별 강성비>

알와크라 스타디움

Alternative VE Design – Mega 기둥 (CFT 적용)



콘크리트 압축강도 (fck, MPa)	소요 두께 (t, mm)	철골 물량 (W, ton)
24	100	803 (100%)
50	30	529 (65.8%)
70	25	509 (63.4%)



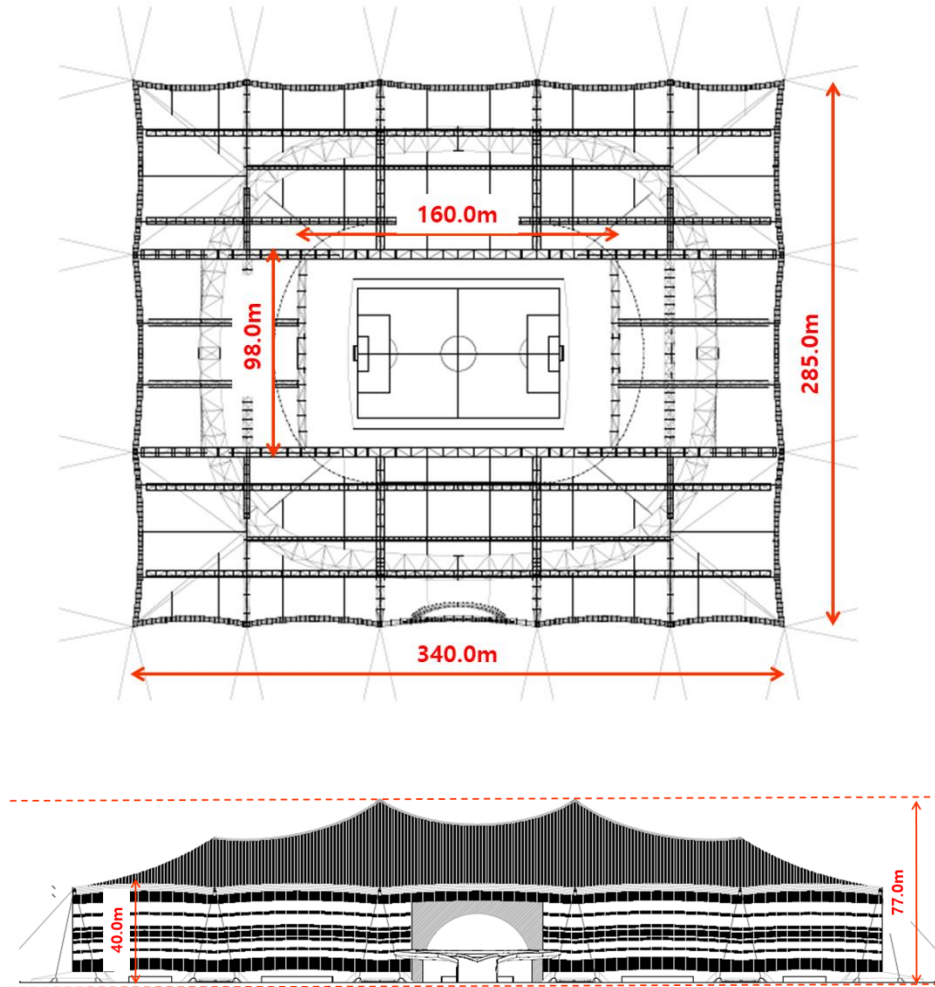
Steel section
콘크리트 충전

알바야트 스타디움

알바야트 스타디움 카타르, 2014년



알바야트 스타디움 카타르, 2014년



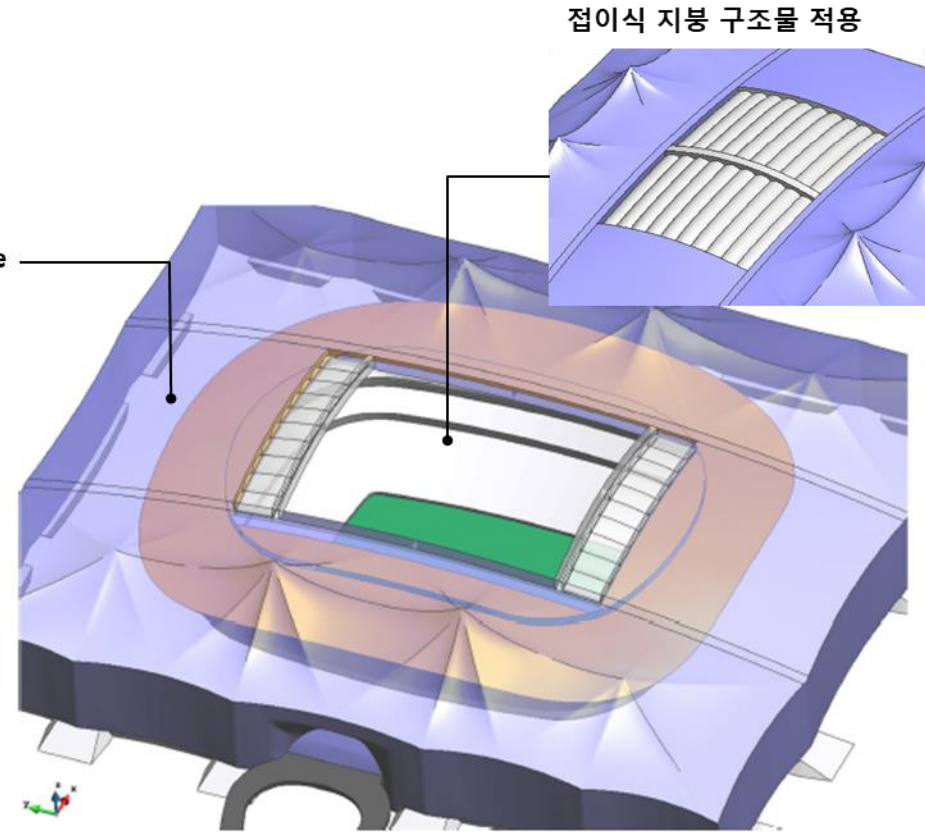
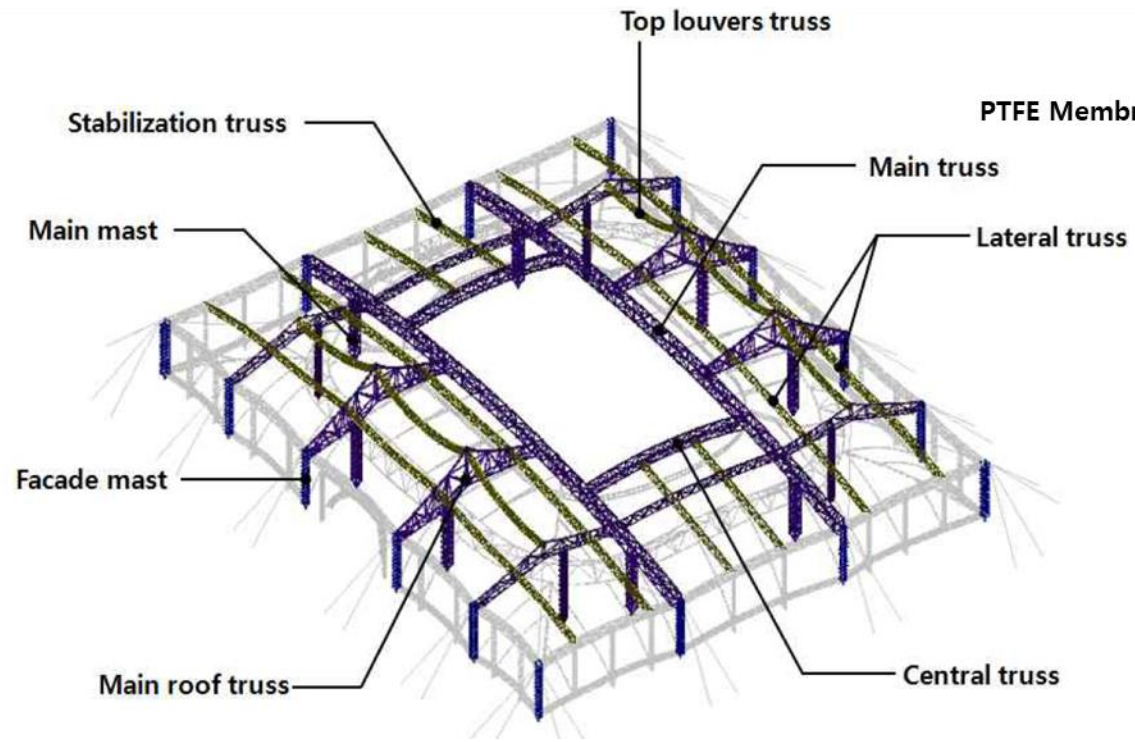
대지위치



- 건축대지 알코르 남쪽에 위치.
- 알코르 공항 근처에 위치
- 대지면적 약 1,000,000m²
- 도하국제공항에서 직선거리 45km 떨어진 곳에 위치
- 수도 도하시 중심부에서 약 50km 떨어진 곳에 위치 (Al khor Coastal Rd.)

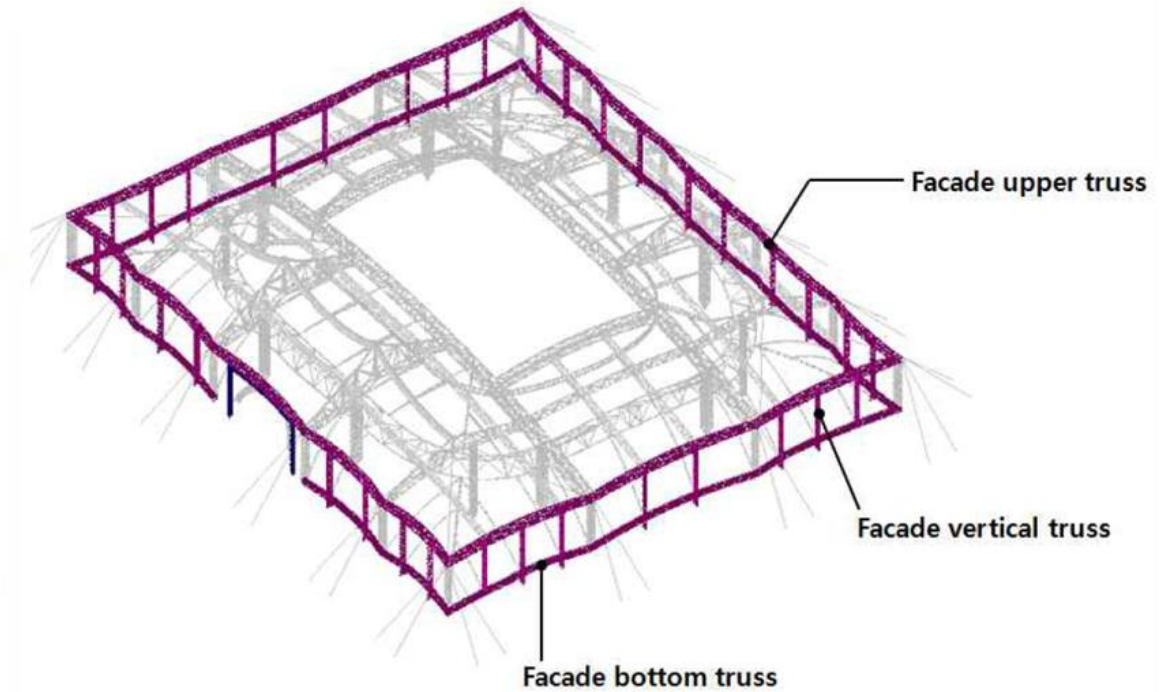
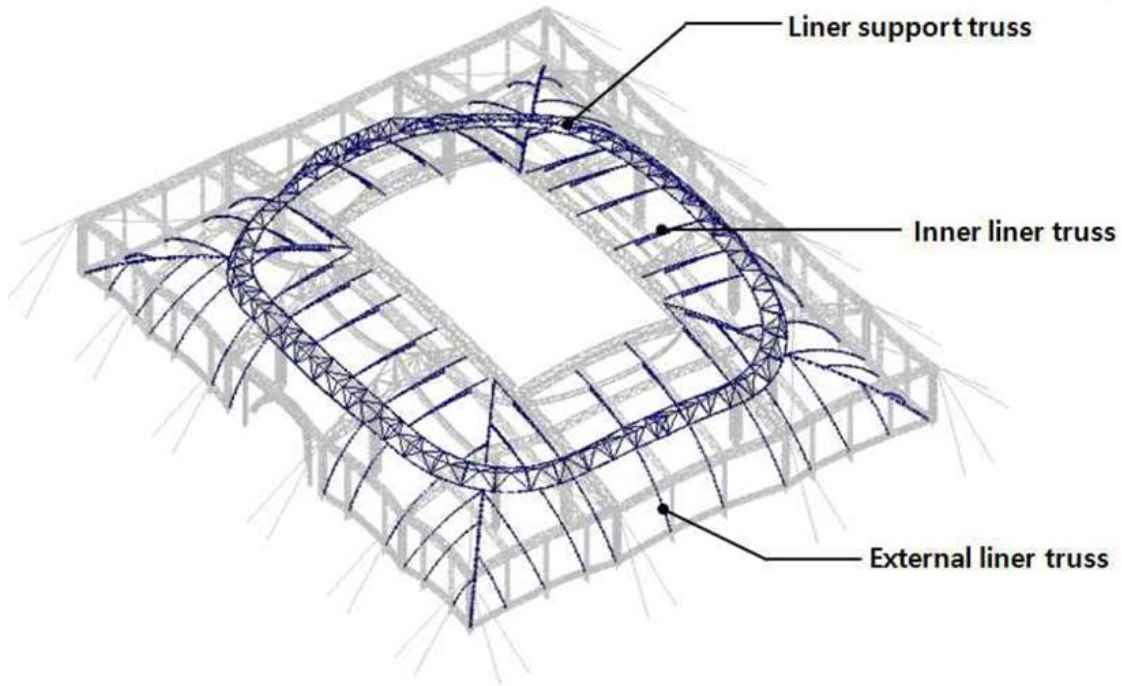
알바야트 스타디움

Roof Structural System - 외부지붕



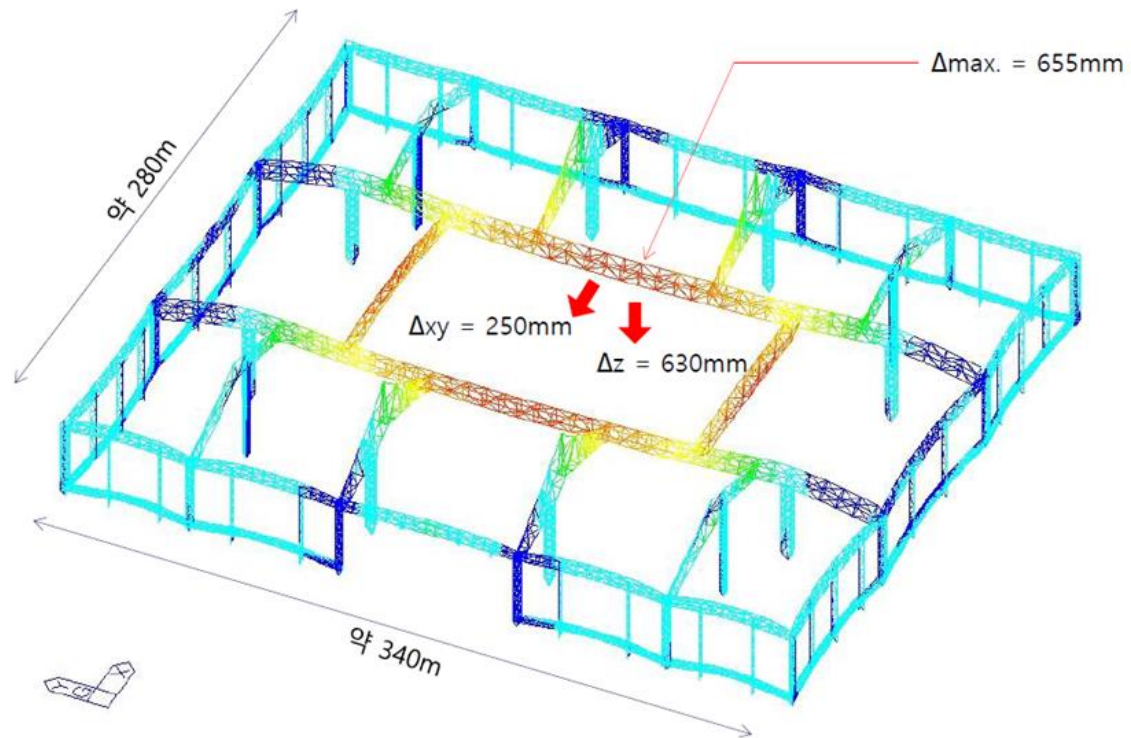
알바야트 스타디움

Roof Structural System - 내부지붕

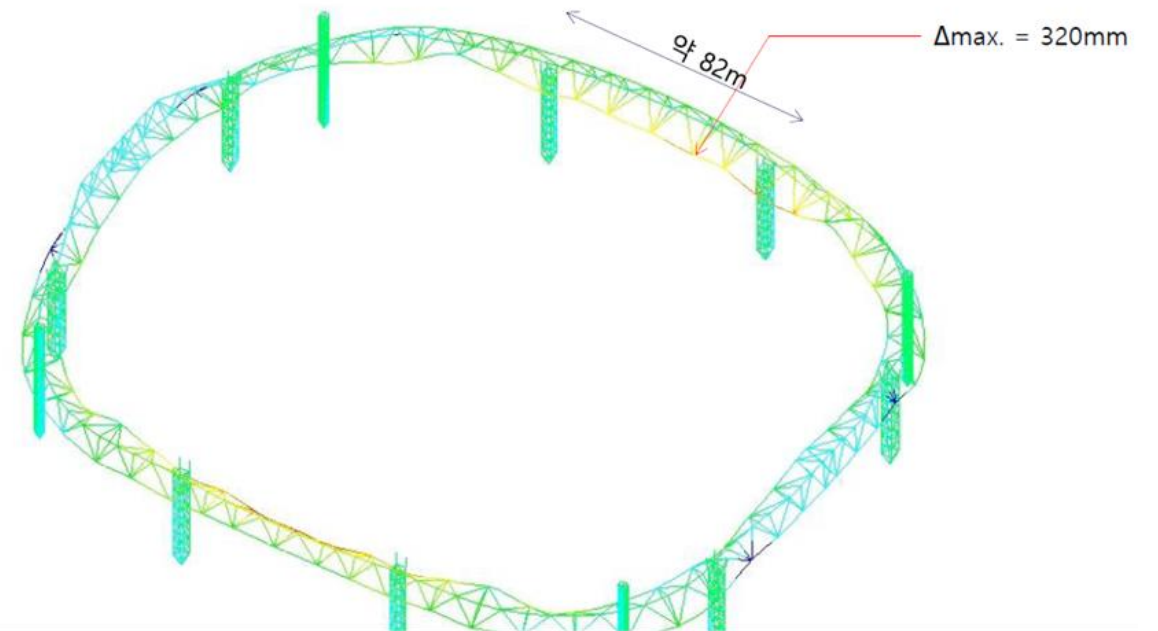


알바야트 스타디움

Gravity Resistance System – Deformation

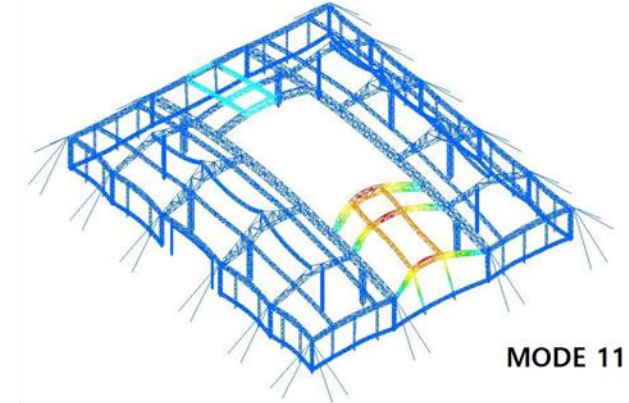
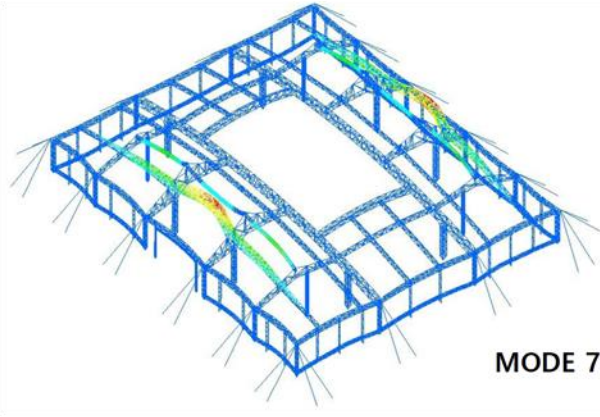
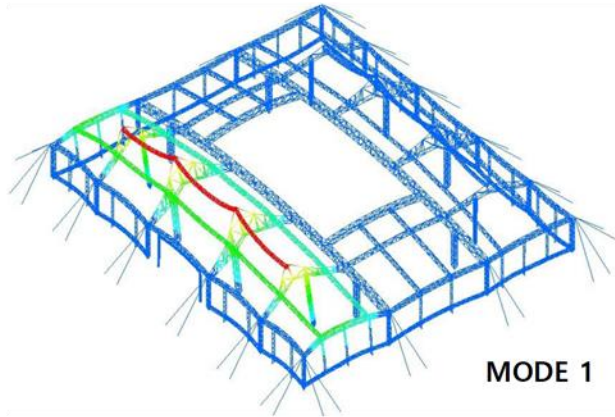


<외부 지붕 트러스>

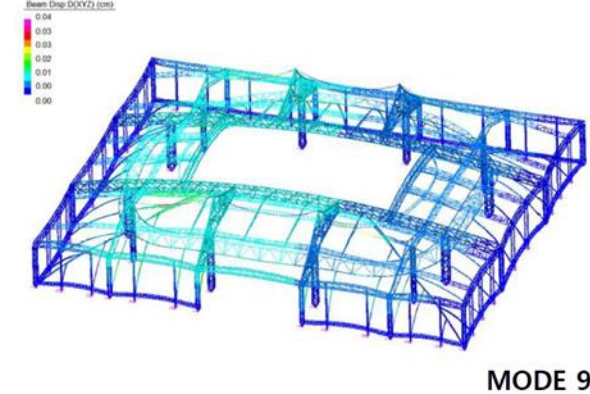
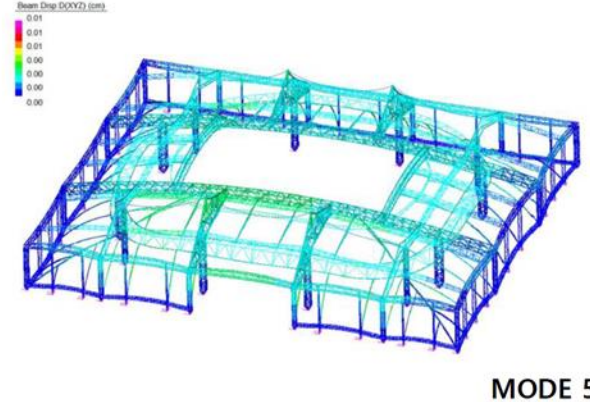
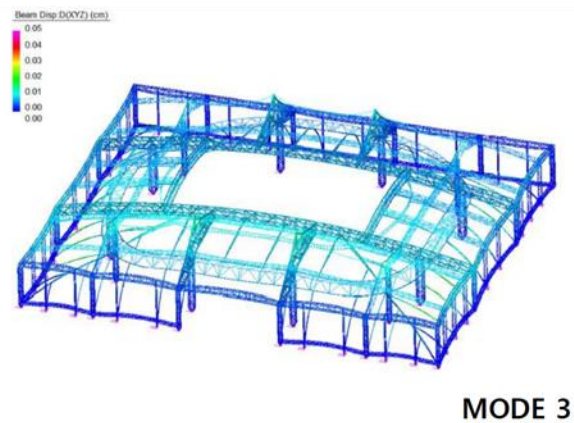


<내부 지붕 트러스>

(1) MODE SHAPE (without Membrane/Cable Diaphragm)

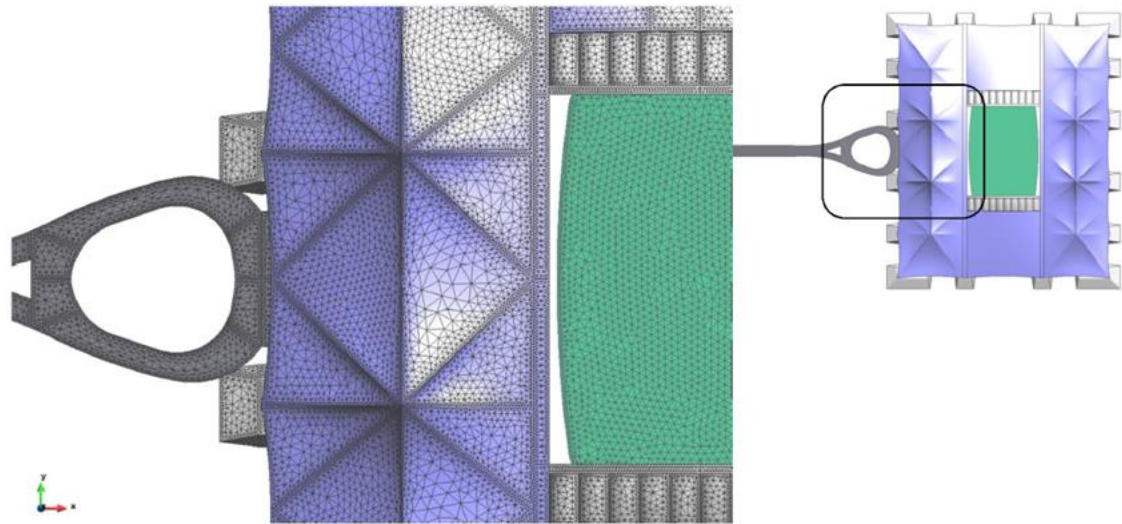


(2) MODE SHAPE (with Membrane/Cable Diaphragm)

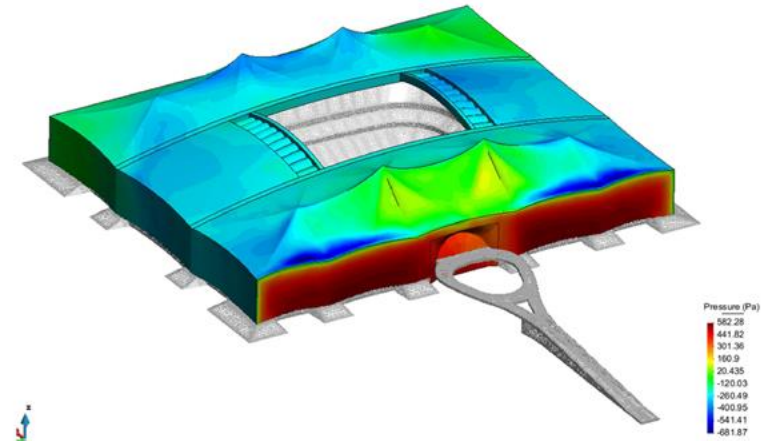


알바야트 스타디움

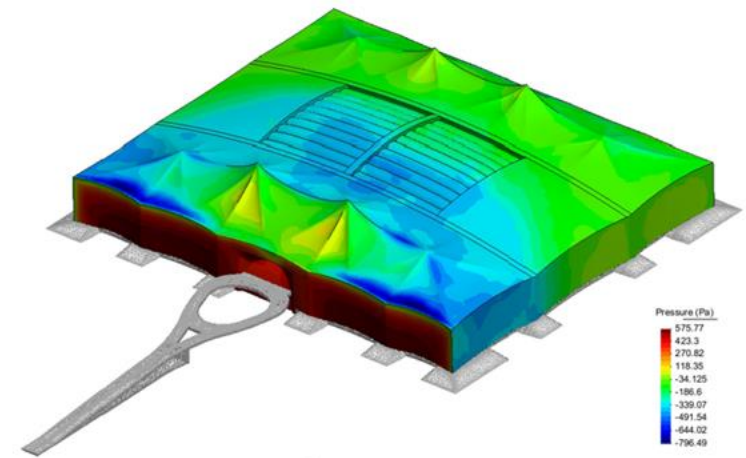
CFD Analysis of Membrane Structure



<막구조물에 대한 MESH 모델링>



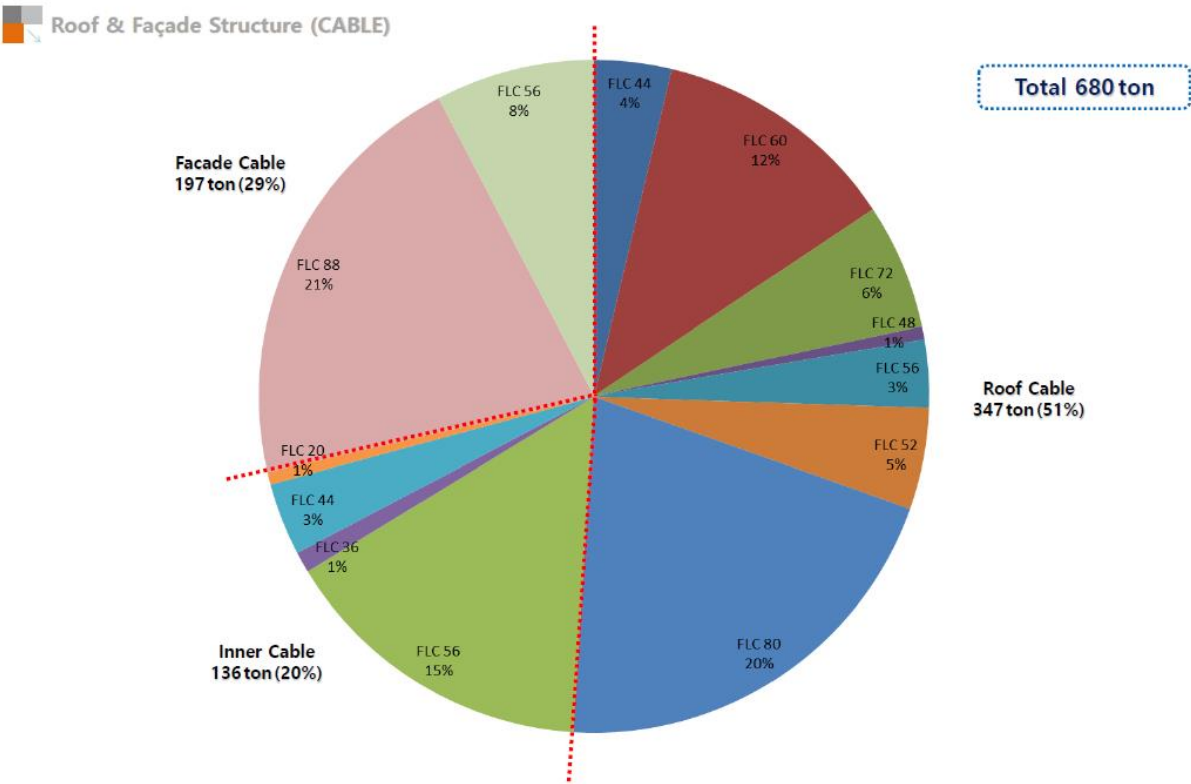
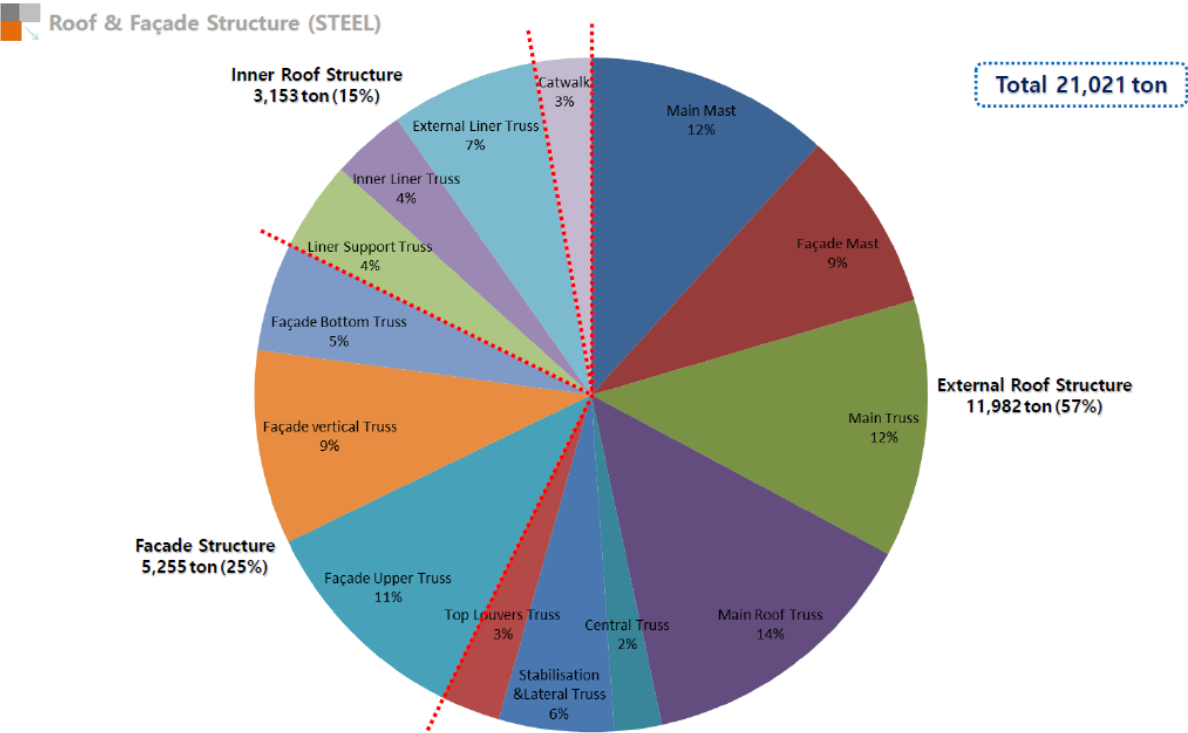
<풍압 결과(West, Open Roof)>



<풍압 결과(West, Closed Roof)>

알바야트 스타디움

Alternative VE Design - 물량분석



알바야트 스타디움 Alternative VE Design

 **VE I** – without architectural plan change

No.	ITEM	Structural Member	Summary	Quantity From Original Design (ton)	Quantity Saved (ton)
1-1	Roof & Façade Structure	Main Roof Truss	3D Truss → 2D Truss + Member Optimization	21021	19071 (-1950)
1-2		Inner Truss	Truss → Single Member (Steel Pipe)		
1-3		Lateral Secondary Roof Truss	3D Truss → 2D Truss		
1-4		ALL	Member Optimization		
1-5		Roof Corner Cable	Cable → Steel Truss		
1-6	Retractable Roof	ALL	Member Optimization	1900	1500 (-400)
1-7	Duct/Sprinkler Support	-	-	1200	1080 (-120)
1-8	Catwalks/Walkways /Gutters	-	-	1000	902 (-98)
TOTAL				25121	22553 (-2568)

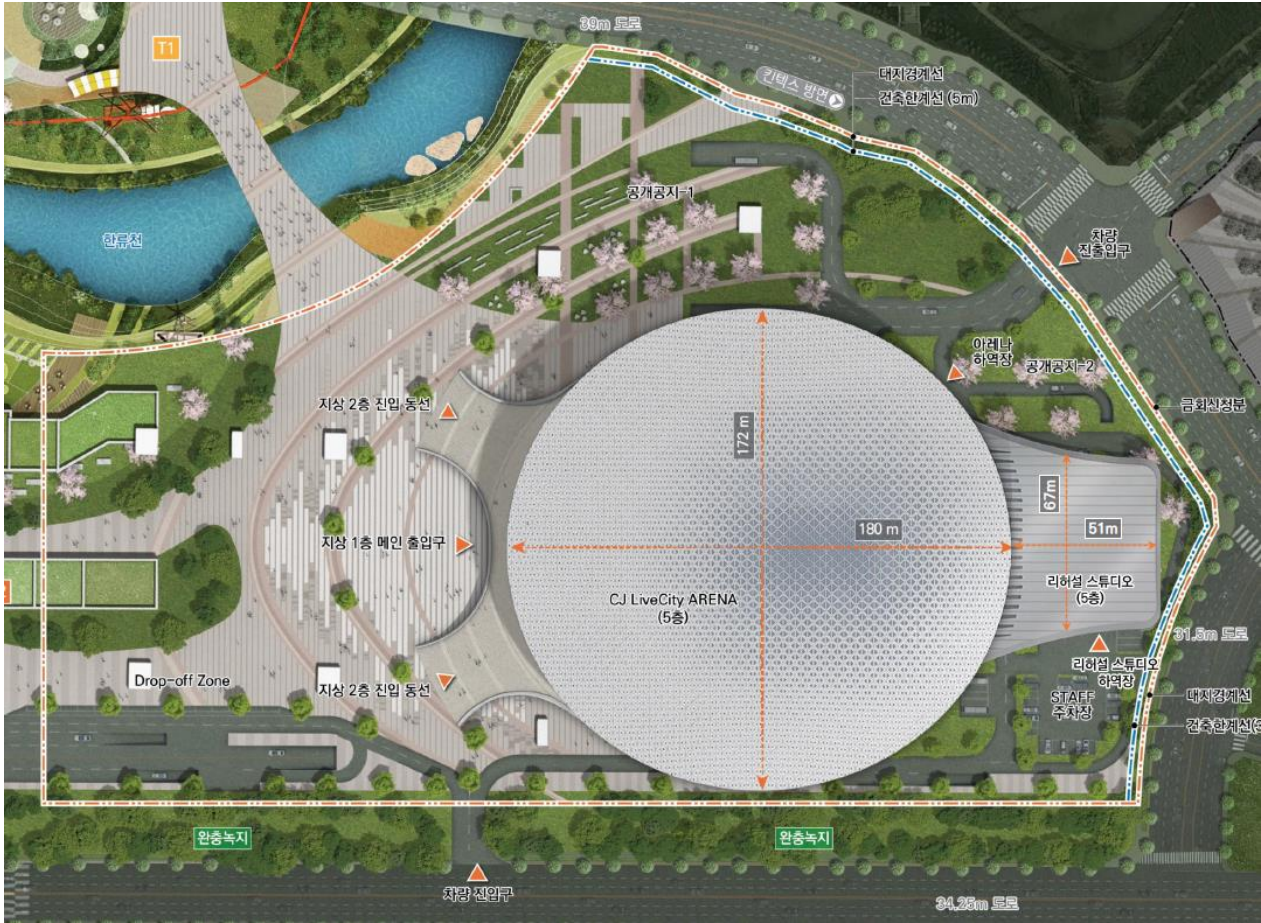
C.J. 아레나 라이브시티

CJ 아레나 라이브 시티

경기도 고양시, 2023년 시공중

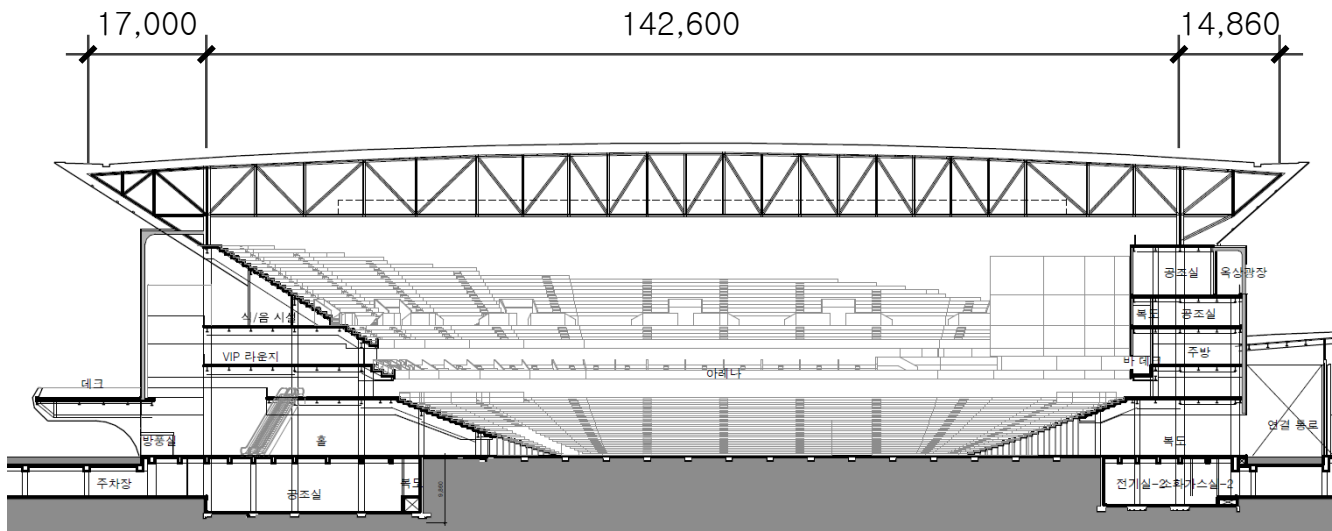


CJ 아레나 라이브 시티

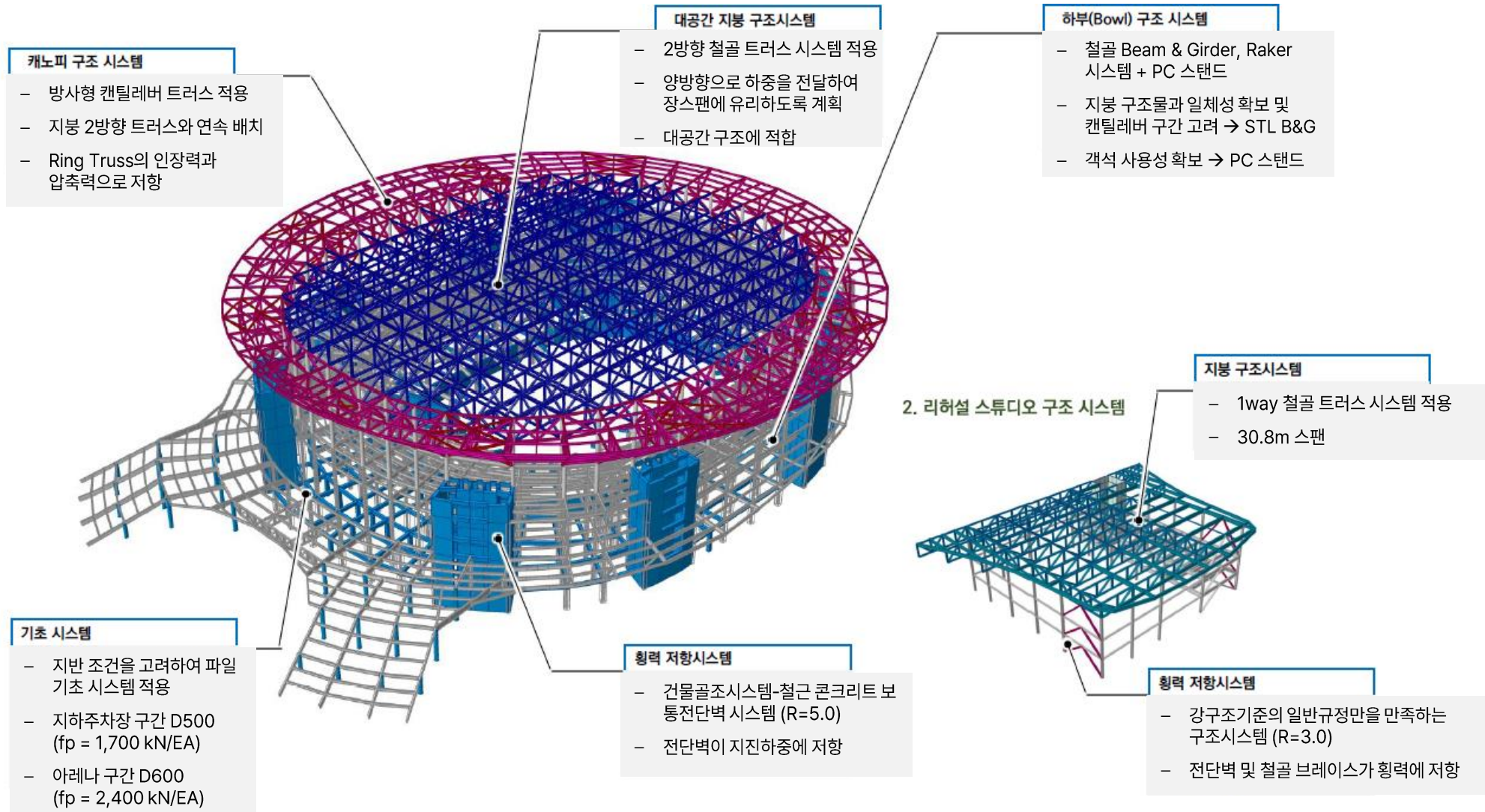


Project	CJ LiveCity ARENA
Floors	B1F / 5F
Structure	Bowl : Steel Beam & Girder, Steel Raker + PC Stand Roof : 2-way Steel Truss
Roof Perimeter	180m X 172m
Seats	18,117

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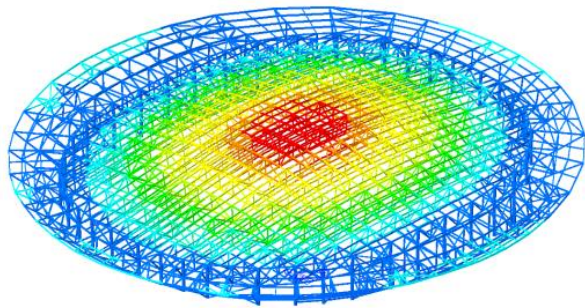
CJ 아레나 라이브 시티



CJ 아레나 라이브 시티

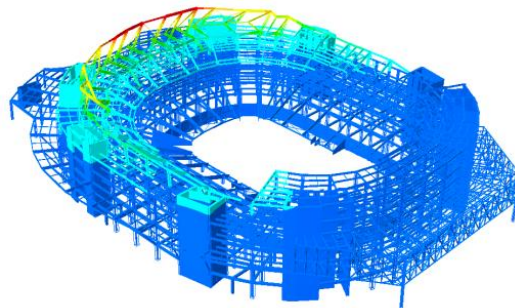
Eigenvalue Analysis

Roof

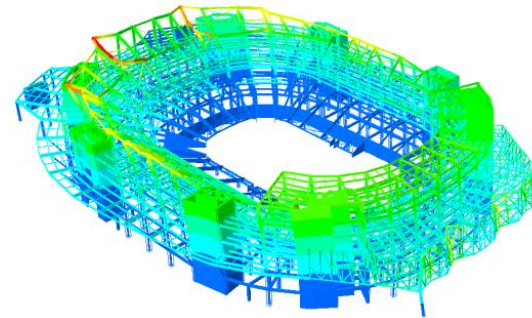


$T_1=0.7717\text{sec}$, $f_1=1.296\text{Hz}$

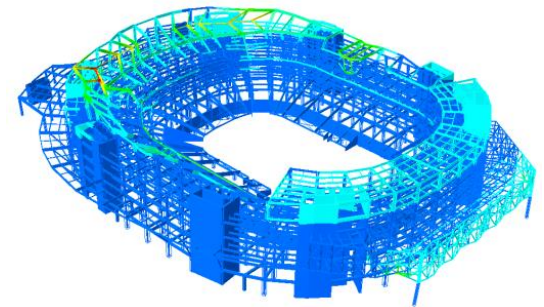
Bowl



1st MODE
Y-Dir, $T=0.4425\text{sec}$



2nd MODE
X-Dir, $T=0.3810\text{sec}$

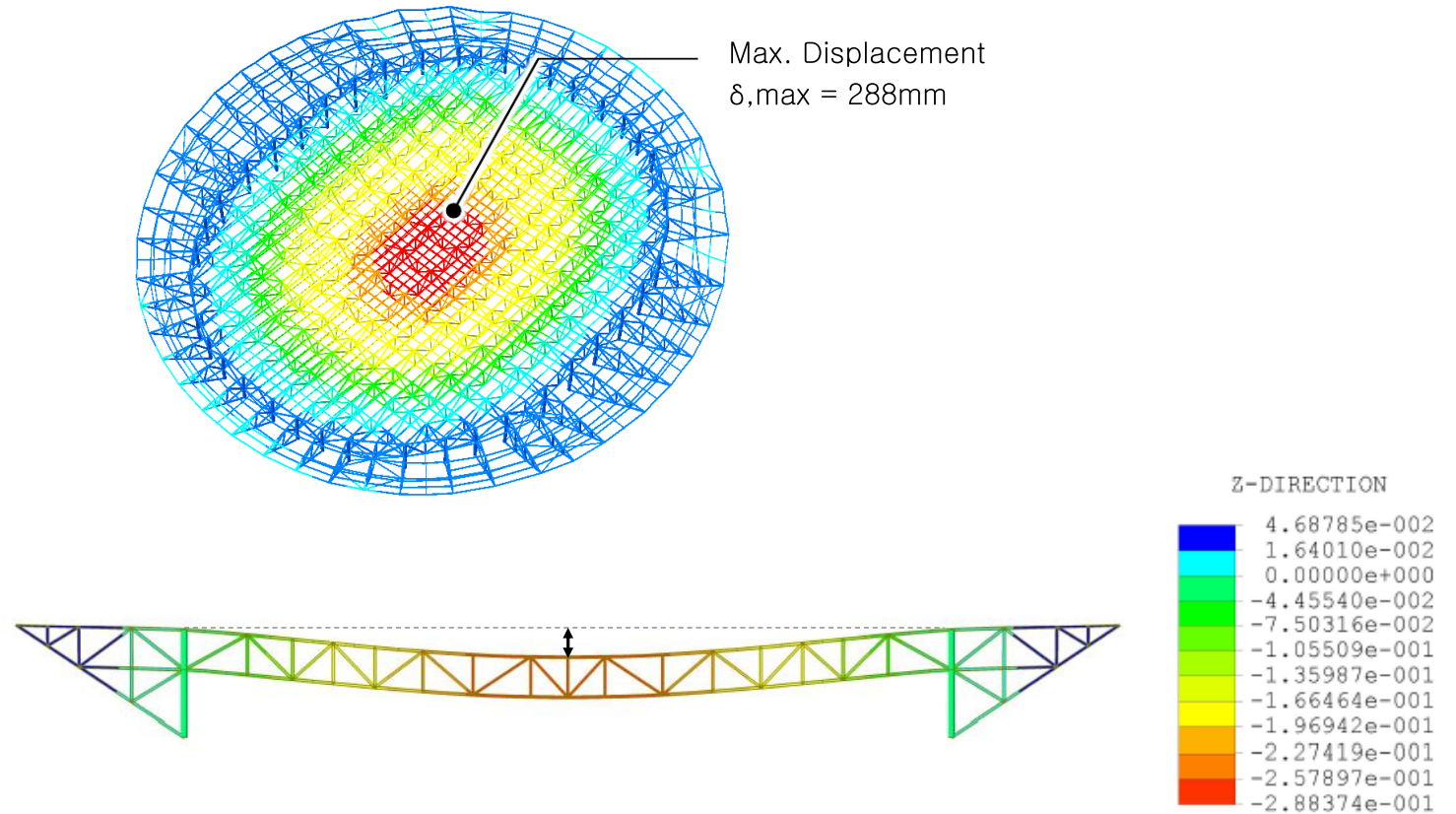


3rd MODE
Z-rot, $T=0.3156\text{sec}$

CJ 아레나 라이브 시티

Deflection Check

Roof

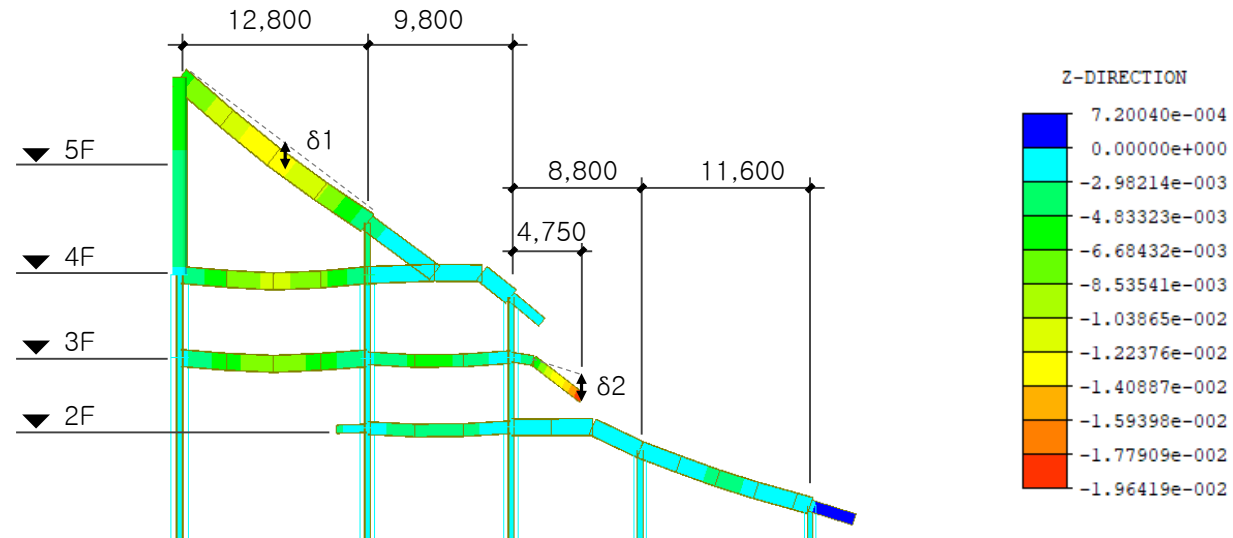


$$\delta = 288.4\text{mm} (=L/400.8) \leq 385.3\text{mm} (=L/300) \rightarrow \text{O.K}$$

CJ 아레나 라이브 시티

Deflection Check

Bowl



12.8m 스패ن 구간 : $\delta_1 = 11.3\text{mm} (=L/1133.7) \leq 42.7\text{mm} (=L/300) \rightarrow \text{O.K}$

캔틸레버 구간 : $\delta_1 = 19.6\text{mm} (=L/242.3) \leq 31.7\text{mm} (=L/150) \rightarrow \text{O.K}$

Others Project of CSSE

안산 돔 경기장

양골라 스타디움

HRD Information Center

인천 국제공항 제2청사

아트센터 (인천)

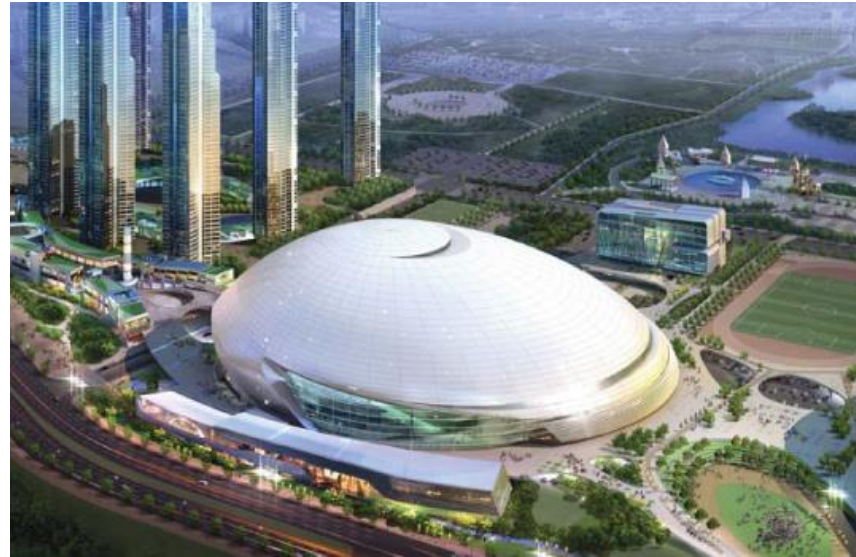
The Gate

파라다이스시티

여수 나인브릿지 (해슬리, 햄릿)

안산 돔 경기장

안산시, 2009년

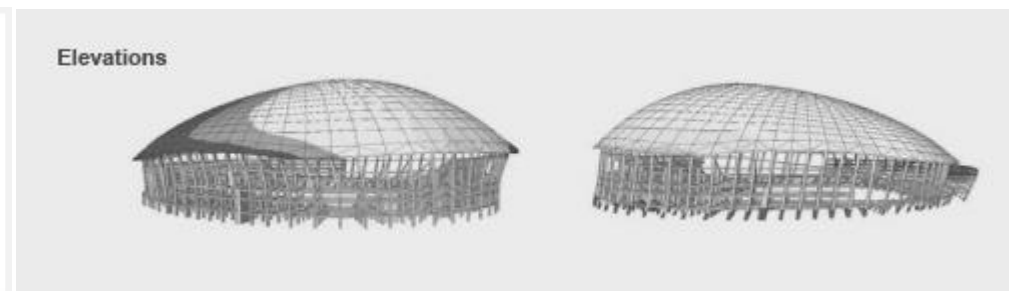
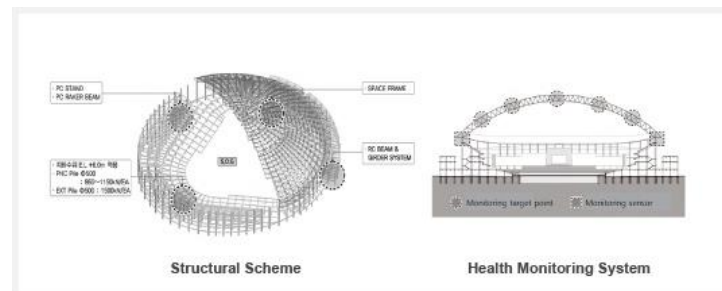


Work Scope: Structural Design
Location: Ansan, Korea
Occupancy: Stadium, Cultural facilities
Size : 202,826m², 5F
Structure System : RC+STEEL+PC / Roof : Space Frame
Architect: Space Group
Contractor : Hyundai E&C

Interior View



Structural System and Health Monitoring

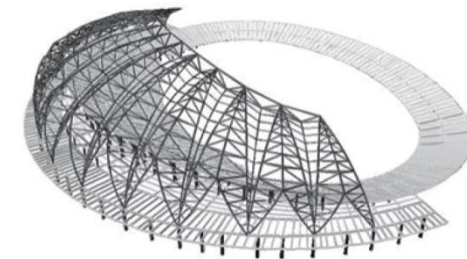


앙골라 스타디움

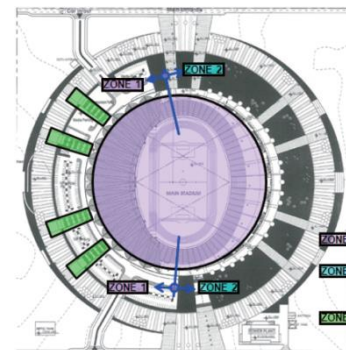
Angola, 2006년



Work Scope: Structural Design
 Architect: Space Group
 Size: 48,122 m² (33,020 seats)
 Structure System: Roof) Cantilever Roof Truss
 Stand) RC Beam & Girder System

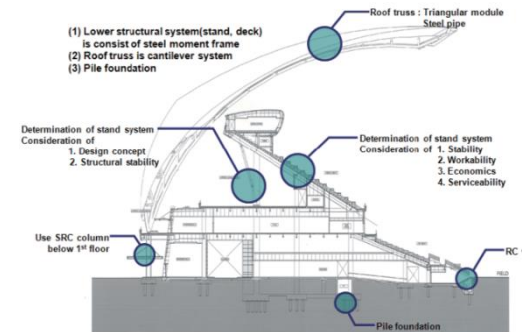


Foundation

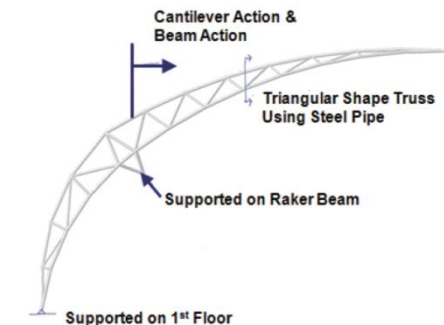


Main Stadium West side
: Pile Foundation
 Main Stadium East side
: S.O.G (Slab On Grade)
 Allowable Soil bearing capacity
: Fe=100kN/m²
 Access Ramp : Spread Foundation
 Allowable Soil bearing capacity
: Fe=100kN/m²

Concept Sketch of Overall Structural System

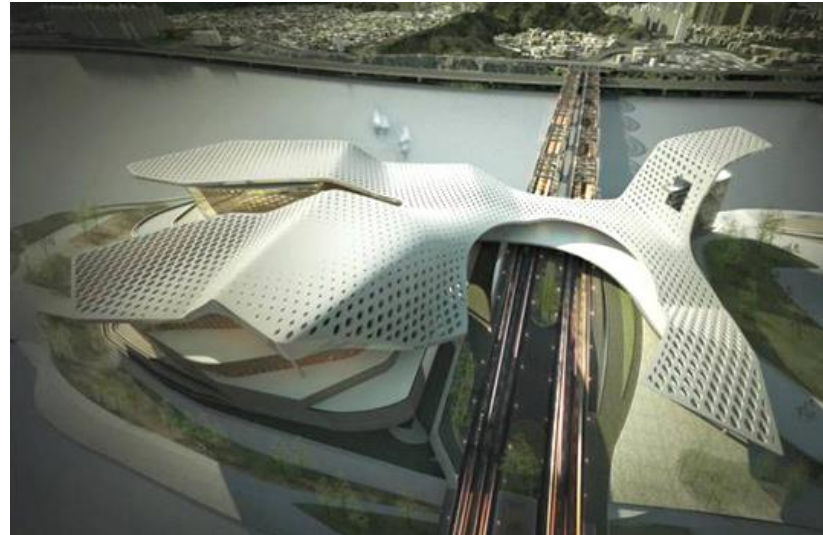


Roof Structure



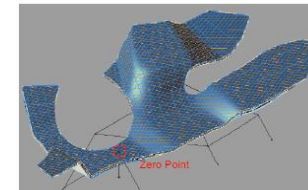
한강 예술섬

서울시, 2009년

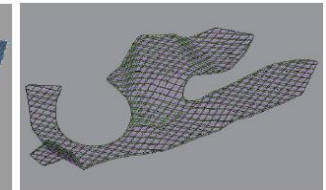


Work Scope: Structural Design
Location: Seoul, Korea
Occupancy: Cultural Facilities, Concert Hall, Auditorium
Size: 99,102m², B2/8F
Structure System: RC+STEEL+SRC / Beam & Girder system
Architect: DMP

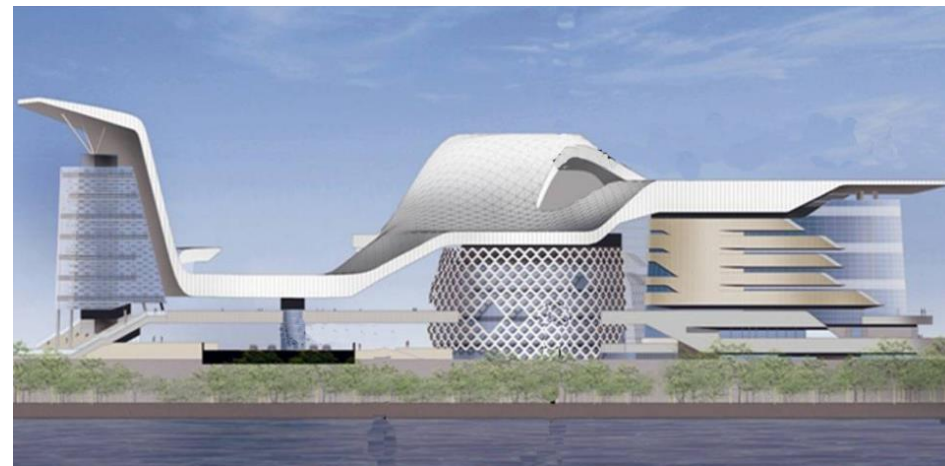
Form of Structural Grid



<Architectural grid>

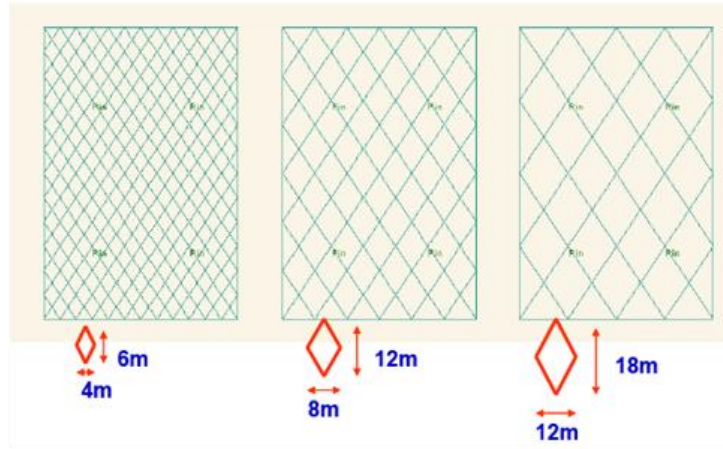


<3D Structural truss from architectural grid>

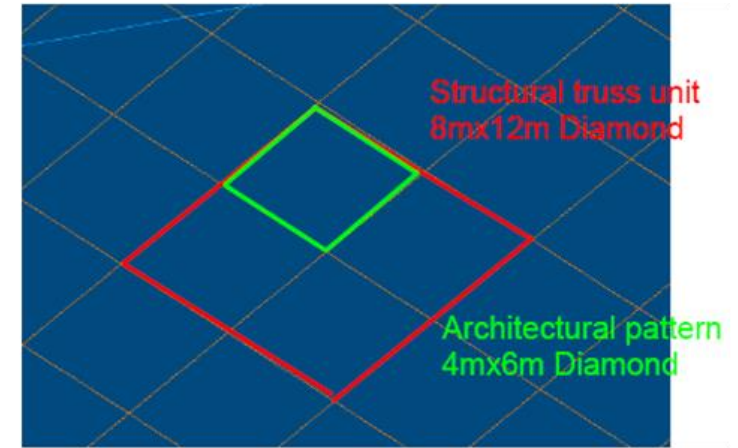


한강 예술섬

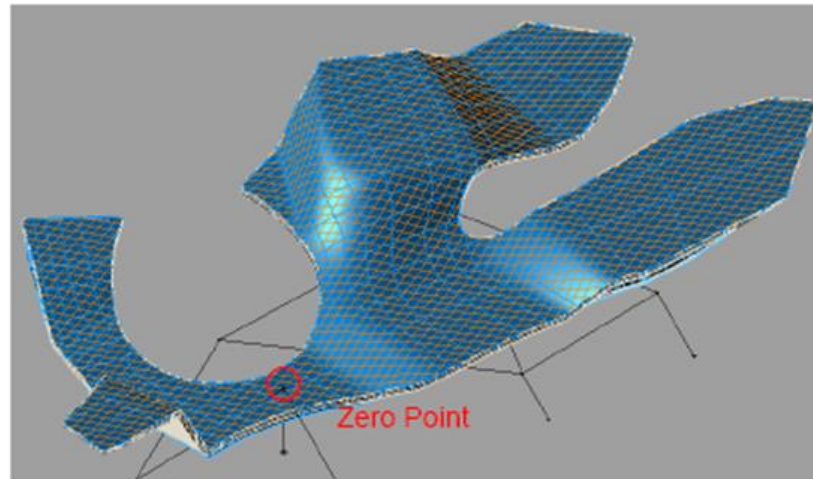
Roof Geometry



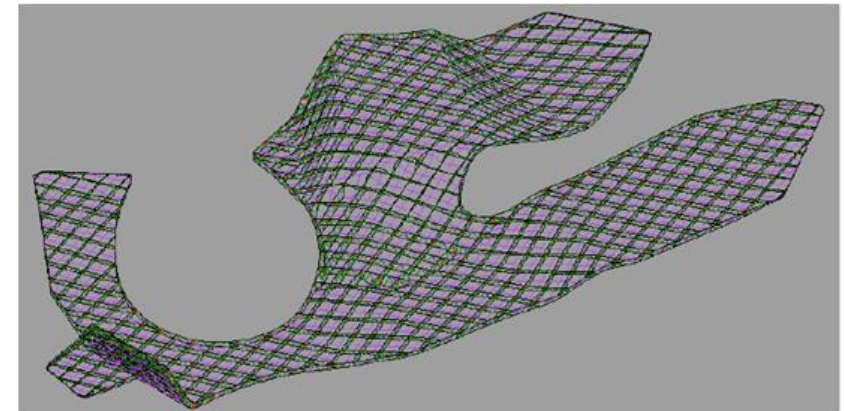
Structural Truss Gird Dimension Options



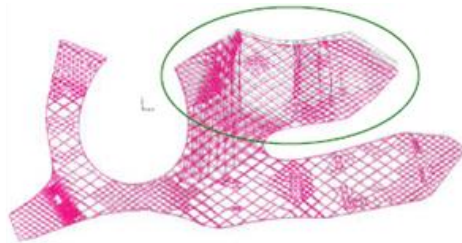
Chosen Structural Truss Grid



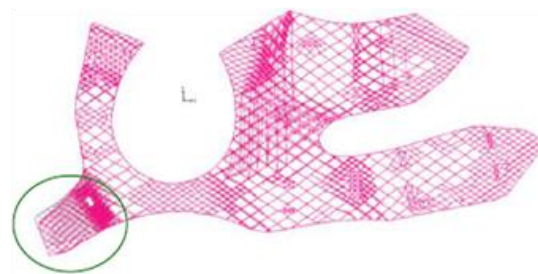
Generated Architecture Grids



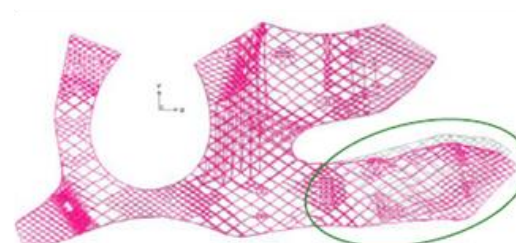
3D Structural Truss



Mode 4 ($f_4=1.087$ Hz)
Translational vibration along Y axis



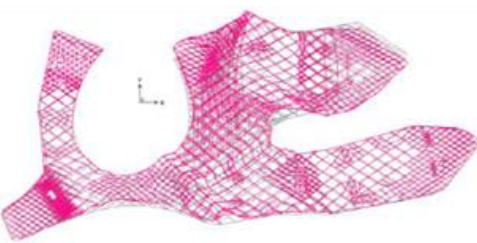
Mode 5 ($f_5=1.361$ Hz)
Translational vibration along X, Y axis



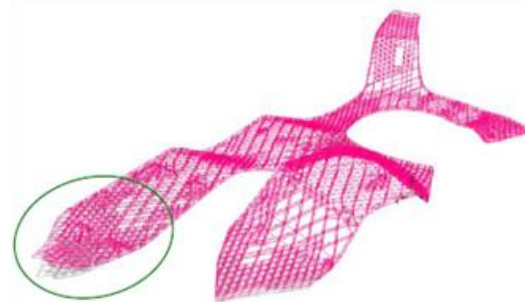
Mode 6 ($f_6=1.369$ Hz)
Translational vibration along Y axis.



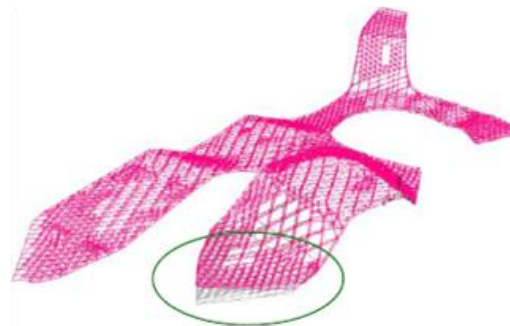
Mode 7 ($f_7=1.417$ Hz)
Translational vibration along X axis.



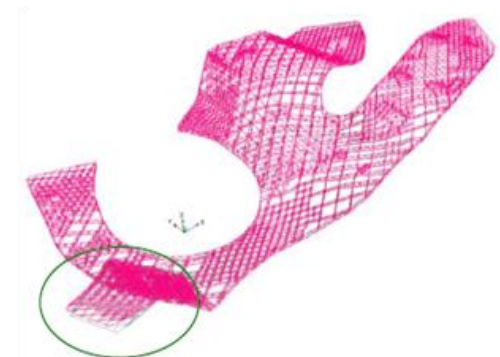
Mode 13 ($f_{13}=1.553$ Hz)
Translational vibration along Y axis.



Mode 14 ($f_{14}=1.631$ Hz)
Translational vibration along Z axis.



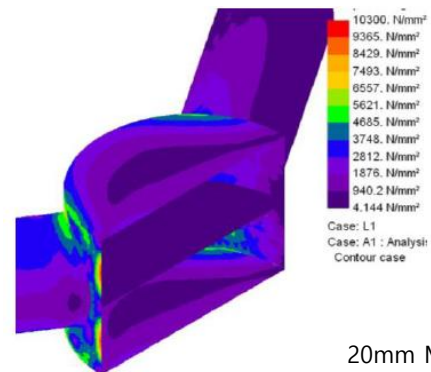
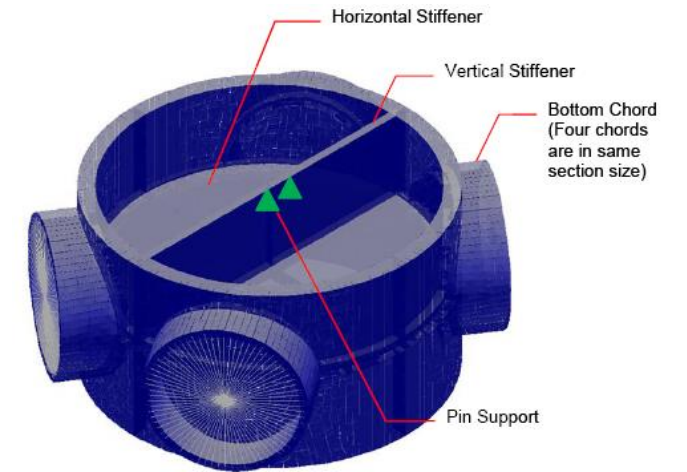
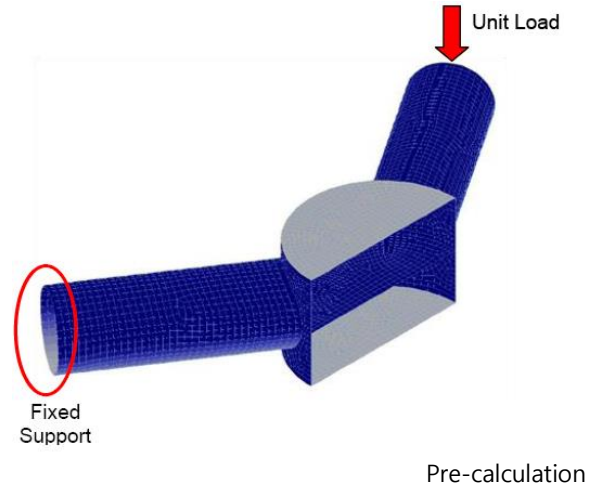
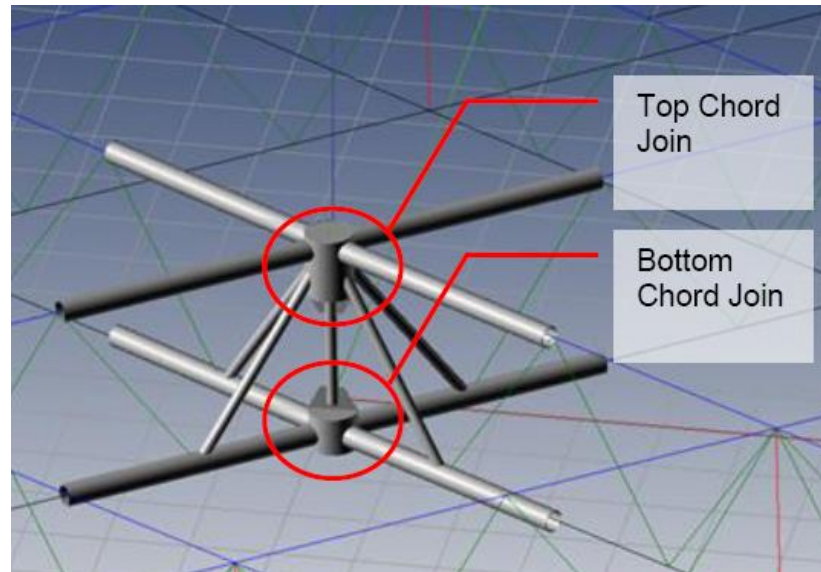
Mode 17 ($f_{17}=1.705$ Hz)
Translational vibration along Z axis.



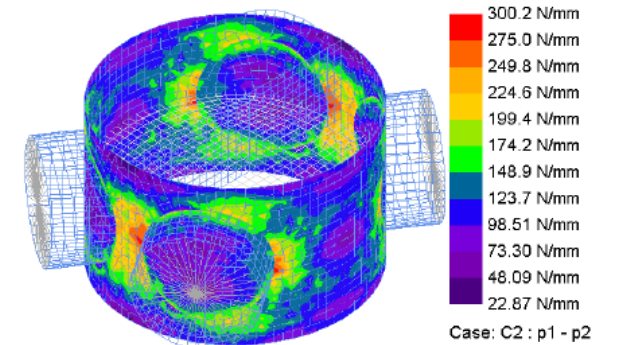
Mode 18 ($f_{18}=1.712$ Hz)
Translational vibration mainly along Z axis.

한강 예술섬

Connection Node Fem Analysis

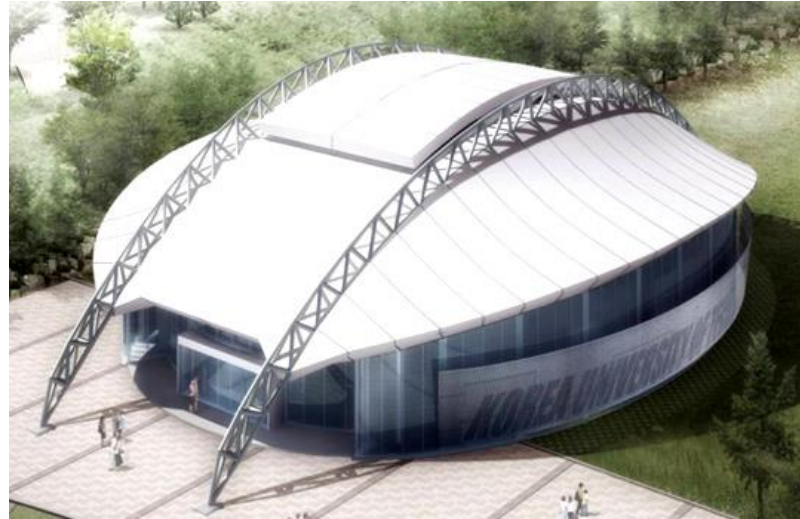


CHS 267.4 x 6.6 (typical area) – without stiffener



HRD Information Center

천안시, 2011년



Exterior View



Work Scope: Structural Design, Research & Development, SHM

Location: Cheon-an, Choong-nam, Korea

Occupancy: Exhibition Hall

Size: 136,340m², 40m X 30m, 1F

Structure System: Steel Structure + Tensioning Air Beam System

Client: Korea University of Technology & Education,

Architect: HaeAhn Architect



Interior View

인천 국제공항 제2 청사

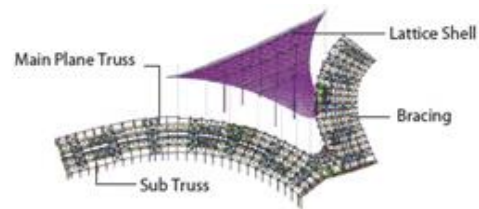
인천시, 2014년



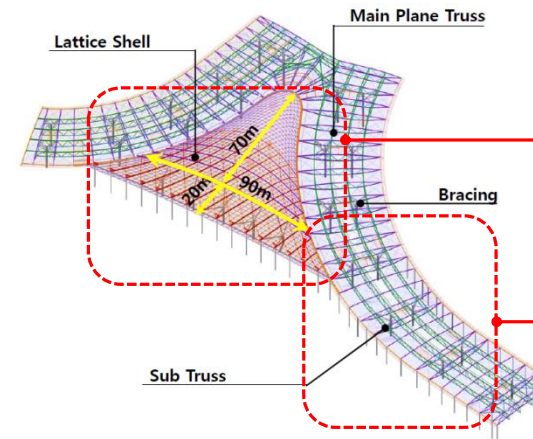
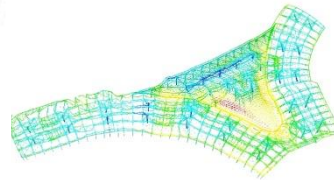
Work Scope: Technical Proposal, Structural design
 Location: Incheon, Korea
 Occupancy: Airport
 Size: 384,332.12m², B2/5F
 Structure System: Lower - RC & PC Steel System
 Upper - Steel System
 Roof - 1-Way-Steel Truss & Lattice Shell
 Client: Incheon International Airport Corporation

Structural System

Wind + Node Shell

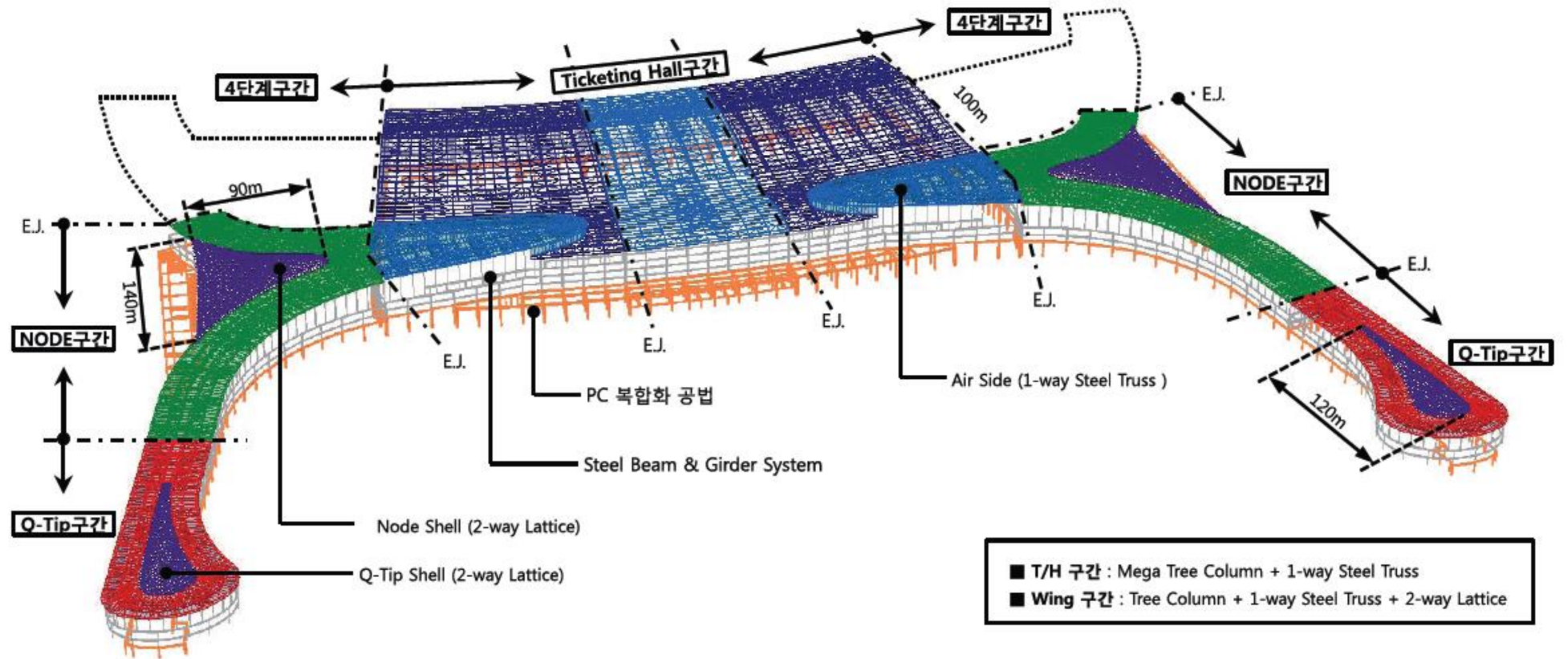


Deformation



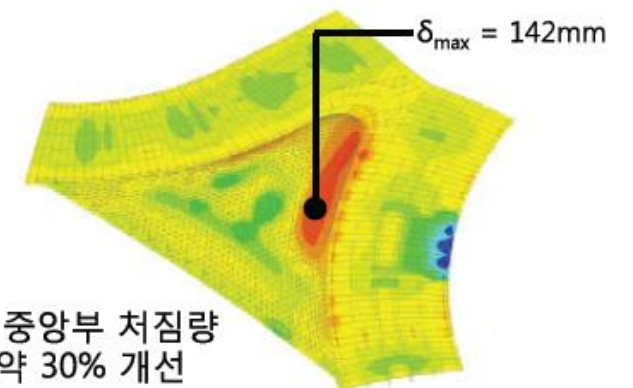
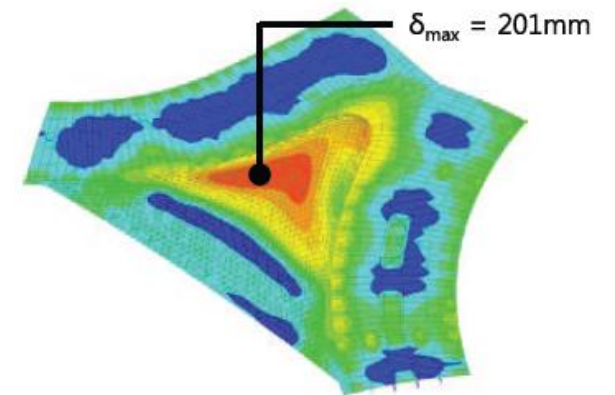
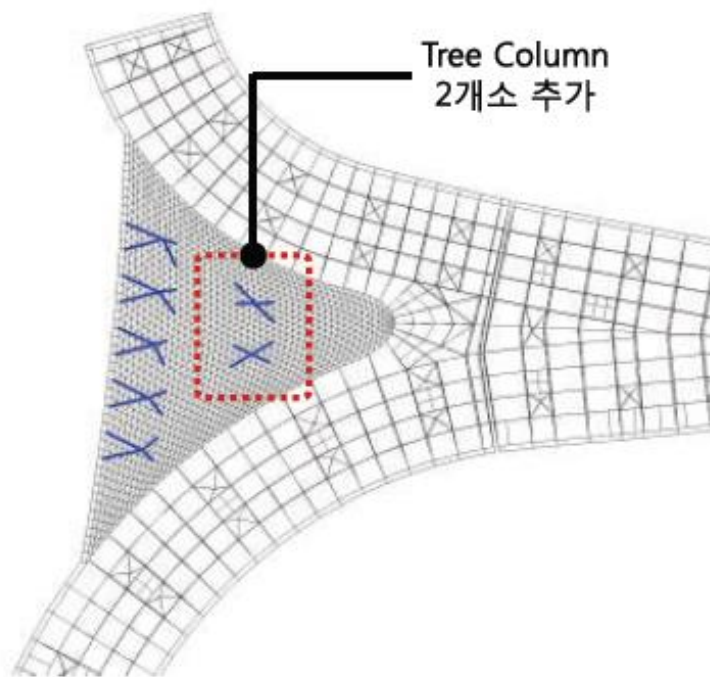
인천 국제공항 제2 청사

인천시, 2014년



인천 국제공항 제2 청사

인천시, 2014년



⇒ 중앙부 처짐량
약 30% 개선

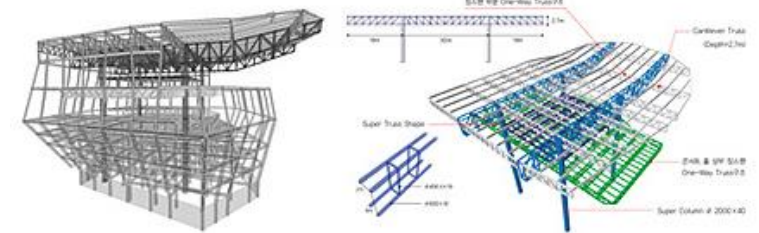
아트센터 인천

인천시, 2014년

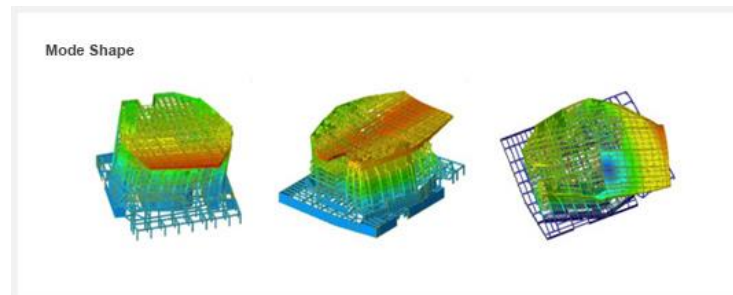


- Work Scope: Structural Design, Structural Drawing
- Location: Incheon, Korea
- Occupancy: Cultural Facilities
- Size: 40,427.48m² , B2/7F (Concert Hall)
/B2/8F (Museum), B2/4F (Opera House)
- Structure System: RC Core + SRC Column + Steel,
RC Beam & Girder System
- Client: DMP + POSCO E&C

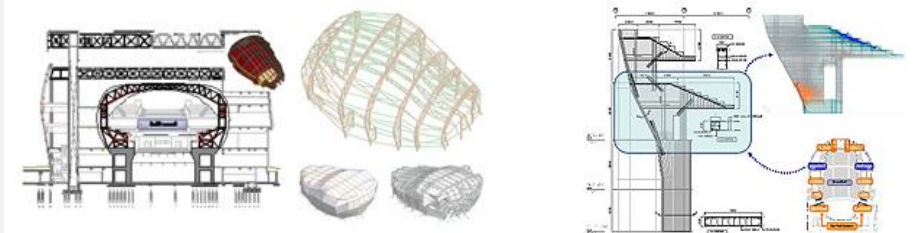
● Structural System (Roof)



● Structural Analysis

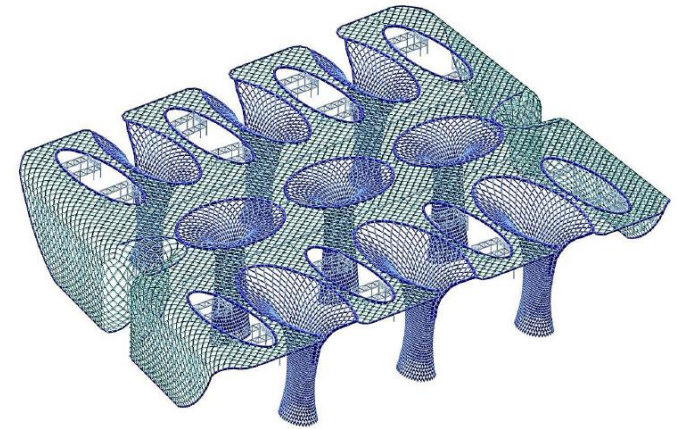
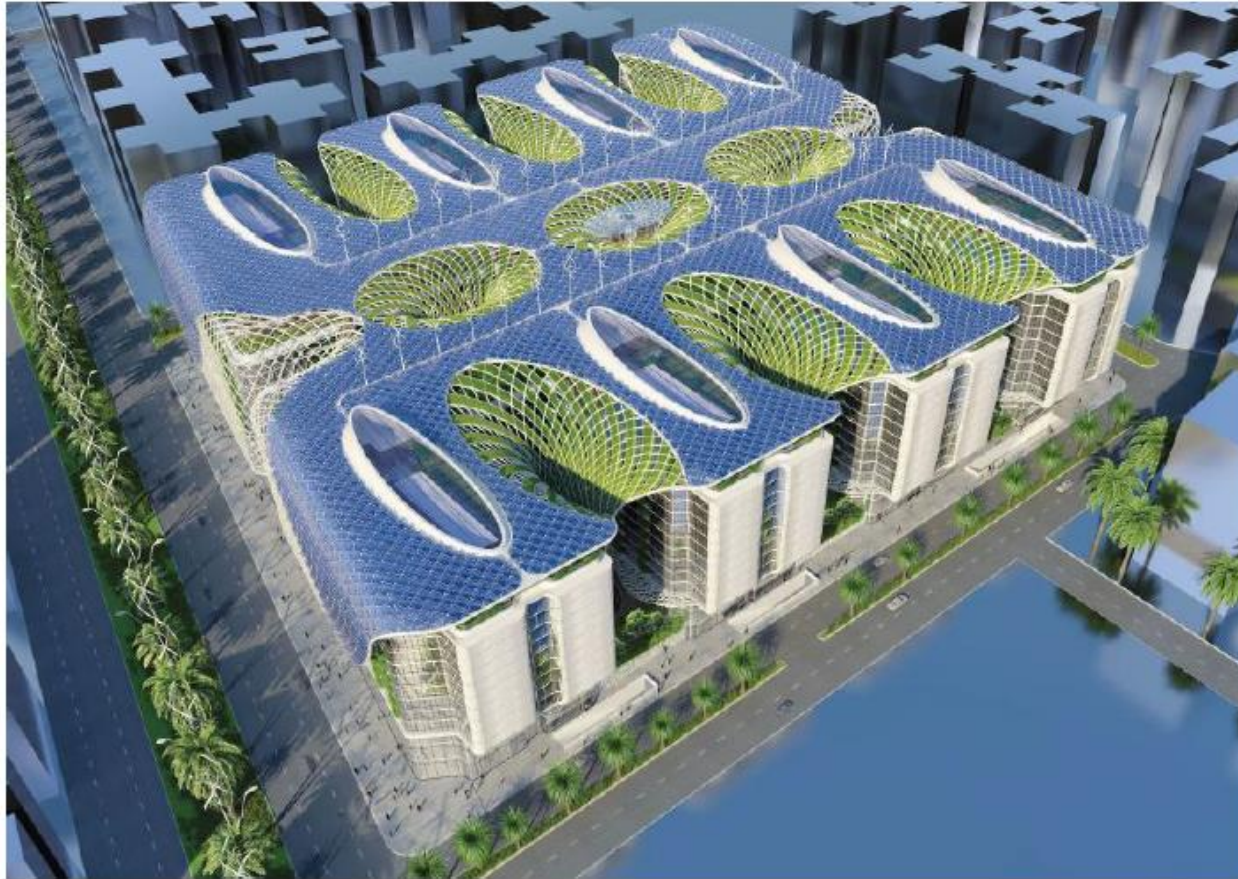


● Structural System (Inner hall) ● Structural Design by FEA



The Gate

이집트, 2015년



The Gate

Roof geometry

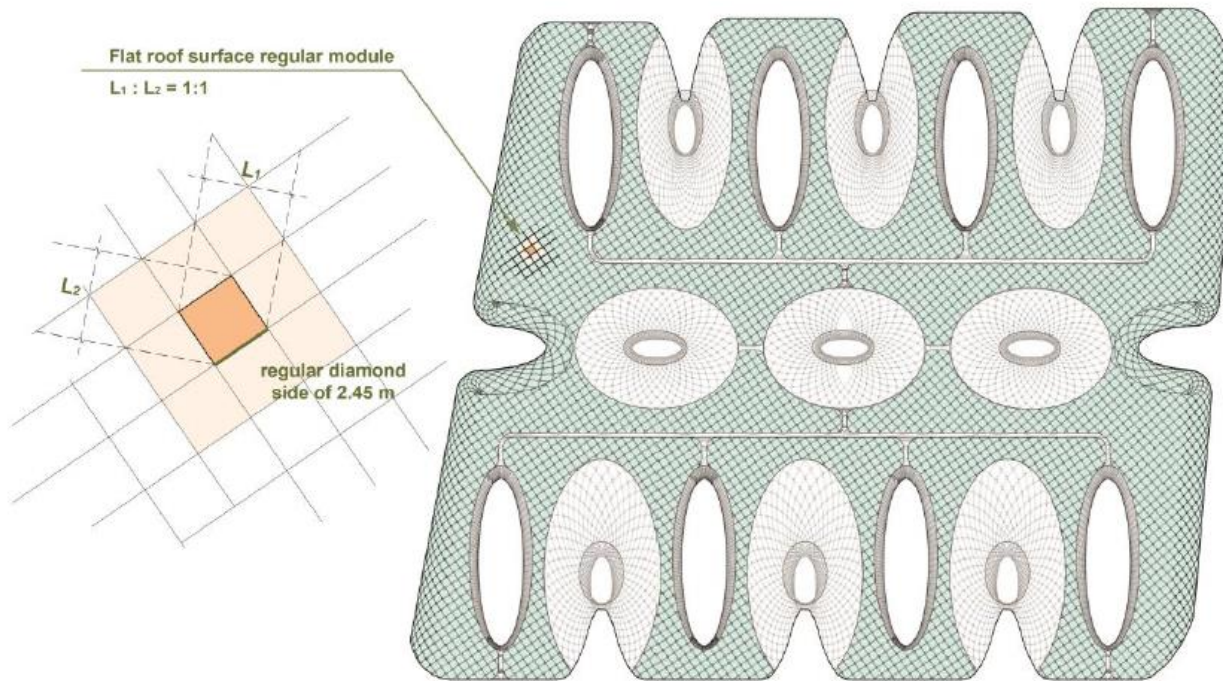


Figure 3-2 Flat roof surface regular module

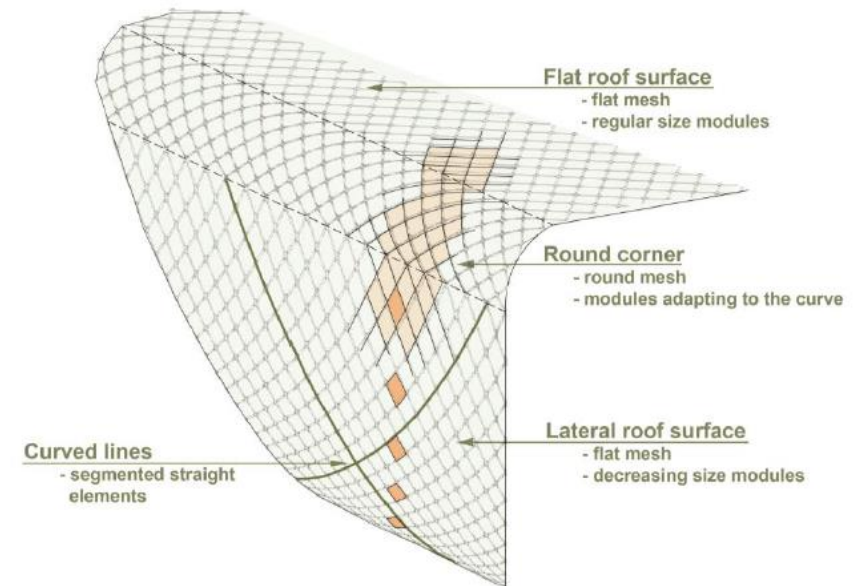
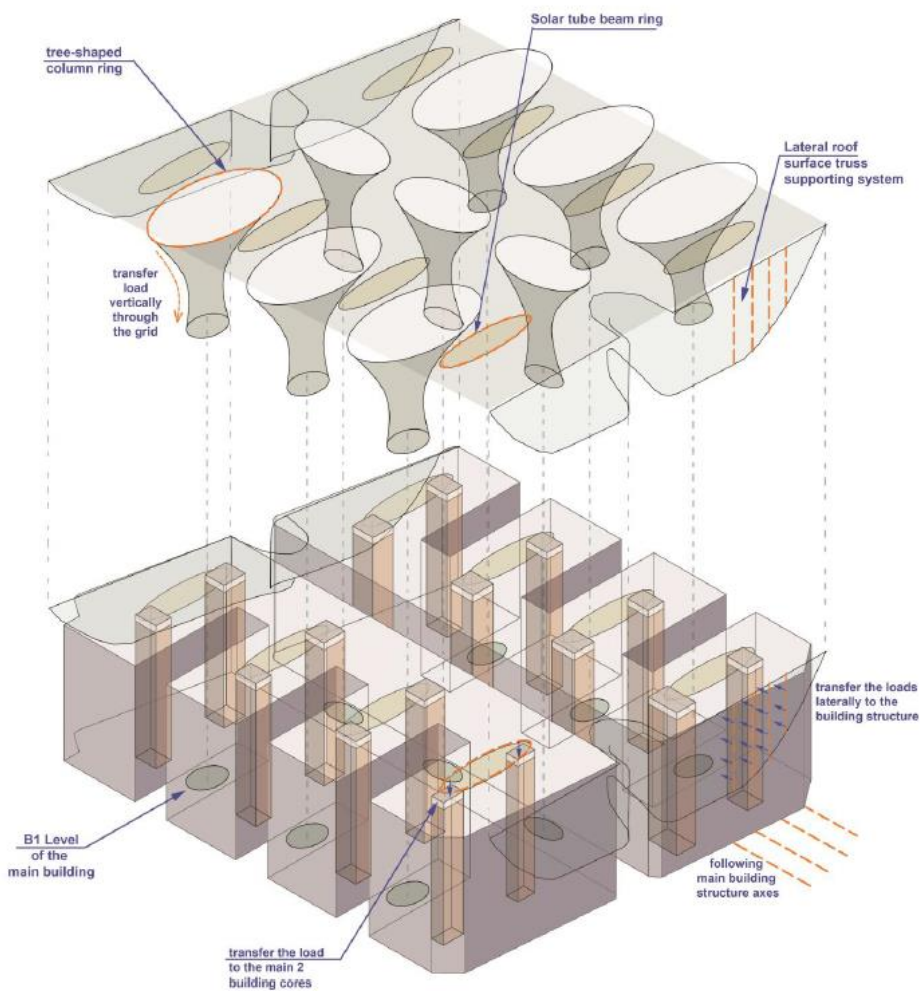
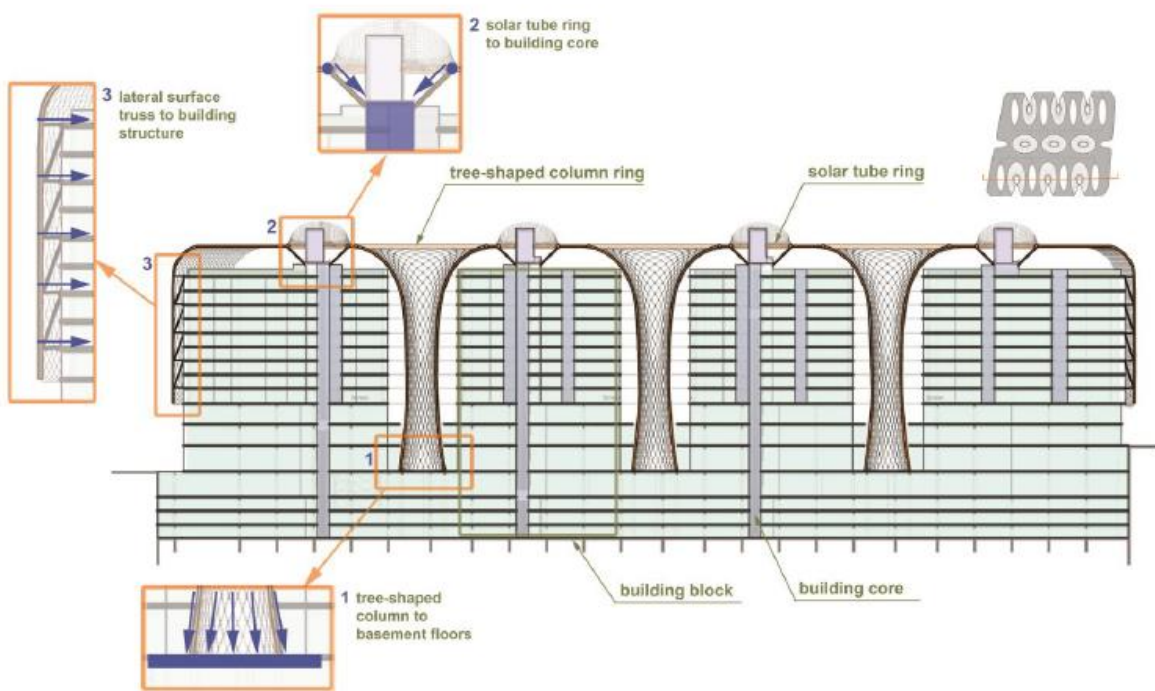


Figure 3-3 Lateral roof surface module and relationship with the flat roof surface

The Gate

Roof Structural System



The Gate

Structural Analysis

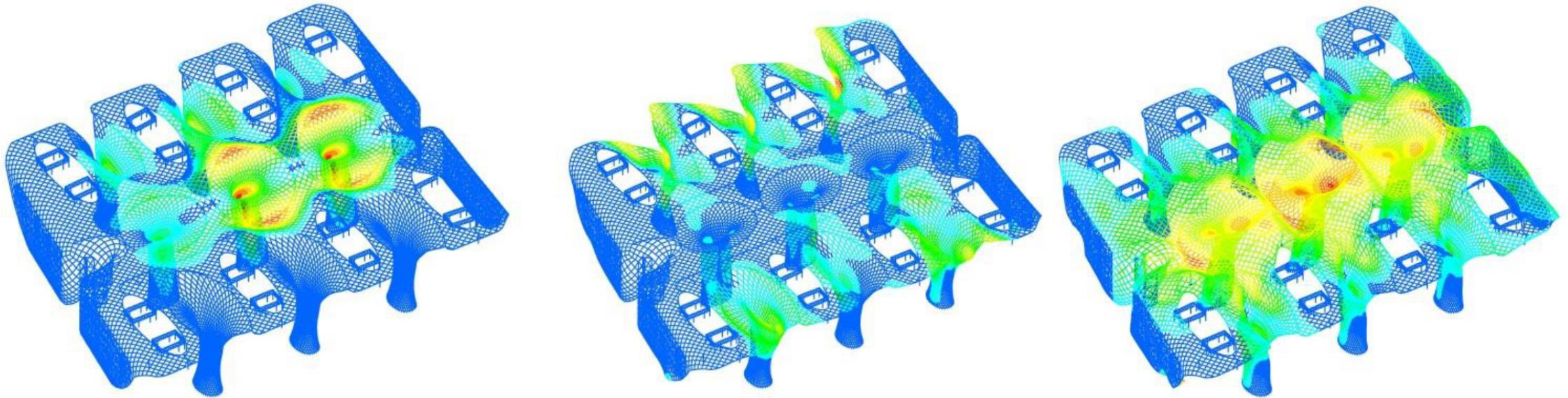


Figure 7-2 MIDAS Gen eigenvalue analysis modes

The Gate

Structural Analysis

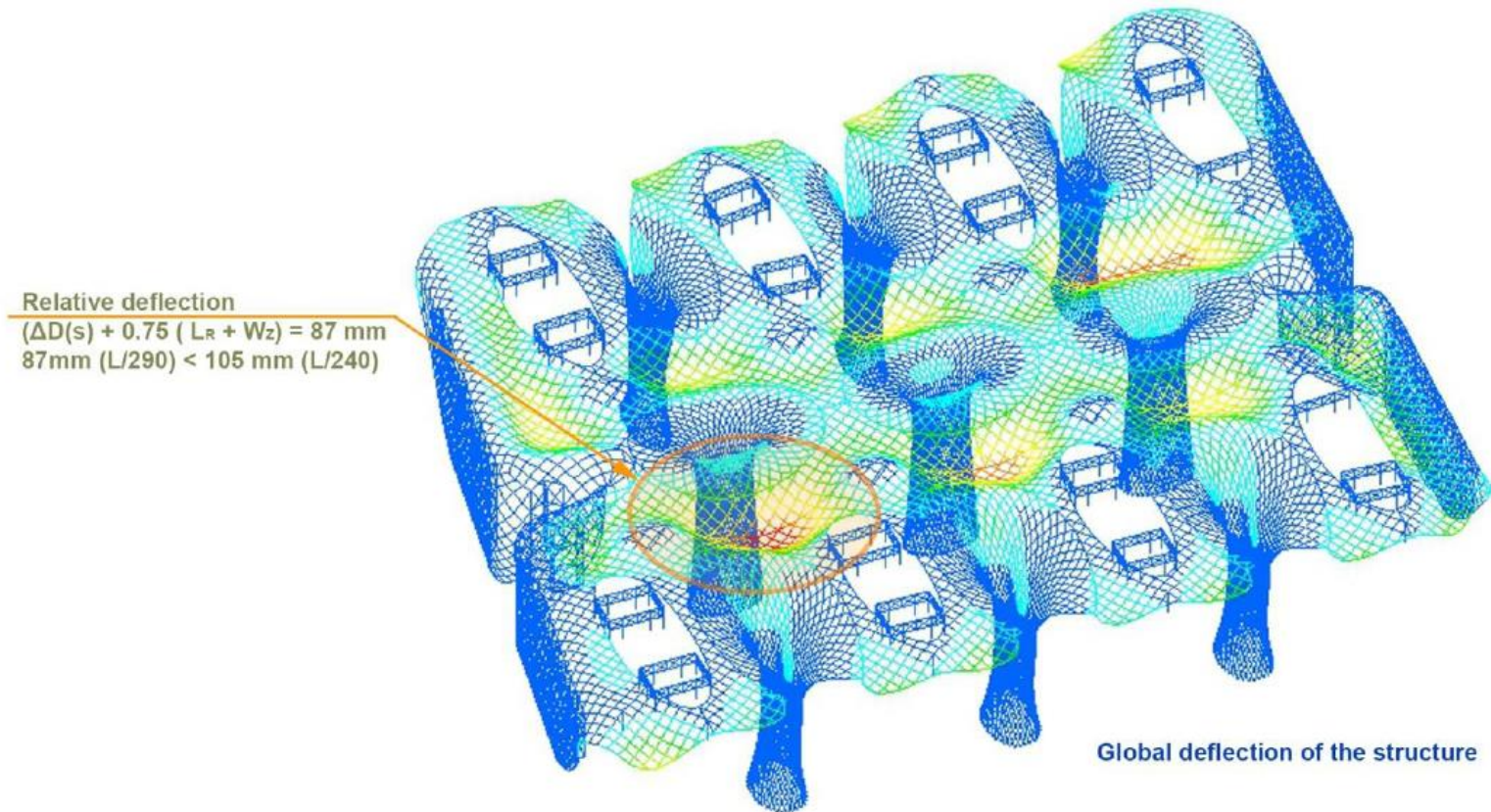


Figure 9-1 Global deflection of the structure limitations checking

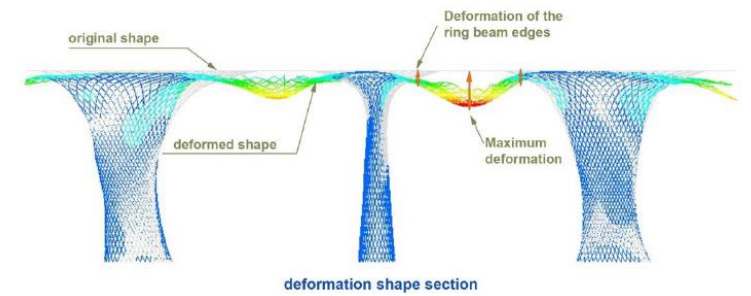


Figure 9-2 Deformation shaped transverse section

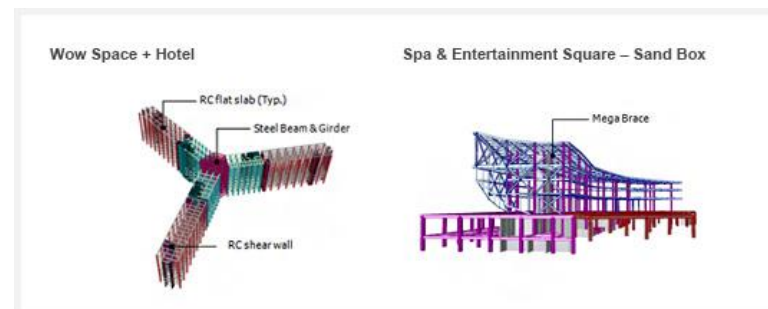
파라다이스시티

인천시, 2017년

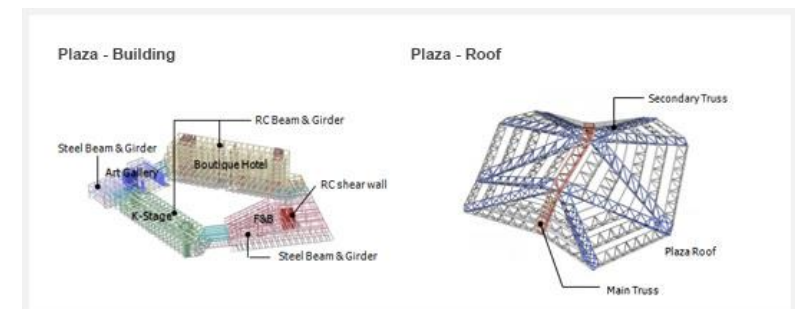


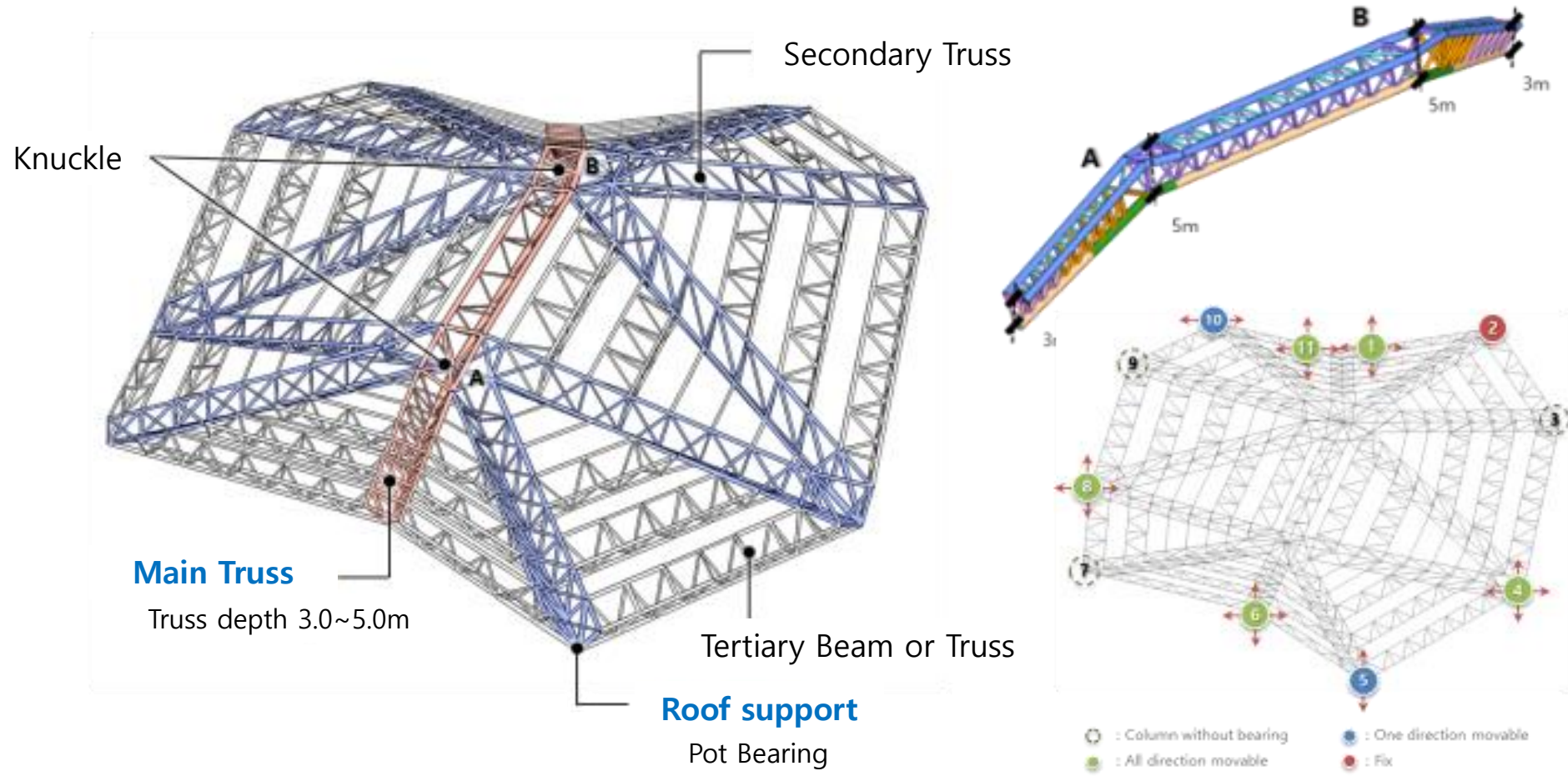
- Project: Paradise City
- Work Scope: Structural Design
- Location: Jung-gu, Incheon, Korea
- Occupancy: Hotel, Casino, SPA, Commercial
- Size: 295,530㎡ Hotel(B2F~10F), Commercial(B1F~8F), SPA(B2F~3F) B3F~10F
- Structure System: RC + Steel Frame
- Client: Paradise Group
- Architect: Gansam Architects
- Contractor: Posco E&C, SK E&C

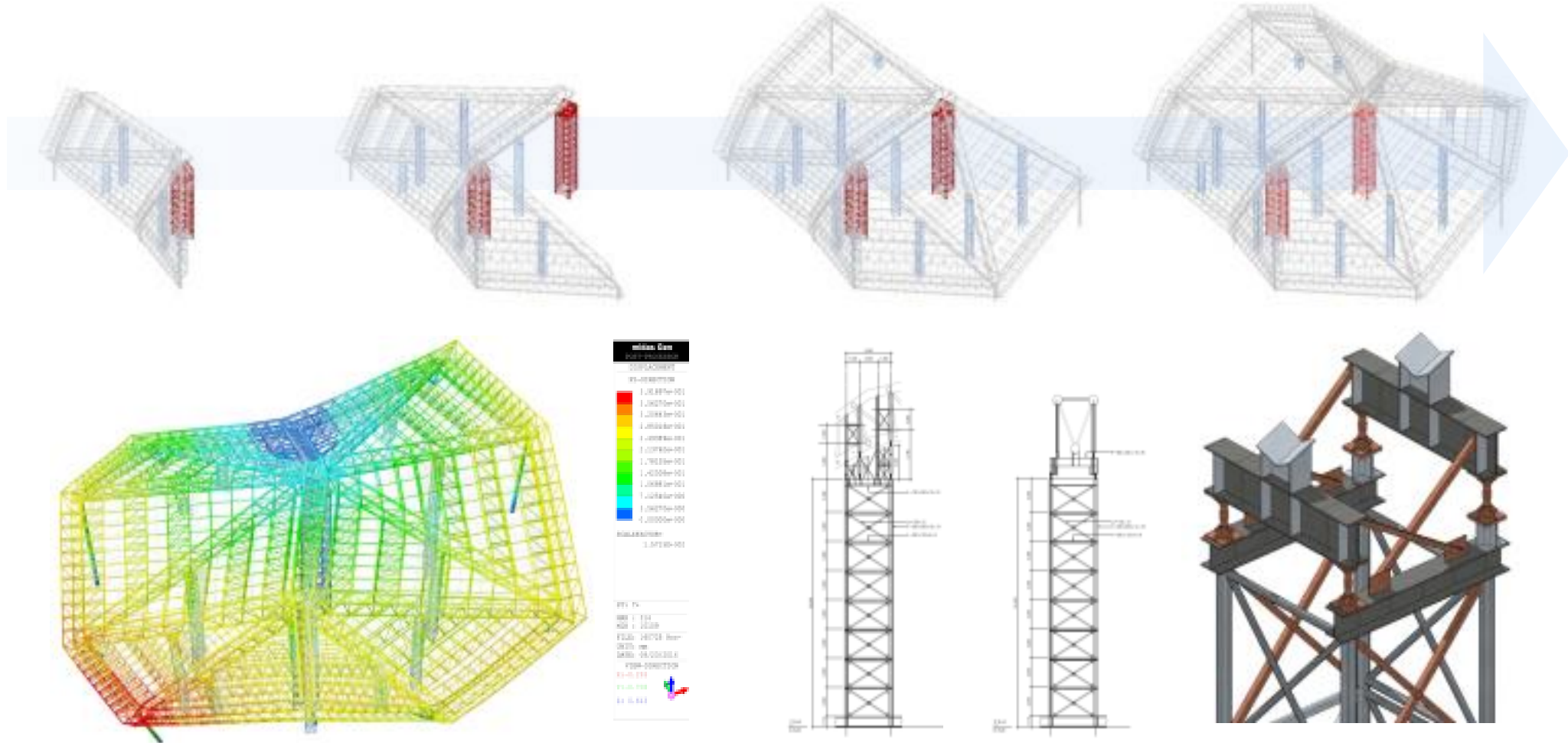
Structural Model



Structures System of Building and Roof







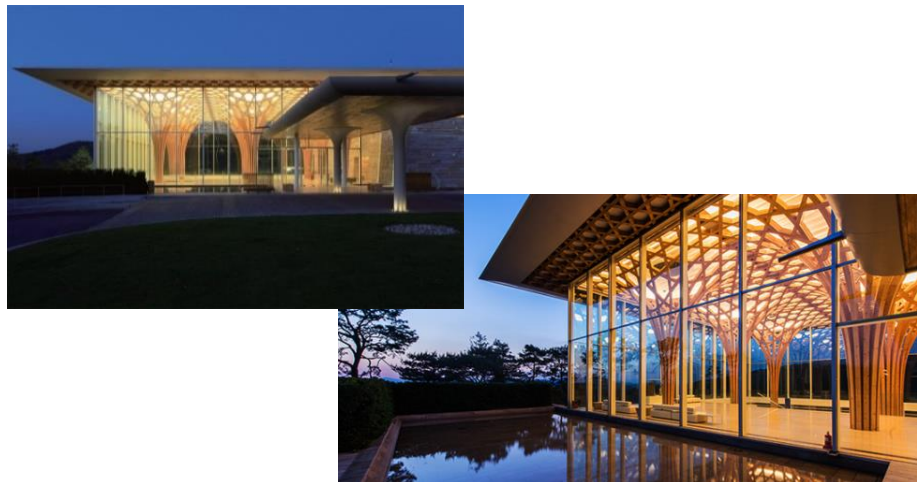
여주 나인브릿지 (해슬리, 햄릿)

여주시, 2018년

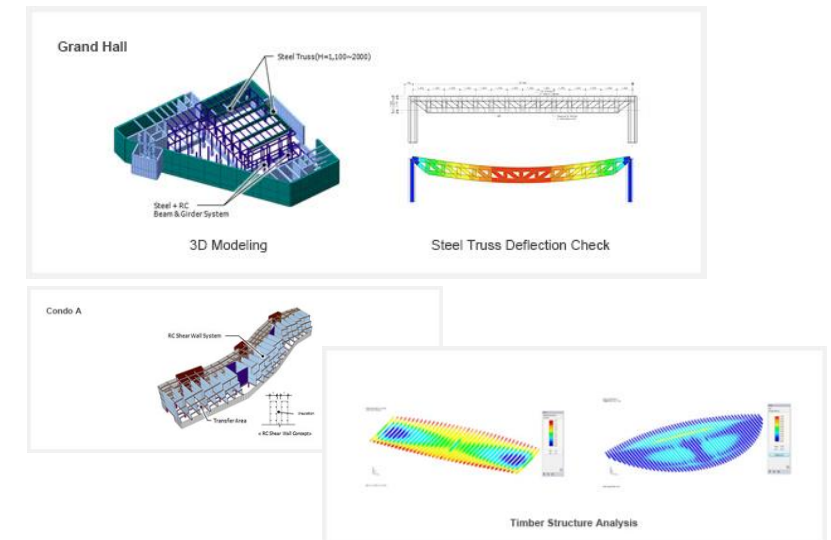


- Work Scope: Structural Design
- Location: Yeosu, Korea
- Occupancy: Club House, Condominium
- Size: 22,528.759m² Grand Hall (B2F~B1F), Condo A (B2F~2F), Learning Center (B2F~3F), Recreation Center (B1F~2F)
- Structure System: Grand Hall (RC Beam & Girder + Timber), Condo A (RC Shear Wall + Timber), Learning Center (RC Beam & Girder + Steel truss + Timber), Recreation Center (RC Beam & Girder + Timber)
- Client: CJ E&C
- Architecture: Gansam

Building View



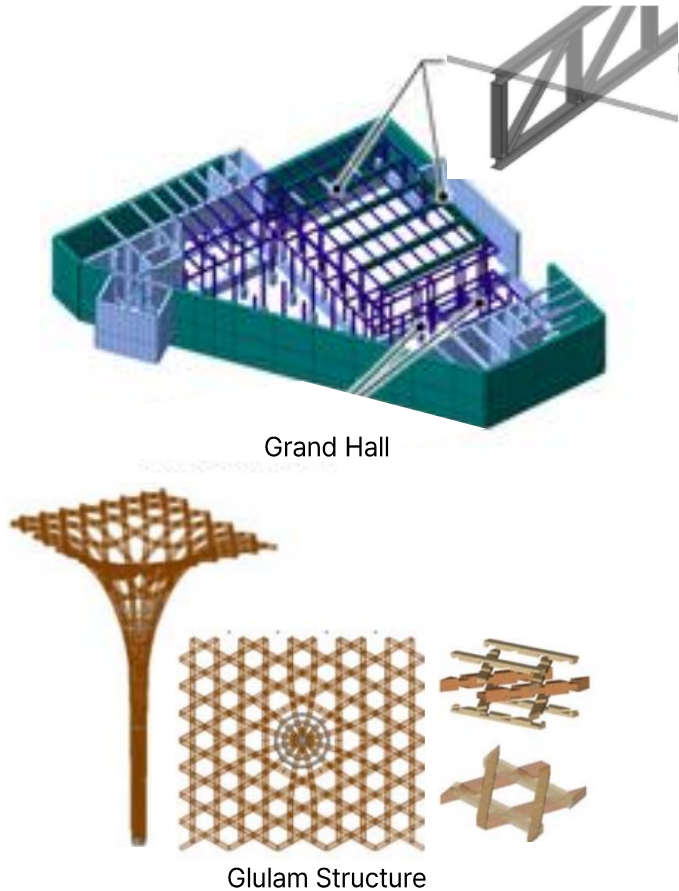
Structural System



여주 나인브릿지 (해슬리, 햄릿)

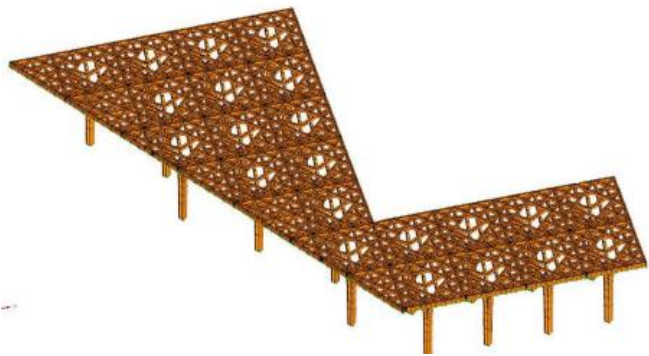
Structural System

구 분	콘크리트 구조	철골구조	목구조
형 상			
특 징	<ul style="list-style-type: none"> 일체화 구조로 내구성과 진동 성능이 우수함 일반적인 시스템으로 시공성이 우수함 	<ul style="list-style-type: none"> 건식 공법으로 시공이 간편하며 품질이 균일함 장스팬 구현이 가능하며 고소 작업이 가능함 	<ul style="list-style-type: none"> 기존 클립하우스와 동일한 일체감 부여 가능함 하중 흐름과 나무결 방향을 고려한 집성목* 적용
선 정	○	○	○
적용위치	일반 모듈 구간	장스팬 및 고소 구간	로비 및 임원식당

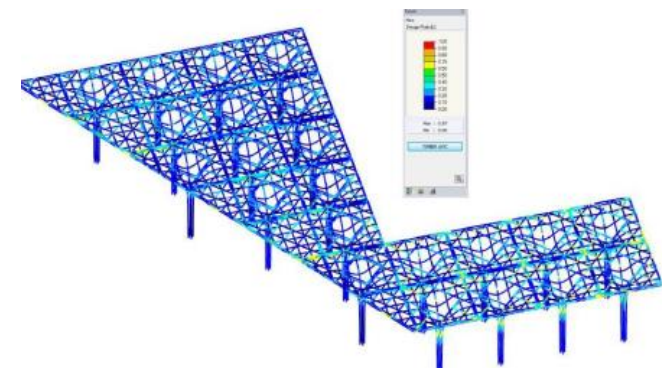


여주 나인브릿지 (해슬리, 햄릿)

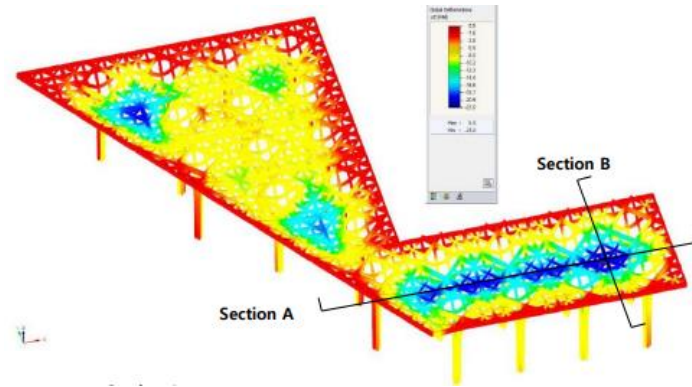
Analysis of Timber Structure



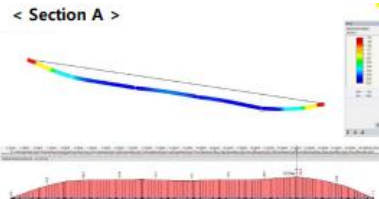
Analysis Model



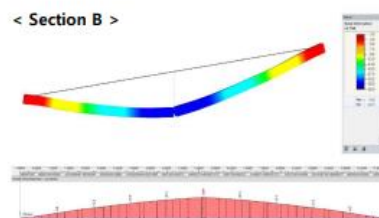
Stress Analysis



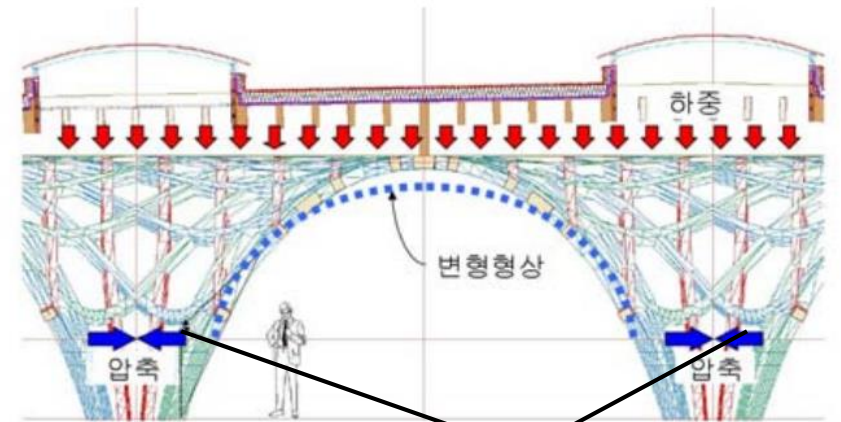
Deflection Analysis



Span = 26700mm
 $\delta_{D+L} = 22.9\text{mm}$
 $L/1165 < L/300 \rightarrow \text{O.K.}$



Span = 11270mm
 $\delta_{D+L} = 22.9\text{mm}$
 $L/492 < L/300 \rightarrow \text{O.K.}$



Buckling : Reinforced by Pipe & Ring

<Deformation Shape of Glulam structure>