

TextileRoofs 2024

# The First ETFE Foil Structure Using 500 $\mu$ m ETFE Cushions and 600 $\mu$ m PTFE Fiberglass in Japan; A Brief Overview of the Histories of MSAJ and the Criteria in Japan

Yoshinaka Iizuka  
Kyoritsu Industries  
April, 2024

## Personal History

- Graduation from Department of Electronics, School of Science and Technology, Meiji University, 1972
- Working at All Nippon Airways as Avionics Engineer from 1972 to 1984
- Working at Kyoritsu Industries as CEO from 1984 to 2021
- Working at Kyoritsu Industries as Chairman & Engineering Advisor from 2021
- Participating at MSAJ as Board Director from 2003
- Participating at MSAJ as Chairman of Dissemination and Information Committee from 2003 to 2022
- Participating at MSAJ as Member of Quality and Technology Committee from 2022

## History of Design Criteria in Japan

- 1966 Tent Structure Research Group Establishment
- 1970 Osaka EXPO 70 (Air Supported Dome, Air Inflated Structure)
- 1971 Temporary Pneumatic Structure Design Recommendation
- 1979 Tent Warehouse Design Criteria ( 2002)
- 1985 Tsukuba EXPO 85 (Frame Structure, Tension Structure)
- 1987 Building Standards Law, Notice: Specific Membrane Structure Design Criteria ( 2002); **succeeded by current criteria**
- 1987 Building Standards Law, Notice: Small & Medium Membrane Structure Design Criteria( 2002) ; **succeeded by current criteria**

## History of Design Criteria in Japan

- 1988 Tokyo Dome (Air Supported Dome with PTFE)
- 2002 Membrane Structure Design Criteria (Building Standards Law Notification No. 666) **Excluding ETFE**
- 2002 Tent Warehouse Design Criteria (Building Standards Law Notification No. 667) **Excluding ETFE**
- 2017 Membrane Structure Design Criteria (Building Standards Law Notification No. 666) **Including ETFE**
- 2017 Tent Warehouse Design Criteria (Building Standards Law Notification No. 667) **Including ETFE**

## History of MSAJ(Membrane Structures Association of Japan)

- 1966 Established as the Tent Structure Research Group
- 1972 Changed the name of the Group to MSAJ
- 1978 Officially Established as Membrane Structures Association of Japan(MSAJ)
- 1987 Certification for Specific Membrane Structure( 2002)
  - ü Design Criteria, Design Assessment, Performance Judgement
  - ü Registration for Membrane Materials and Periodic Inspection Engineer

## History of MSAJ

- 2002 Performance Evaluation Service for Membrane Structures
- 2007 Performance Evaluation Organization by MLIT (Ministry of Land, Infrastructure, Transportation and Tourism) for Membrane Structures
- 2009 Type Conformity Certification for Membrane Structures by MLIT

## General Information about MSAJ

- Regular Member
  - ü Category 1(Fabricator): 19
  - ü Category 2(Supplier): 16
  - ü Category 3(Academic Experience): 94
  - ü Category 4(General Contractor): 6
- Affiliate Member: 1
- Board of Directors: 13  
(3 Fabricators, 2 Suppliers, 8 Others)

## Quality Assurance by MSAJ

- Committee System for Assuring and Improving the Quality
- Organizing the Technical Standards
- Membrane Processing Factory Registration System
- Periodical Inspection System/Periodical Inspection Engineer Registration System
- Membrane Construction Management Engineer Registration System

## Quality Assurance by MSAJ

- Membrane Processing Factory Registration System
  - ü Category 1 (Fabricator) of Regular Member must register own factory to Membrane Processing Factory Registration System
  - ü The Registration System categorizes into Advanced Level and Standard Level.
    - Registered Advanced Level & All Membrane Materials including ETFE : 2 Members
    - Registered Advanced Level & All Membrane Materials excluding ETFE: 1 Member

## Quality Assurance by MSAJ

- Membrane Materials(Typical Materials)
  - ü Type A(PTFE Coated Fiber Glass)
  - ü Type B(PVC Coated Fiber Glass)
  - ü Type C(PVC Coated Polyester)
  - ü For Tent Warehouse(PVC Coated Polyester)
  - ü Structural Film(ETFE)

Kyoritsu Proprietary

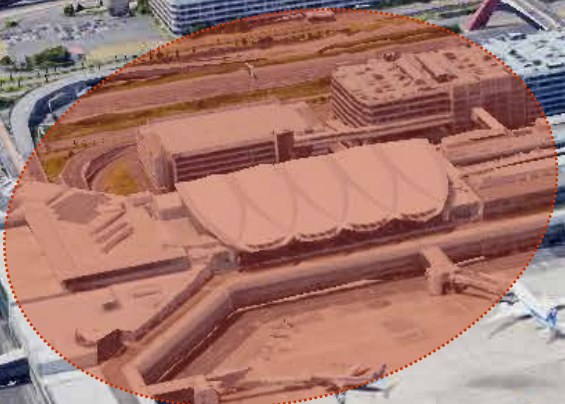


# Tokyo International Airport ETFE Foil Structure



T3 International

T1 Domestic



T2 Domestic + International



## General Information

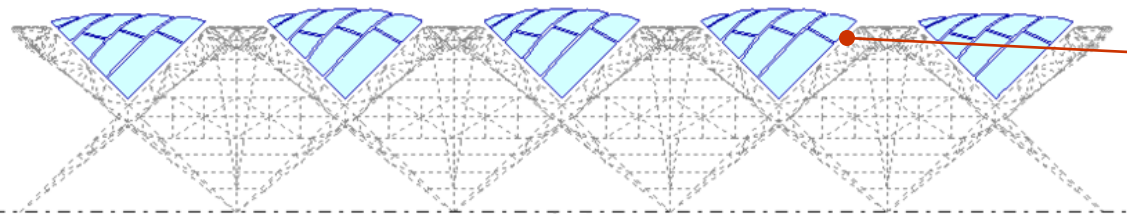
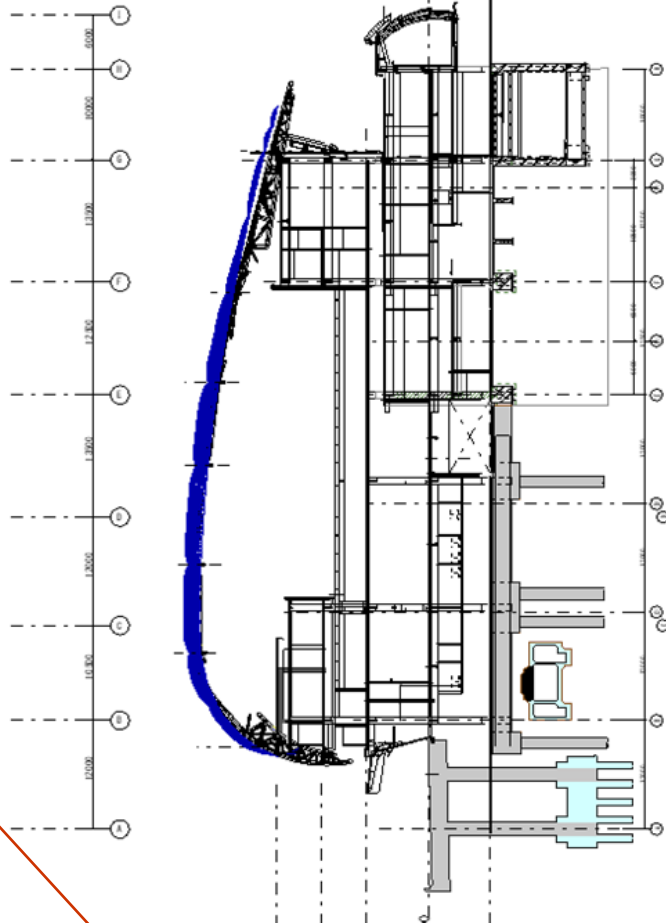
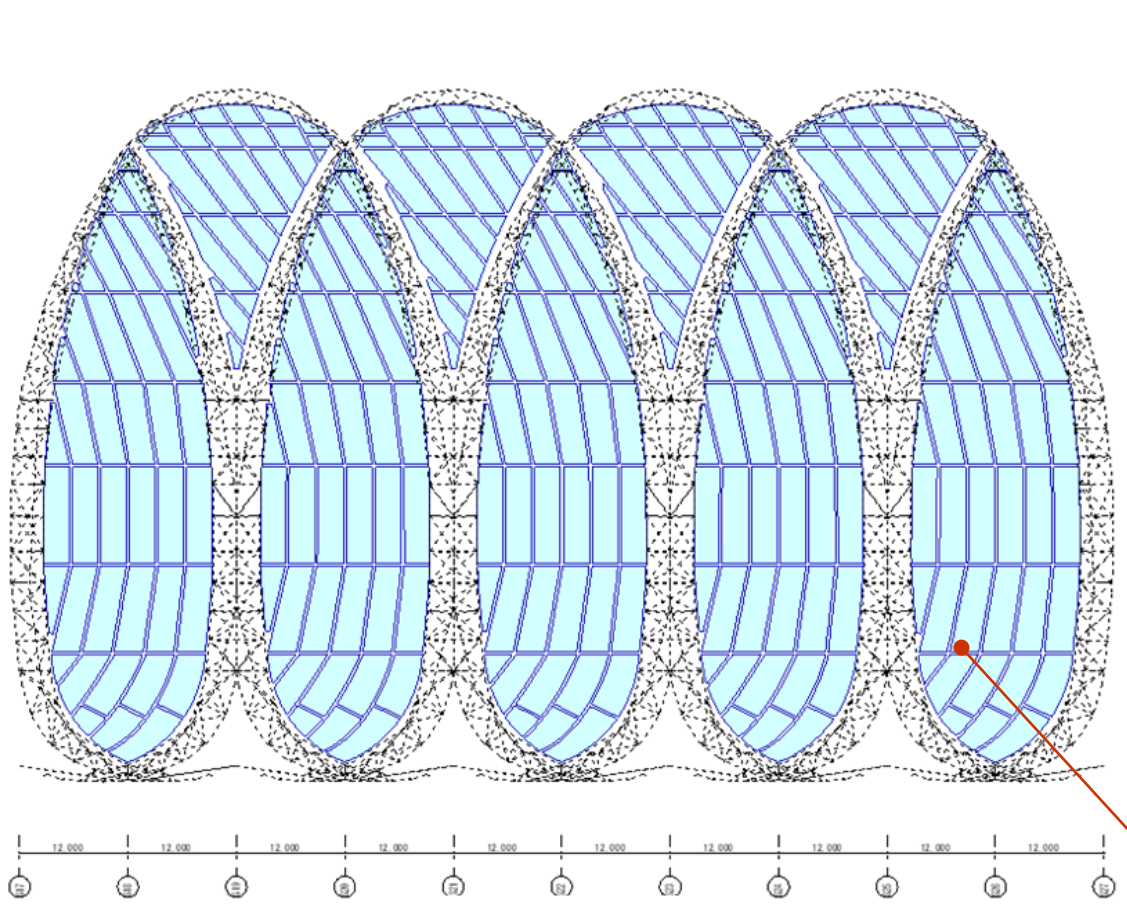
- Name: International Flight Facilities
- Owner: Japan Airport Terminal Co., Ltd
- Area of Extension: Approx. 66,000 m<sup>2</sup>
- Main Use: Airport passenger terminal facilities
- Floors: 5 above-ground floors & 1 basement floor
- Operator: Tokyo International Air Terminal Corporation

Continued on Next Page



- Design Contractor: Azusa, Yasui, PCPJ Tokyo International Airport Terminal 2 International Flight Facilities Construction Design and Supervision Joint Venture
- Construction Contractor: Taisei Corporation
- Membrane Contractor: Kyoritsu Industries Co., Ltd

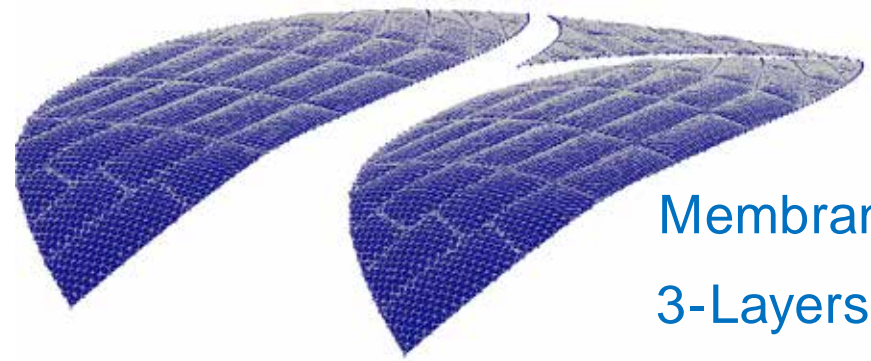
# Overview of Membrane Roof Structures



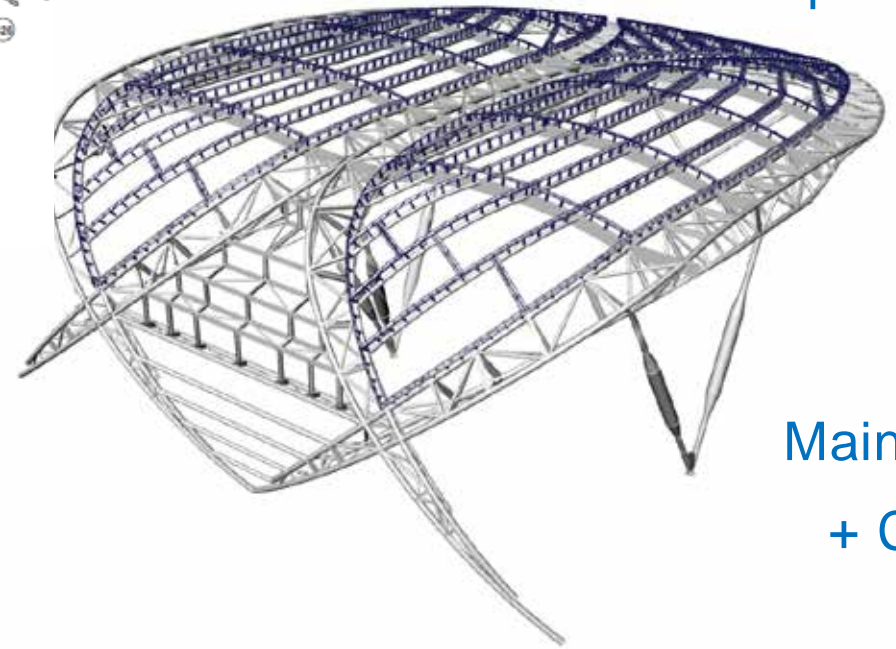
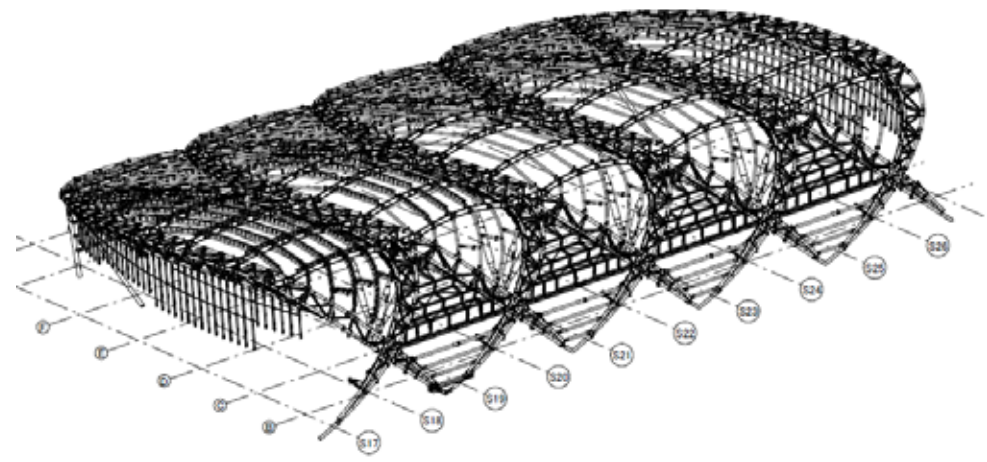
- Area of Membrane Roof : 6,474m<sup>2</sup>
- 3-Layers Cushion Panel : 318 EA

# Structural system

Area of Membrane Roof : 6,474m<sup>2</sup>  
3-Layers Cushion Panel : 318 EA

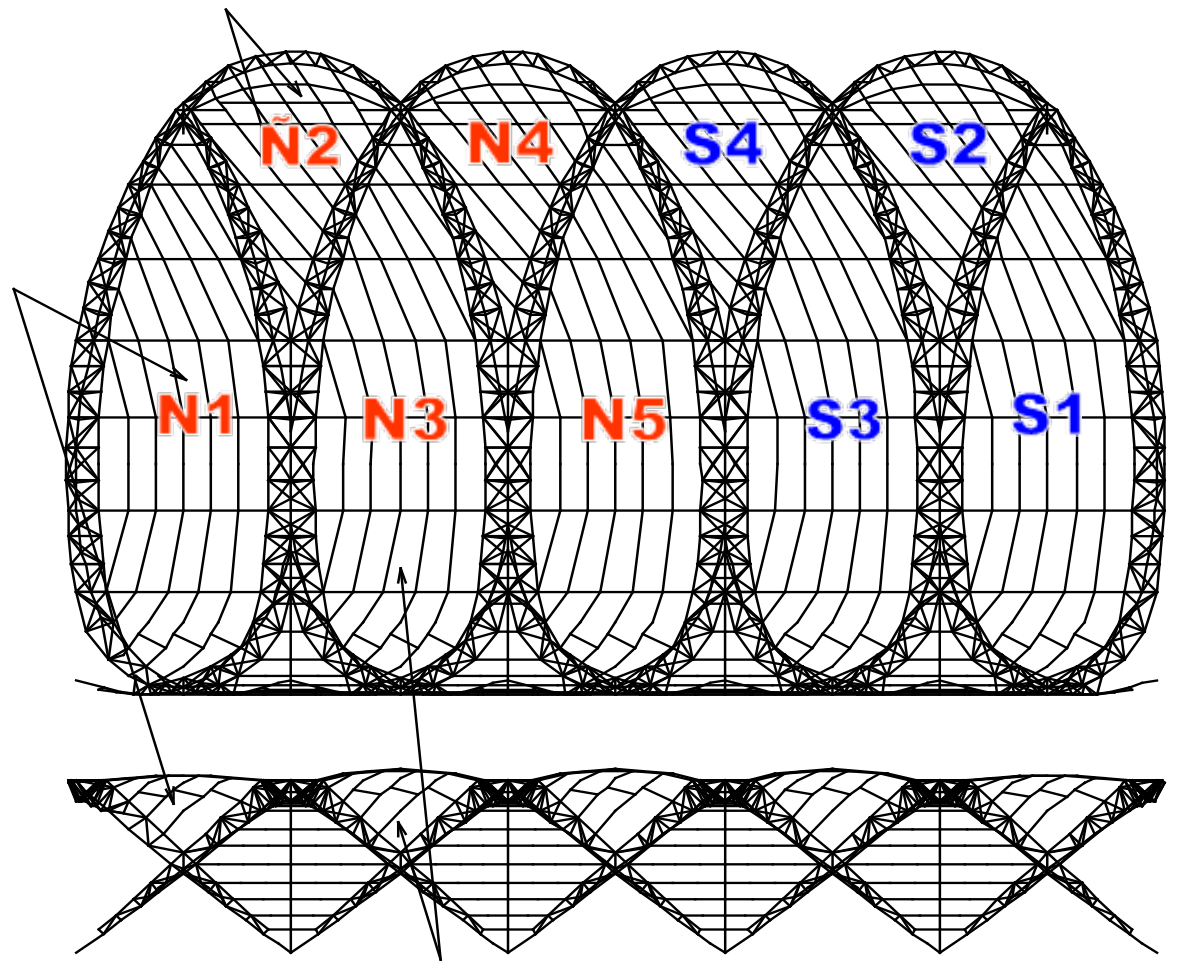


Membrane Roof  
3-Layers Cushion  
(ETFE+PTFE+ETFE)  
500 μ m + 600 μ m + 500 μ m



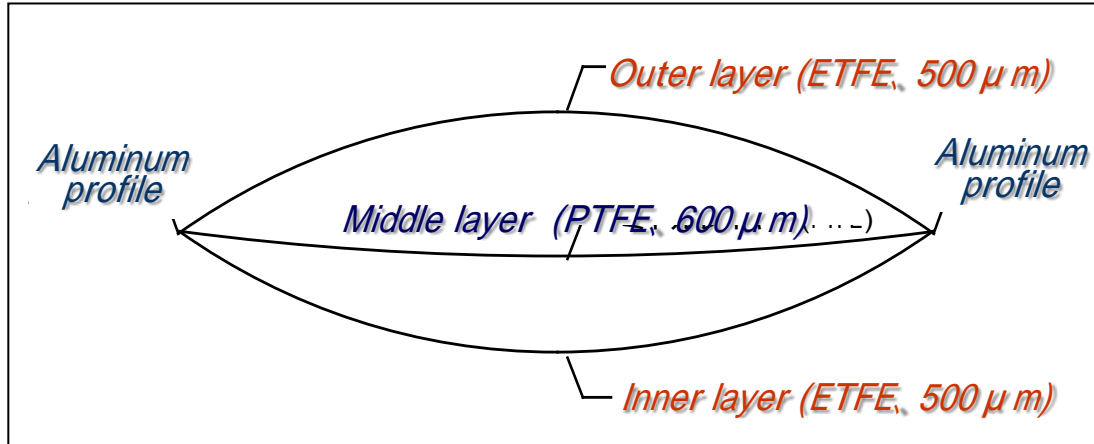
Main Steel Frame  
+ Clamp Base

# Review Model of ETFE Cushion Type Membrane Roof



- General Parts Review Model
- Outer Parts Review Model

## Tripple Layers Cushion Panel



- ETFE 500 μ m:  
Maximum Stress < Allowable Stress
- PTFE 600 μ m:  
Prevention for Penetration of Embers and Sparks  
in accordance with Japanese Building Standards Law

# Tripple Layers Cushion Panel

## Material Properties and Allowable Stress

- AGC ETFE 500  $\mu$  m:

Material	Direction	Young`s Modulus (N/mm <sup>2</sup> )	Standard Strength (N/cm)	Allowable Stress (kN/m)		
				Long Term	Snow Load	Wind Load
ETFE film(500 $\mu$ m)	Machine Dir.	800	70	3.5	6.3	8.4
	Transverse Dir.					

- Standard Strength : Stress in Strain 2.5% ( MD & TD : 14N/mm<sup>2</sup>)
- Allowable Stress[Long Term] : Standard Strength  $\times$  0.5 times
- Allowable Stress[Snow Load] : Standard Strength  $\times$  0.9 times
- Allowable Stress[Wind Load] : Standard Strength  $\times$  1.2 times

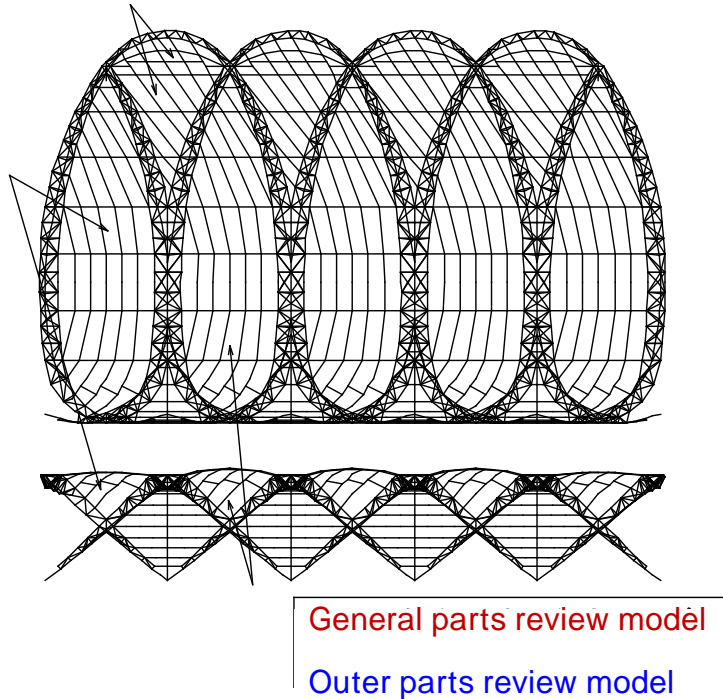
# Tripple Layers Cushion Panel

## Material Properties and Allowable Stress

- PTFE 600  $\mu$  m Sheerfill-V:

Direction	Tensile Stiffness	Standard Strength	Allowable Stress (kN/m)
	(kN/m)	(N/cm)	Short-Term
Warp	1686.7	979	24.5
Fill	1045.4	1044	26.1

## Review Condition



## Internal Pressure

- $Ip1 = 300 \text{ Pa}$  (Constant mode)
- $Ip2 = 1100 \text{ Pa}$  (Snow load mode)
- $Ip3 = 600 \text{ Pa}$  (Wind load mode)

## Load Condition

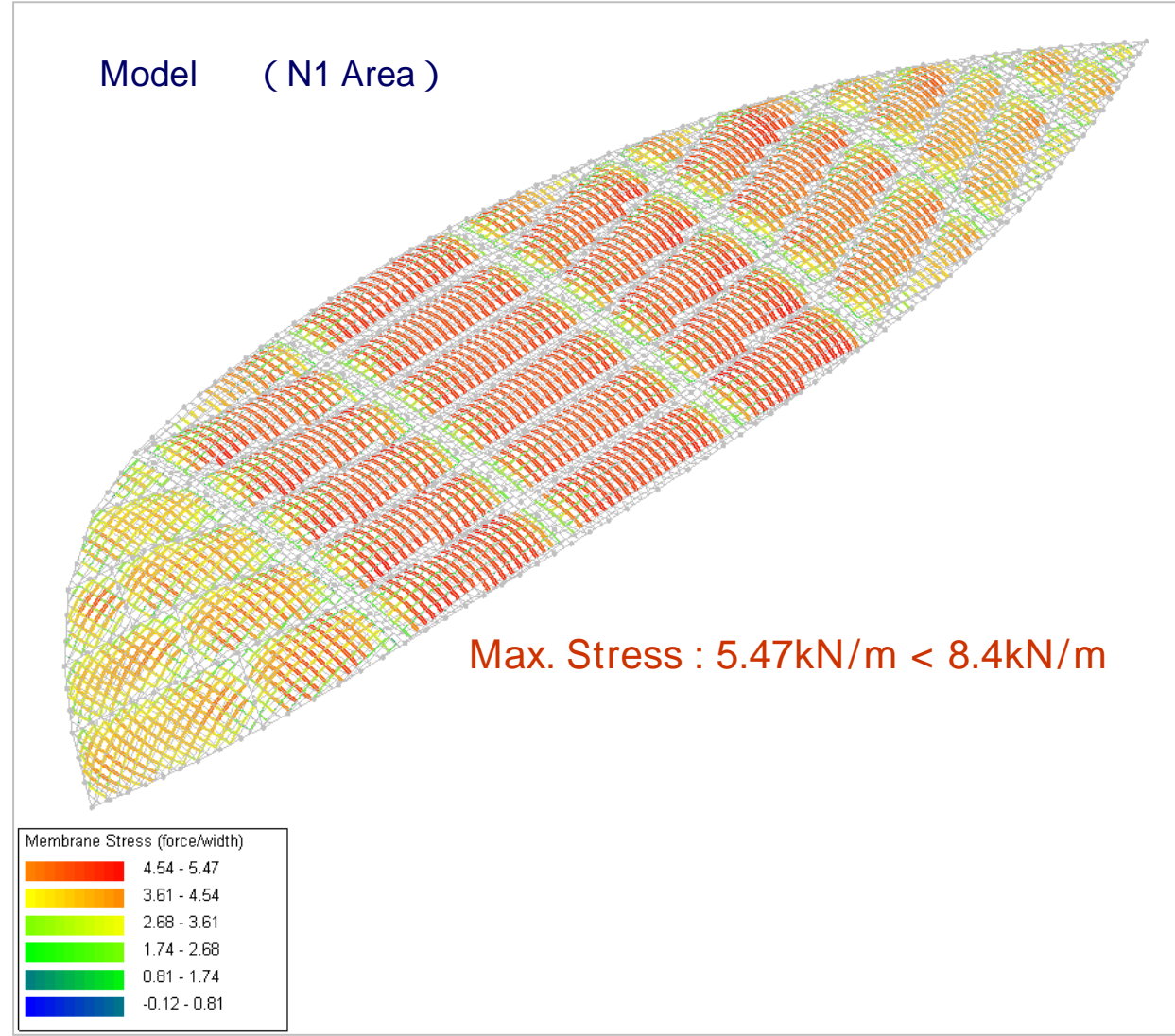
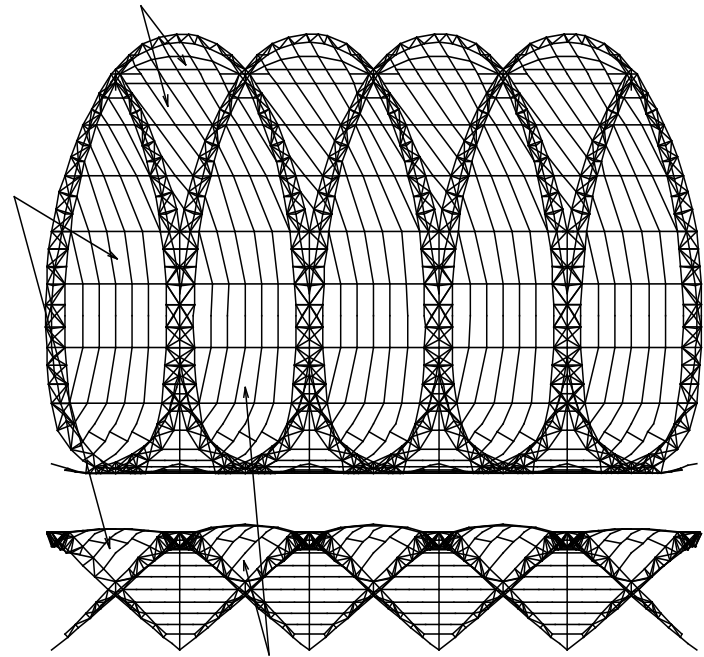
- Dead Load :  $0.01 \text{ kN/m}^2$
- Snow Load :  $1.075 \text{ kN/m}^2$  (Return Period of 500 Years)
- Wind Load(Peak):
  - $-3.2 \text{ kN/m}^2$  (Upper Side of Outer Parts)
  - $-1.1 \text{ kN/m}^2$  (Lower Side of Outer Parts)
  - $-2.1 \text{ kN/m}^2$  (Upper Side of General Parts)
 ( through the wind tunnel experiment )
- Max. Displacement :
  - $-1.0 \text{ kN/m}^2$  (Outer Parts)
  - $-1.0 \text{ kN/m}^2$  (General Parts)

## Analysis Condition

- $PV = \text{Const.}$  (According to the Boyle Charles Law, Wind load)
- $P = \text{Const.}$  (Dead load & Snow load)
- Analysis software : EASY (TechNet GmbH)

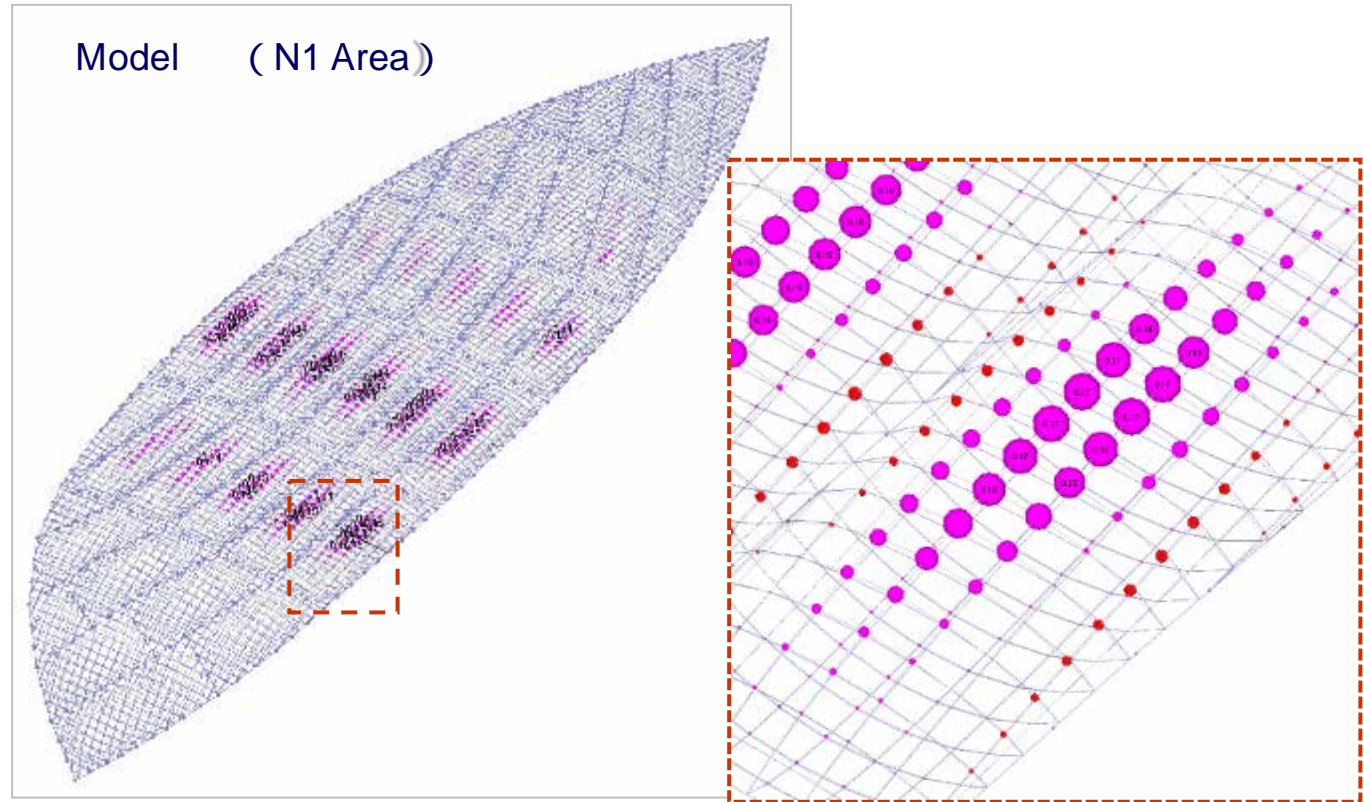
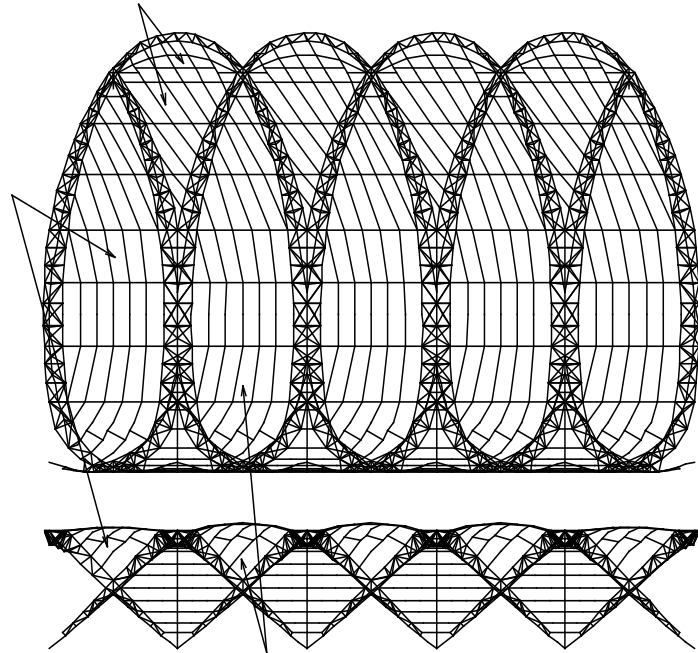
# Stress Results of Membrane Surface

- ✓ Under Wind Load(Uplift)  
Pressure : 600Pa  
(PV= Const.)



# Deformation Results of Membrane Surface

✓ Under Snow Load  
Pressure : 1100Pa  
(P = Const.)



Max. disp. :  $0.173\text{m} / 3.391\text{m} = 1 / 19.6 < 1 / 10$

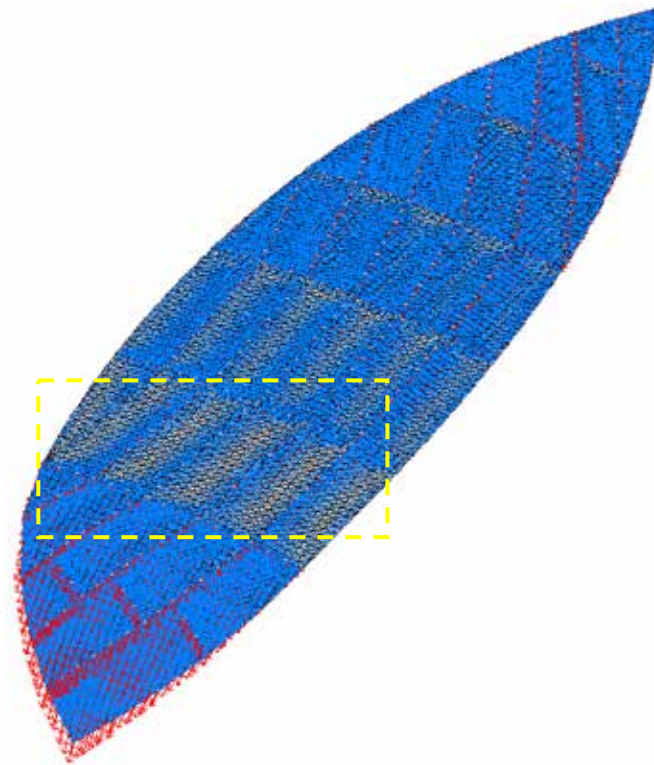
# Review for Fail-Safe by Middle Layer

Case 1  
When all systems of the pressurized air supply are inoperative in south and/or north sides,

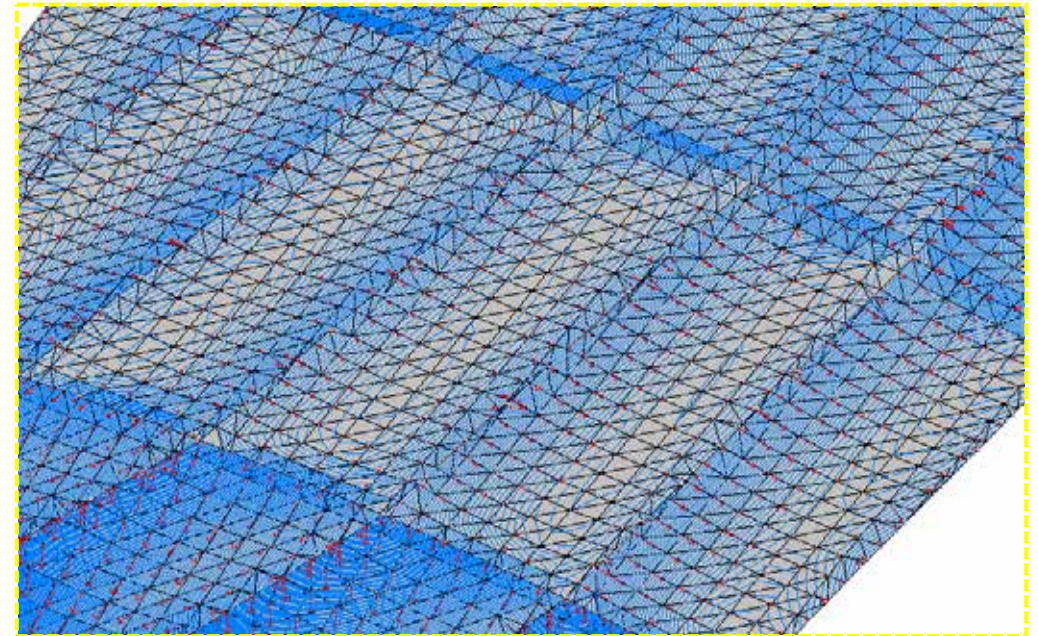
or

Case 2  
When ETFE membranes are broken due to excessive loads or a natural disaster

Model ( N1 Area )

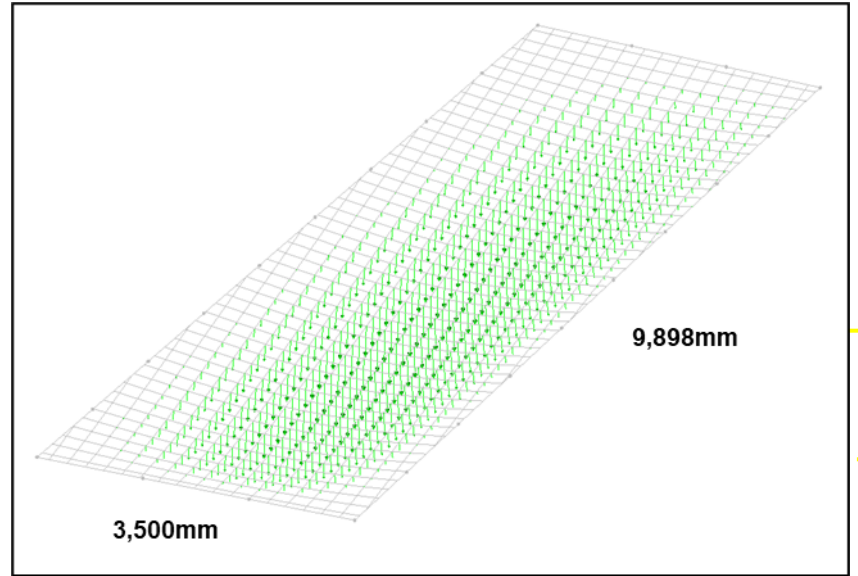


Confirmation of the ponding phenomenon using contour lines

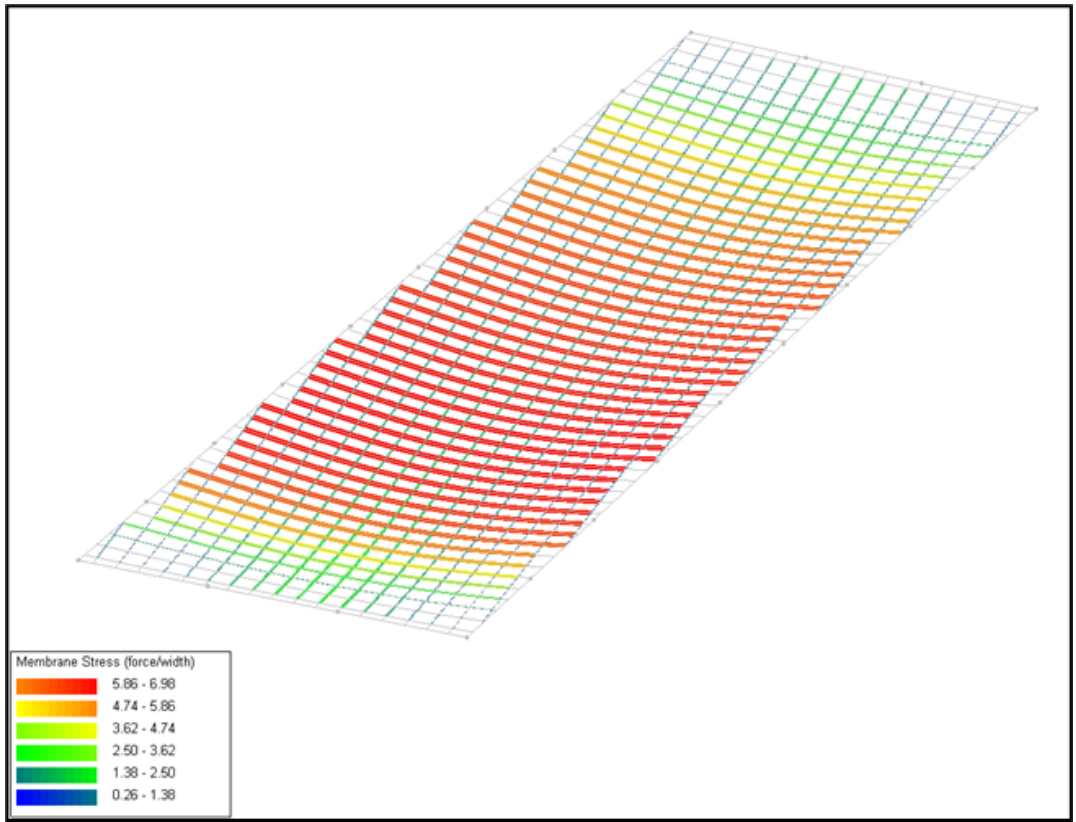


# Review for Fail-Safe by Middle Layer

[Case 1] Review of the maximum stress on the middle layer(PTFE membrane)



Load Condition : rainwater weight in time

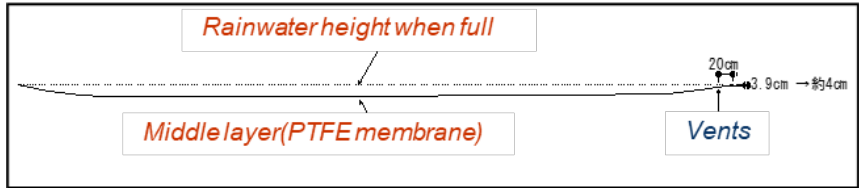


Max. Stress : 6.98kN/m < 24.48kN/m

# Review for Fail-Safe by Inner Layer

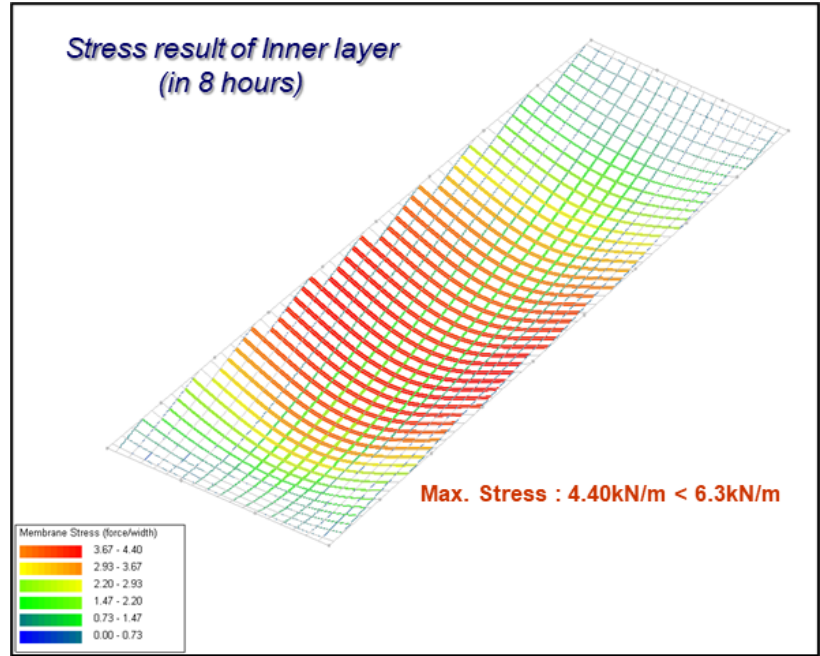
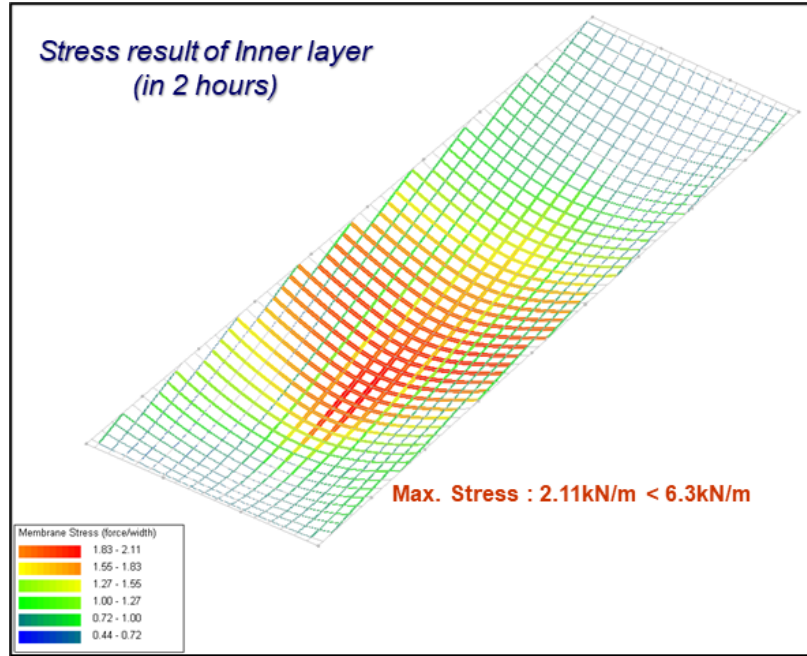
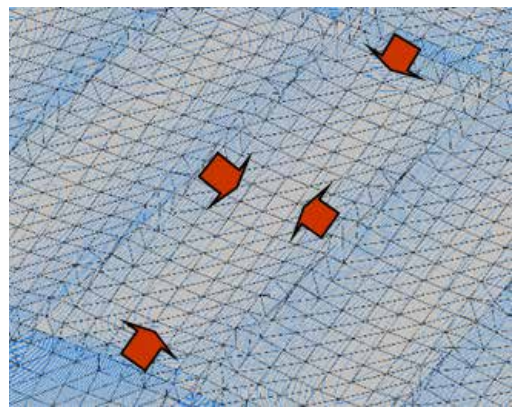
[Case 2] Review of the maximum stress on the Inner layer(ETFE film)

Load condition : Inflow of rainwater into the inner layer(ETFE film)

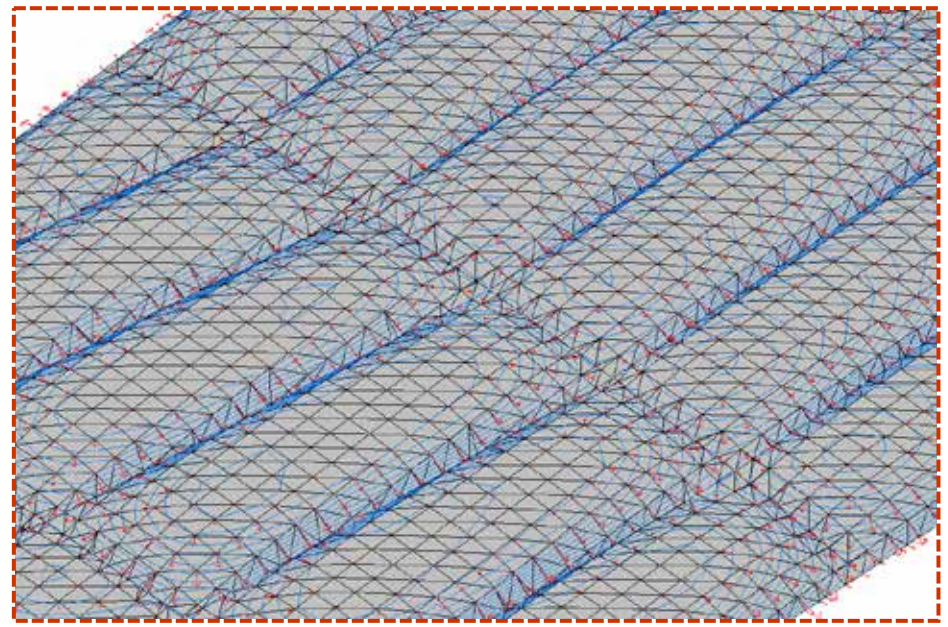
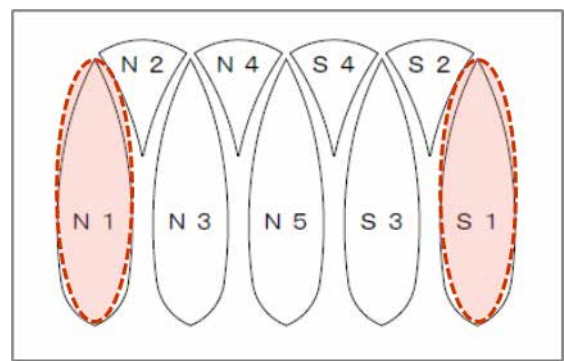
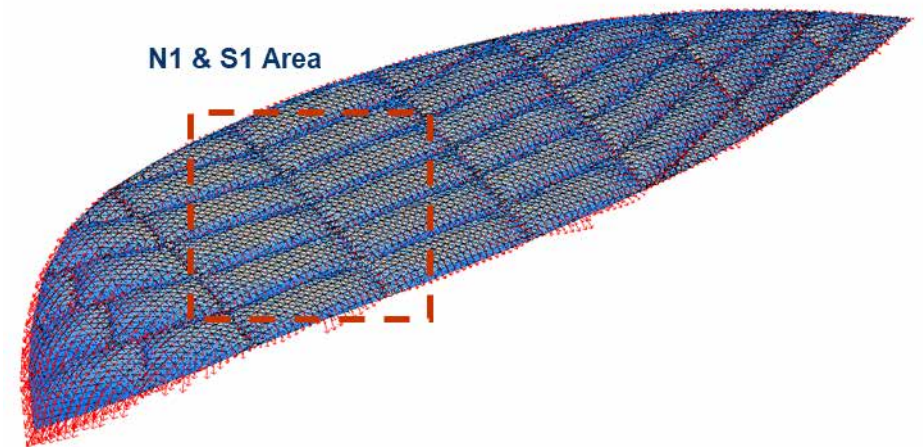


When the flooding occurs by rainwater on an inner layer after an outer layer is damaged.

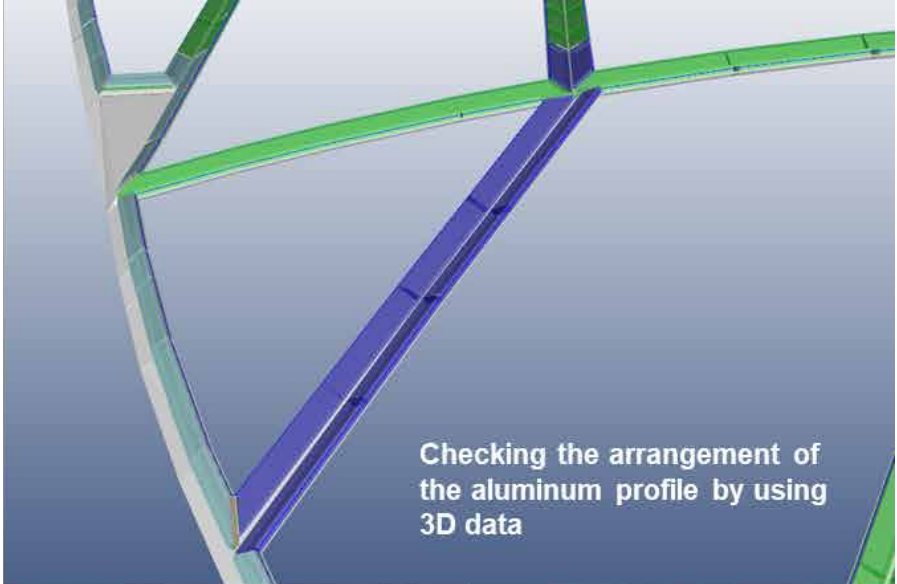
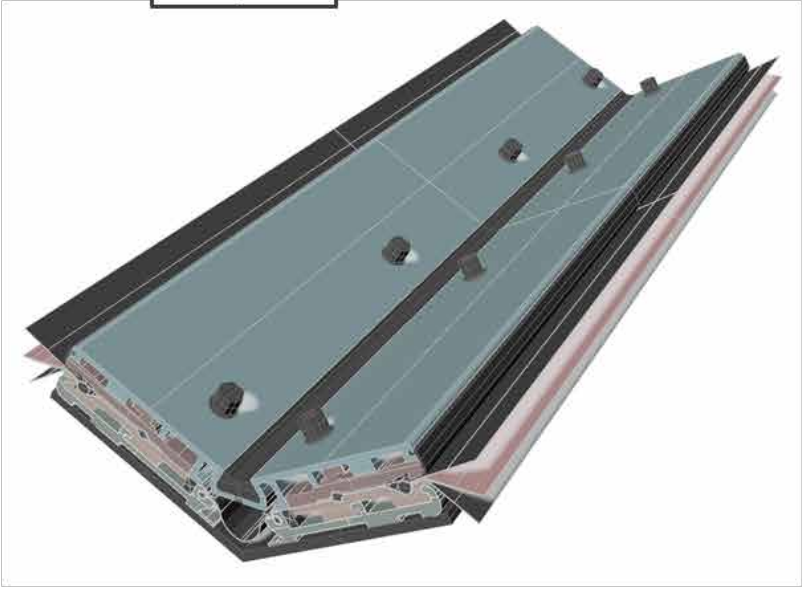
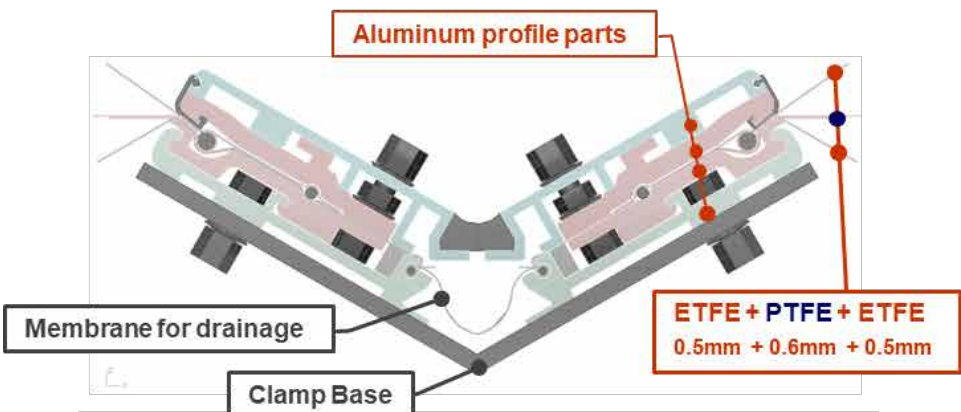
- $V = \sqrt{2gh} \rightarrow Q = \left(\frac{D}{2}\right)^2 \cdot \pi \cdot V = 0.25m^3/s$
- $W(\text{water load}) = Q \times h(\text{hour}) \times 10 \text{ kN/m}^3$



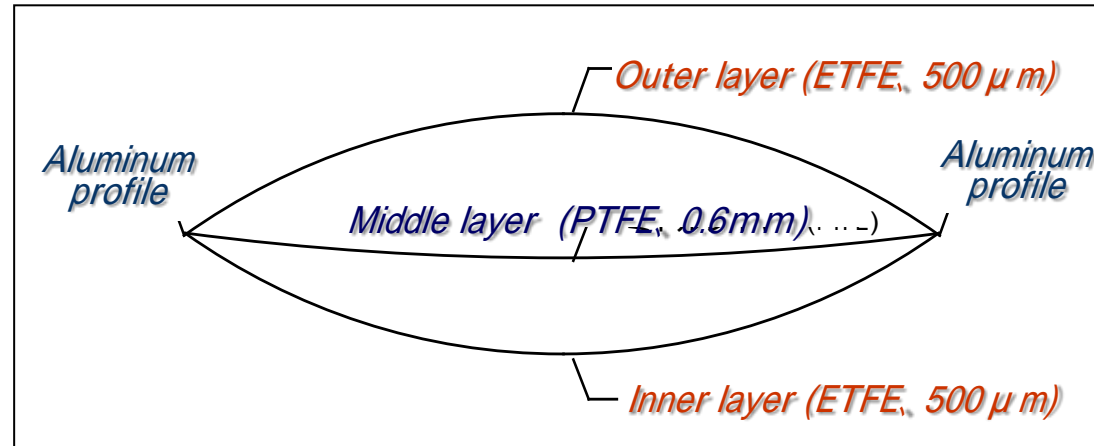
# Drainage Plan for Membrane Roof (under Snow Load)



# Aluminum Profile Detail



## Environmental Data of Triple Layers Cushion



### Outer Layer

ETFE Film 500 μ m thickness  
High Reflection + White Design Print

### Middle Layer(Non-Flammable)

PTFE Coated Fiberglass 600 μ m thickness

### Inner Layer

ETFE Film 500 μ m thickness  
White Design Print

### Thermal Insulation

Heat Transmission Coefficient  
1.7(W/m<sup>2</sup>K )

From MSAJ Report dated 2009

# Environmental Data of Triple Layers Cushion

## Light Transmission

Triple layers Light Transmission

2.4%

Outer Layer: Light Transmission 9% Light Reflection 59%

Middle Layer: Light Transmission 17% Light Reflection 72%

Inner Layer: Light Transmission 48% Light Reflection 50%

# Pressure Control System

## Fundamental Specification

Inflow Side - Pressure/Air Flow Control

## Main Pressure Control

Blower Speed Control by Electric Inverter

## Area Pressure Control

VAV(Variable Air Volume Control Valve)

N1 & N2, N3 & N4, N5, S1 & S2, S3 & S4

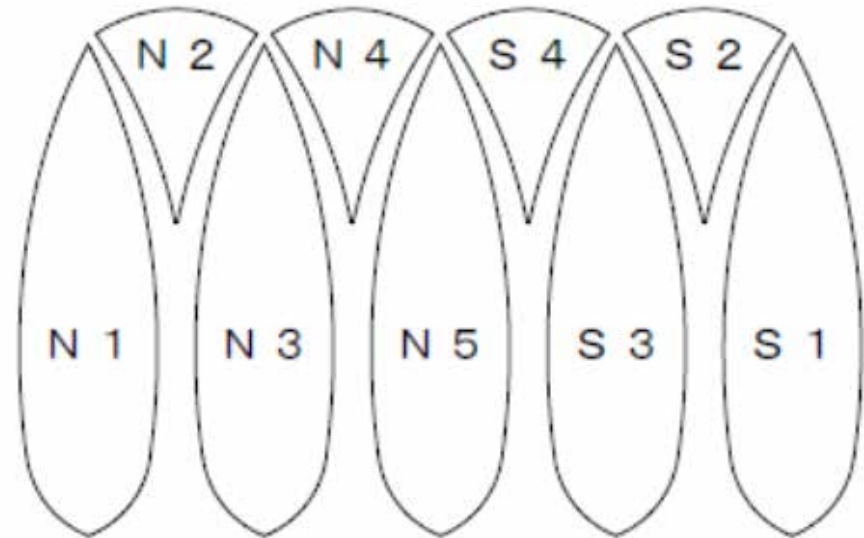
## Prevention for Condensation

Desiccant Dehumidifier

## Area Pressure Monitor

Total 9 Areas, N1 to N5 and S1 to S4, Monitored by Pressure Monitor Sensors

Prevention of Deflation by Shutoff Valve at Each Area



# Pressure Control System

Standard: 300Pa

(10 minutes average wind speed is under 16m/sec)

Strong Wind & Typhoon: 600Pa

Snow : 1100Pa

Design Maximus Pressure: 1500Pa

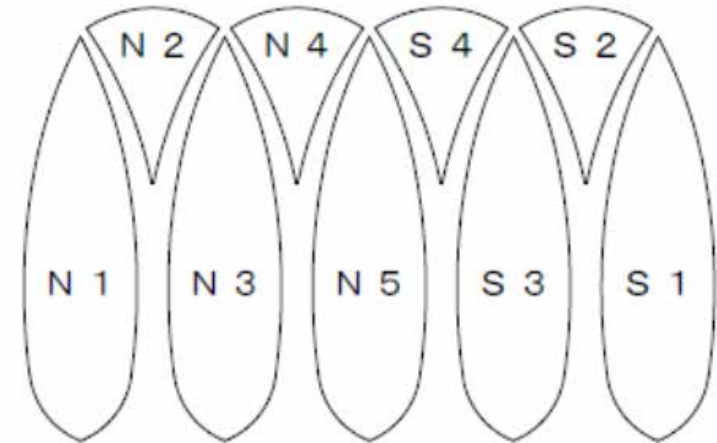
North Area(N1 to N5) : Main & Back Up

South Area(S1 to S4) : Main & Back Up

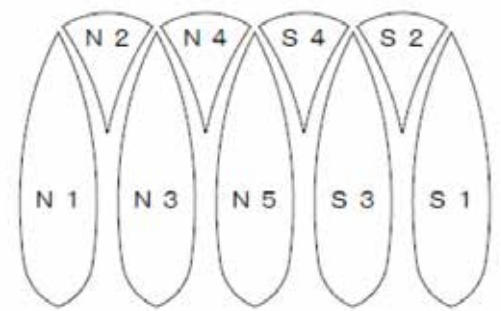
Control Instrument & Equipment:

PID, PLC, Inverter, Differential Pressure Sensor, VAV, Motor Damper

Anemometer, Snowfall Monitor

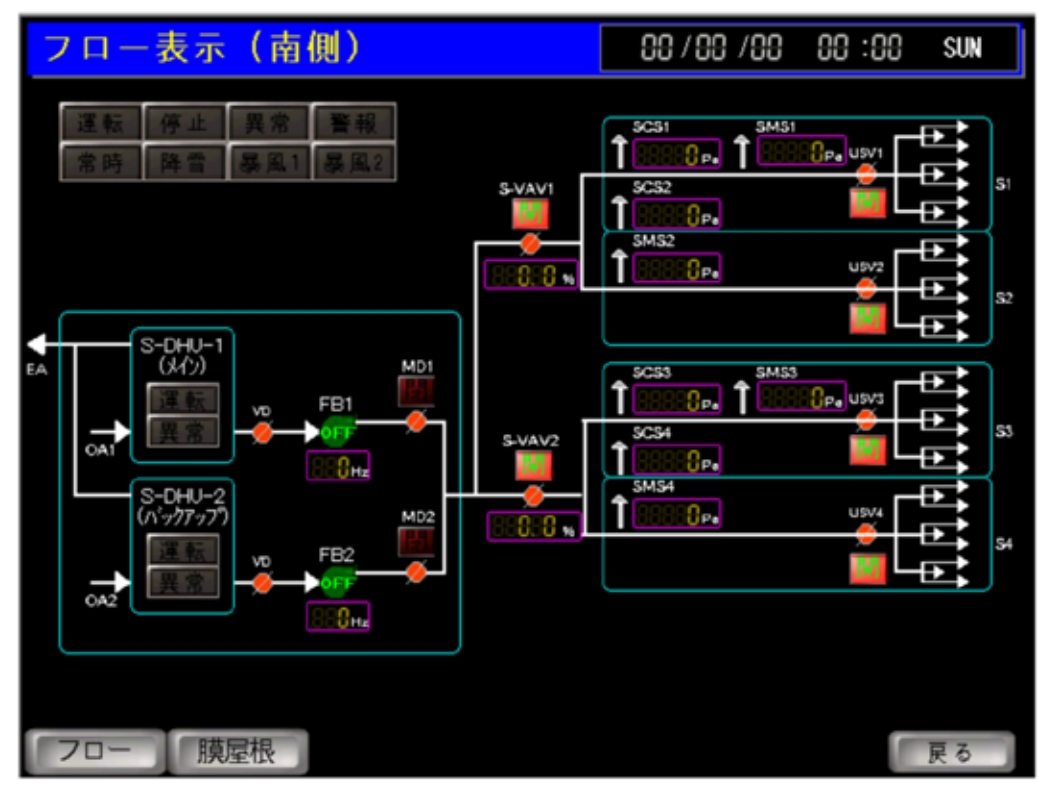
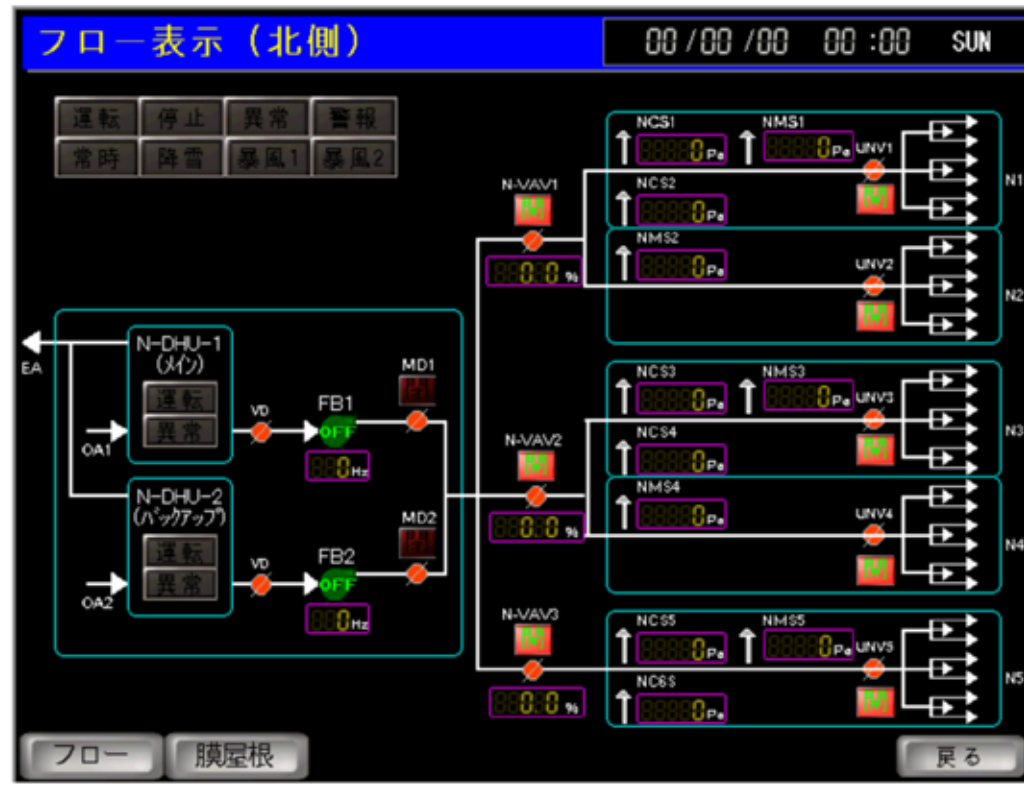


# Pressure Control System



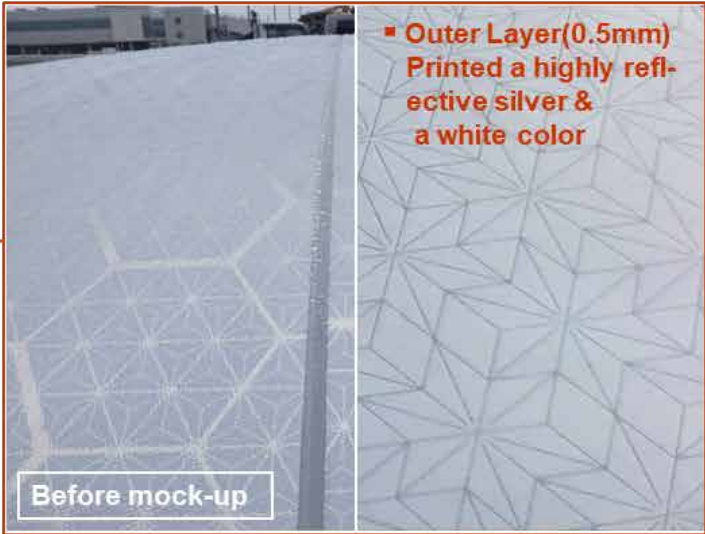
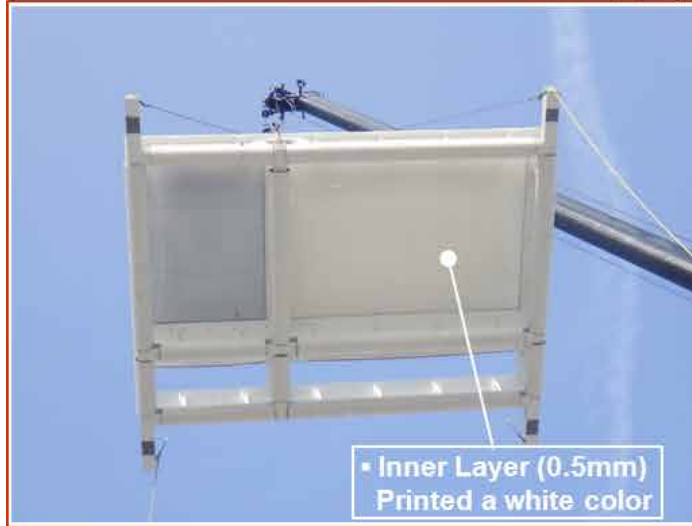
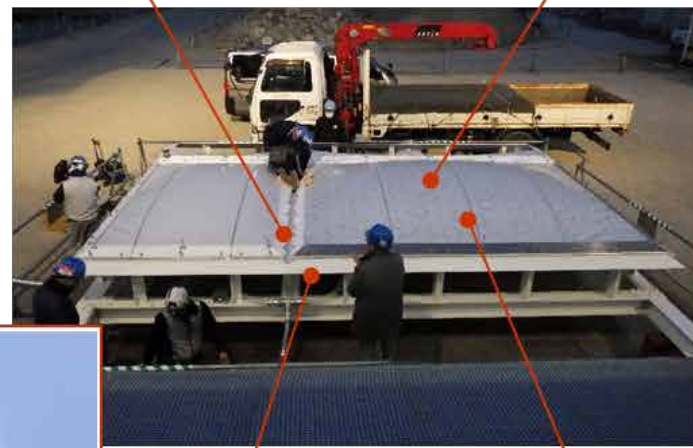
【フロー表示(北側)画面】 North

【フロー表示(南側)画面】 South

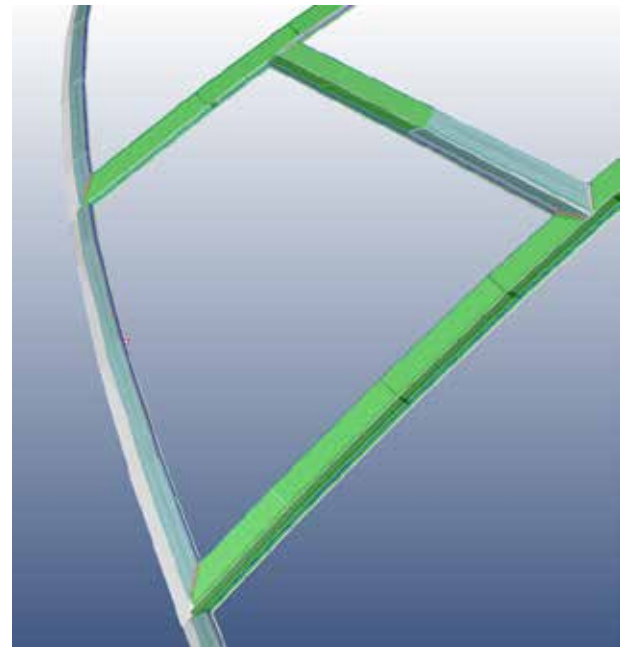
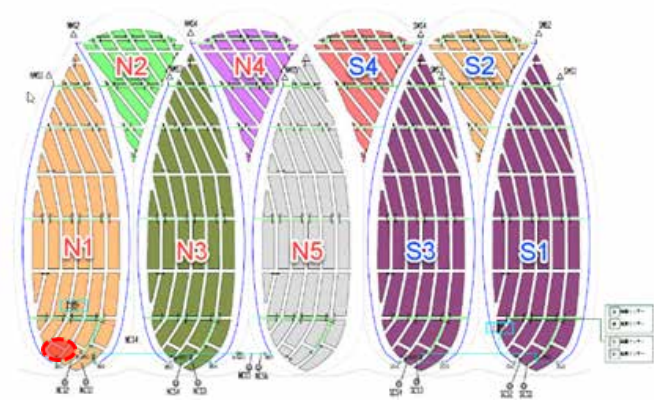


# Evaluations for ETFE Panel

## Checking Drain system, Safety & Interior color of ETFE Panel



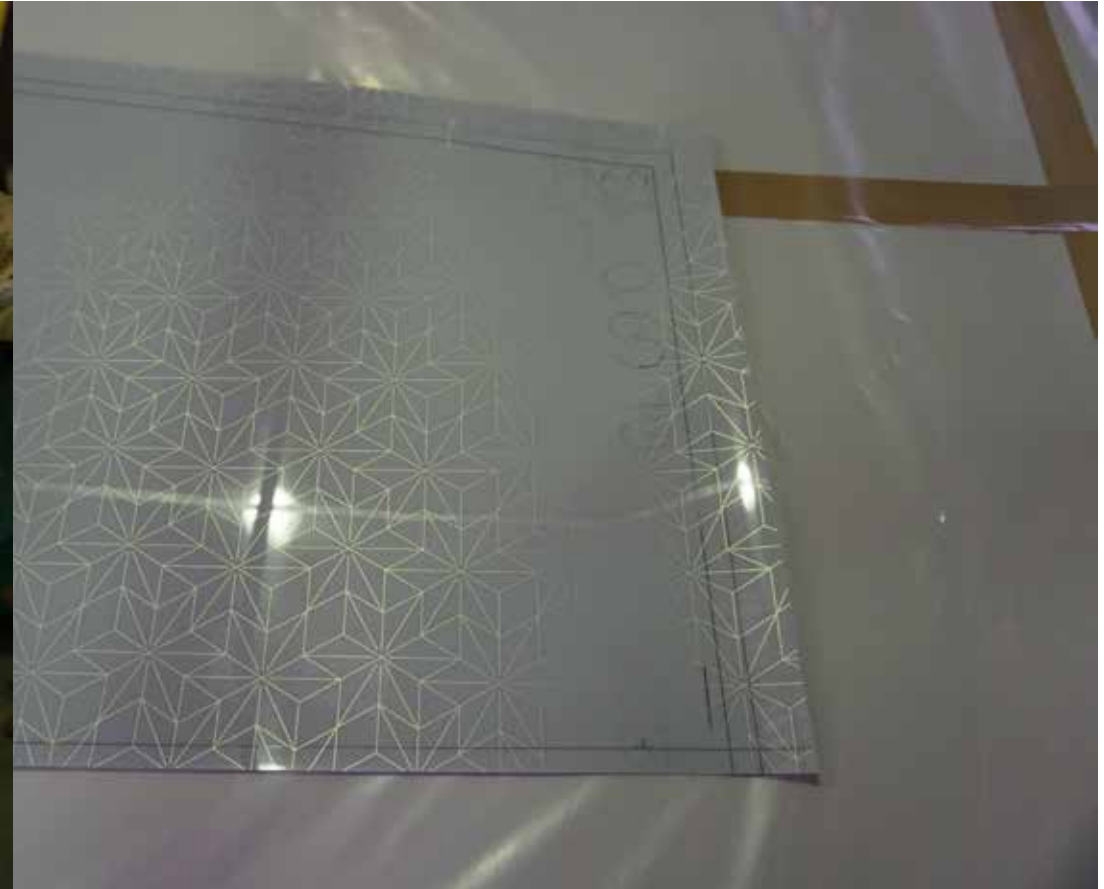
# Pre-Confirming Workability of Installation



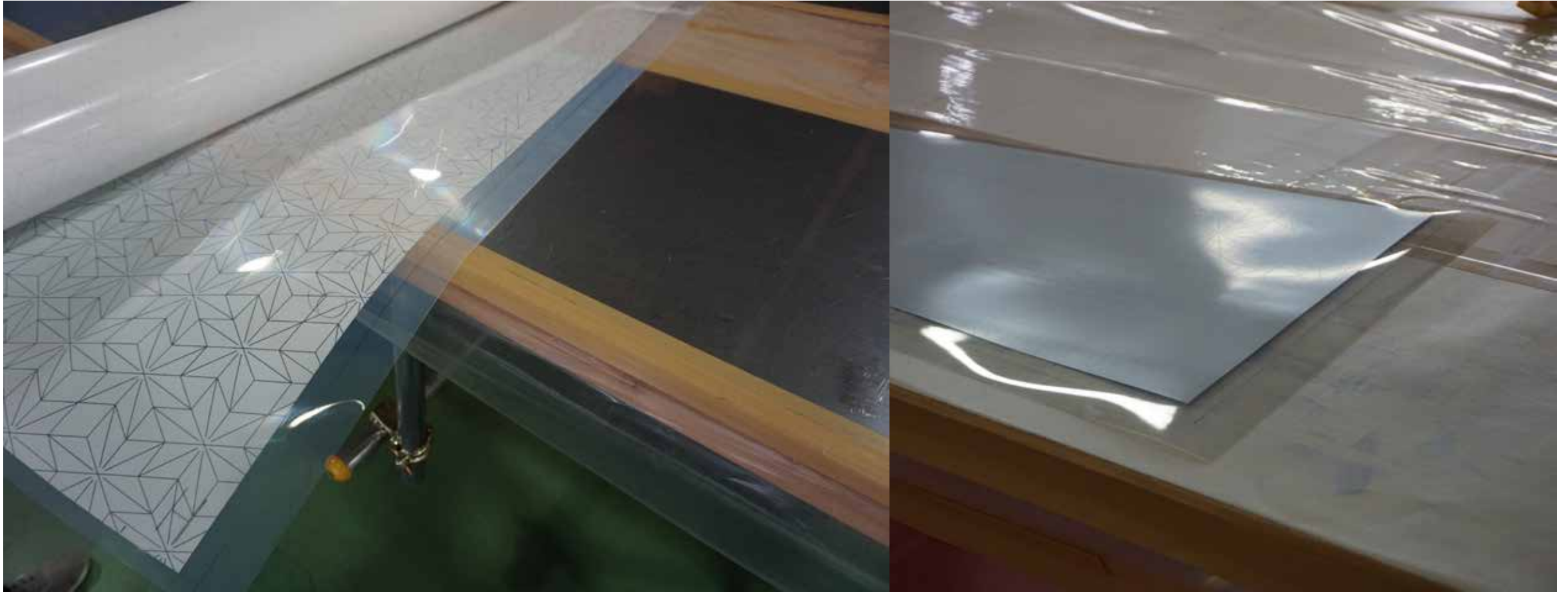
# Pre-Confirming Workability of Installation



## Fabrication of ETFE Panel



## Fabrication of ETFE Panel



# Fabrication of ETFE Panel



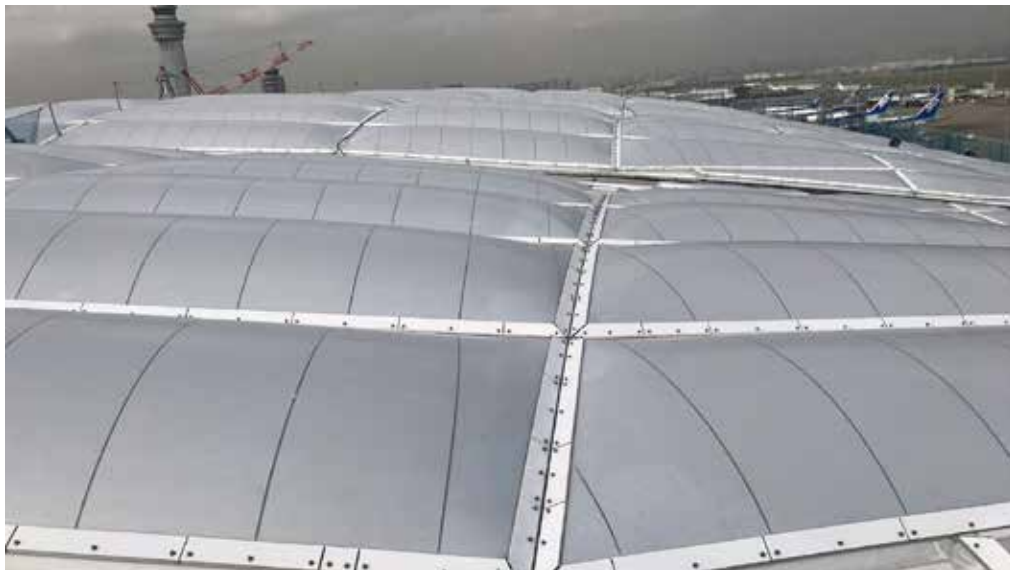
## Fabrication of ETFE Panel



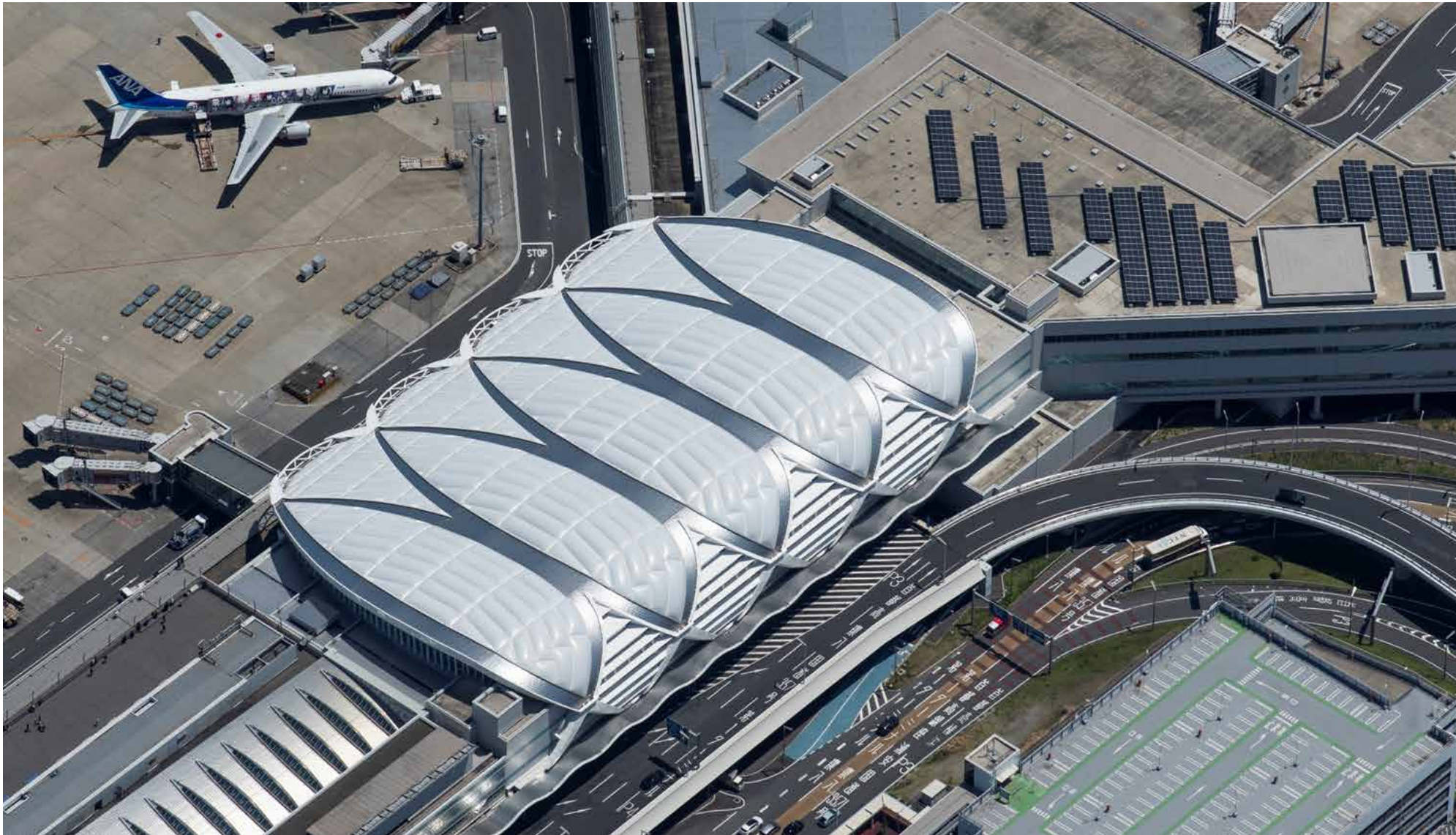
# Installation of ETFE Panel



# Installation of ETFE Panel



# External View of Tokyo International Airport



# External View of Tokyo International Airport



# Internal View of Tokyo International Airport



# Internal View of Tokyo International Airport



## Kyoritsu PTFE Projects



Kanseki Stadium, Tochigi

# Kyoritsu PTFE Projects



Tokyo Olympic Tennis Game Show Court, Tokyo

# Kyoritsu PTFE Projects



Yanbaru Visitor Center, Okinawa

t

Thank you for your kind attention!

