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SEISMIC RESISTANCE CAPACITY ON PIPE BRACED SUPPORTING FRAME OF SPHERICAL TANK

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OUTLINE

1. **Introduction**
   - ◆ **seismic damage for high pressure gas equipment in japan in 2011**
   - ◆ **Investigation into the cause of accident**
   - ◆ **objective ～ evaluation of seismic reinforcement～**
2. **Stress analysis for Spherical tank using FEA**
   - ◆ **Deformation behavior**
   - ◆ **Stress distribution**
3. **Evaluation of seismic capacity using FEA**
   - ◆ **Plastic strain distribution**
   - ◆ **Seismic capacity**
4. **Evaluation of seismic capacity using Shaking tests**
   - ◆ **Experimental conditions**
   - ◆ **Result of response character and seismic capacity , fracture mode from Shaking test**
5. **Summary**

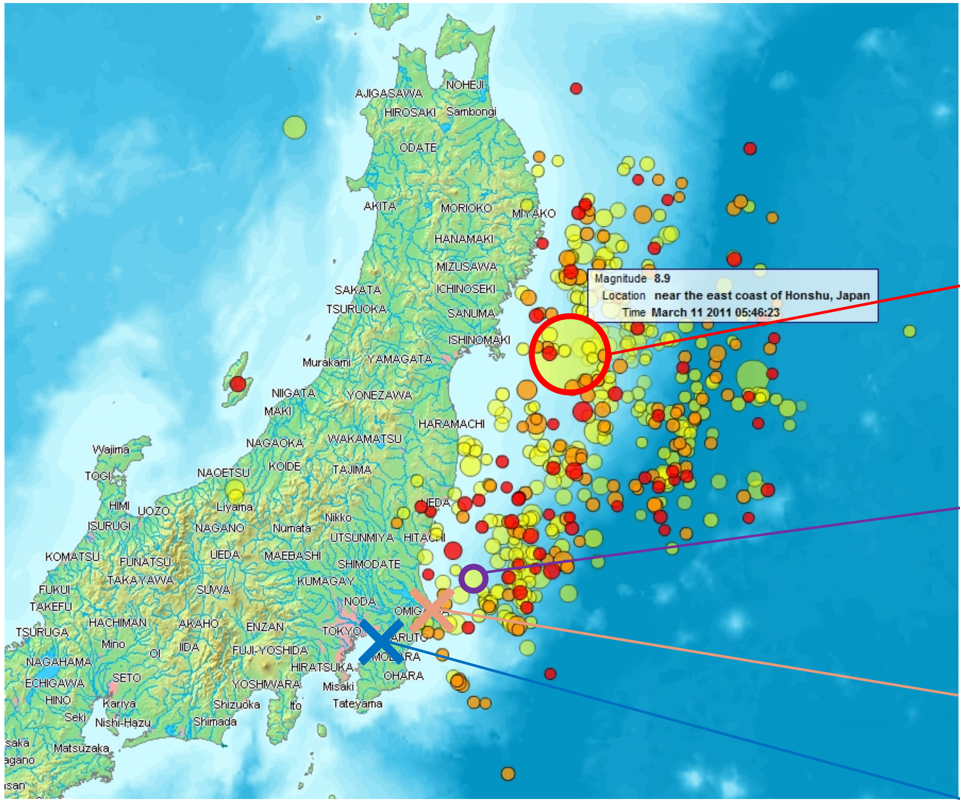
INTRODUCTION(1/3)

Huge earthquake hit East Japan (March.11th.2011)

→Fire and explosion accident (LPG spherical tank was collapsed)

→Investigation into the cause of accident

the 2011 Great East Japan Earthquake



Epicenter of Main shock
date and time : 2011/3/11 14:46:18
magnitude : 9.0

Epicenter of Max. After shock
date and time : 2011/3/11 15:15:34
magnitude : 7.6

Accident 2 :Spherical tank support broke

Accident 1:Spherical tank collapsed

INTRODUCTION(2/3)

Huge earthquake occurred in Japan (March.11th.2011)

→Fire and explosion accident (LPG spherical tank was collapsed)

→Investigation into the cause of accident

Accident 1

Collapsed spherical tank

Steel pipe brace breaking

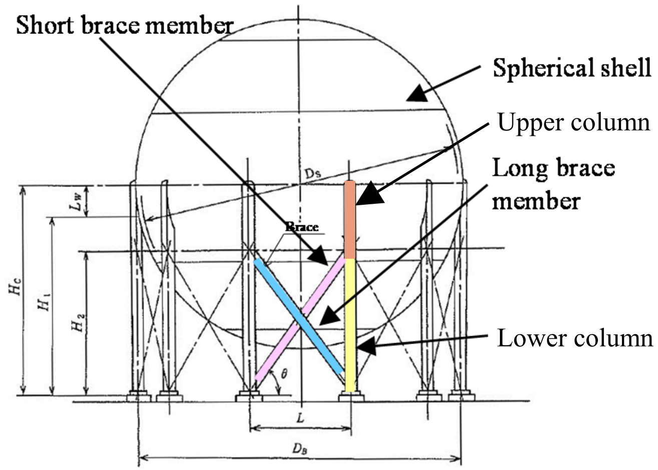
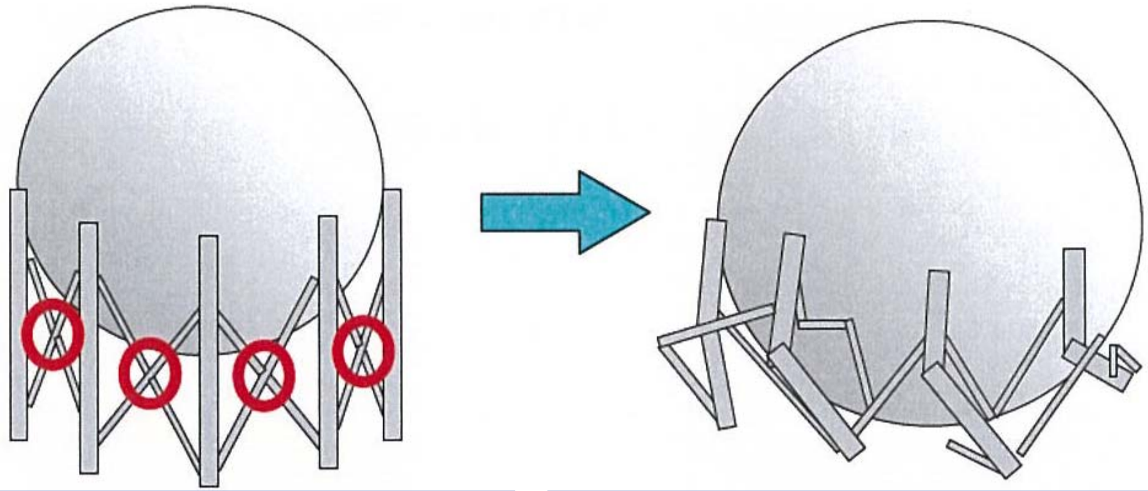


Fig. Spherical Tank with steel pipe brace and column structure

Accident 2

INTRODUCTION(3/3)

Huge earthquake occurred in Japan (March.11th.2011)
→Fire and explosion accident (LPG spherical tank was collapsed)
→Spherical tank support was broken
→Investigation into the cause of accident



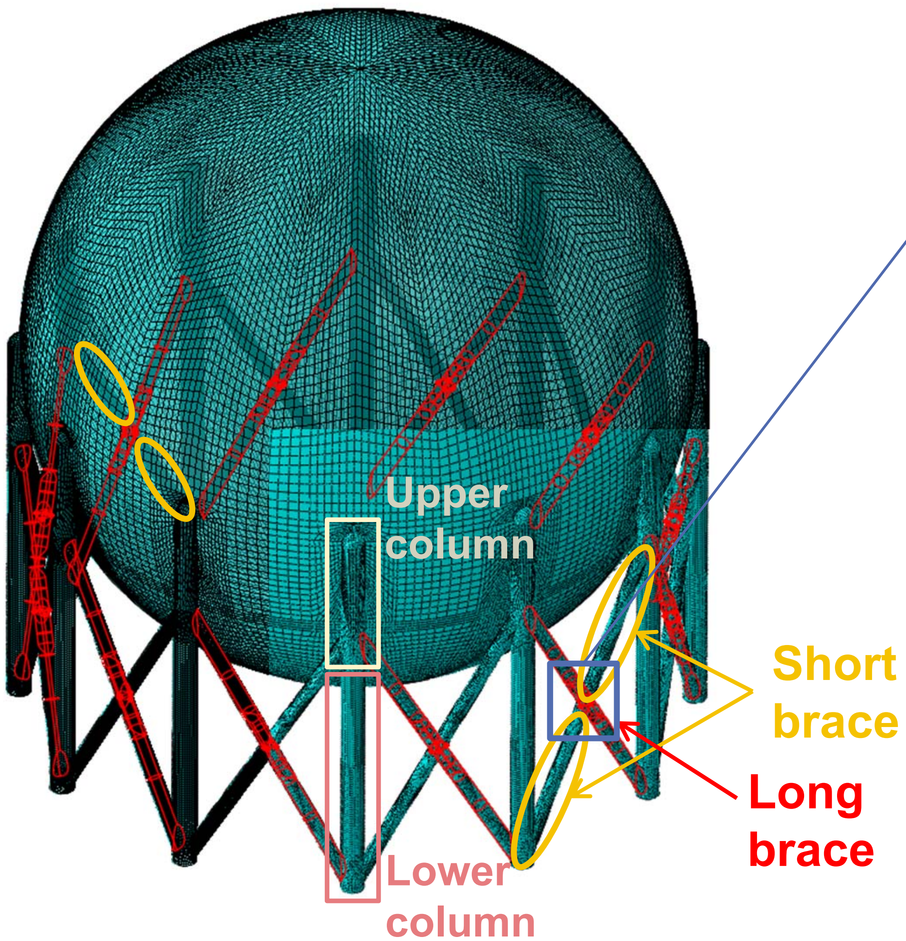
Main shock (14:46)
Intersection of braces breaking

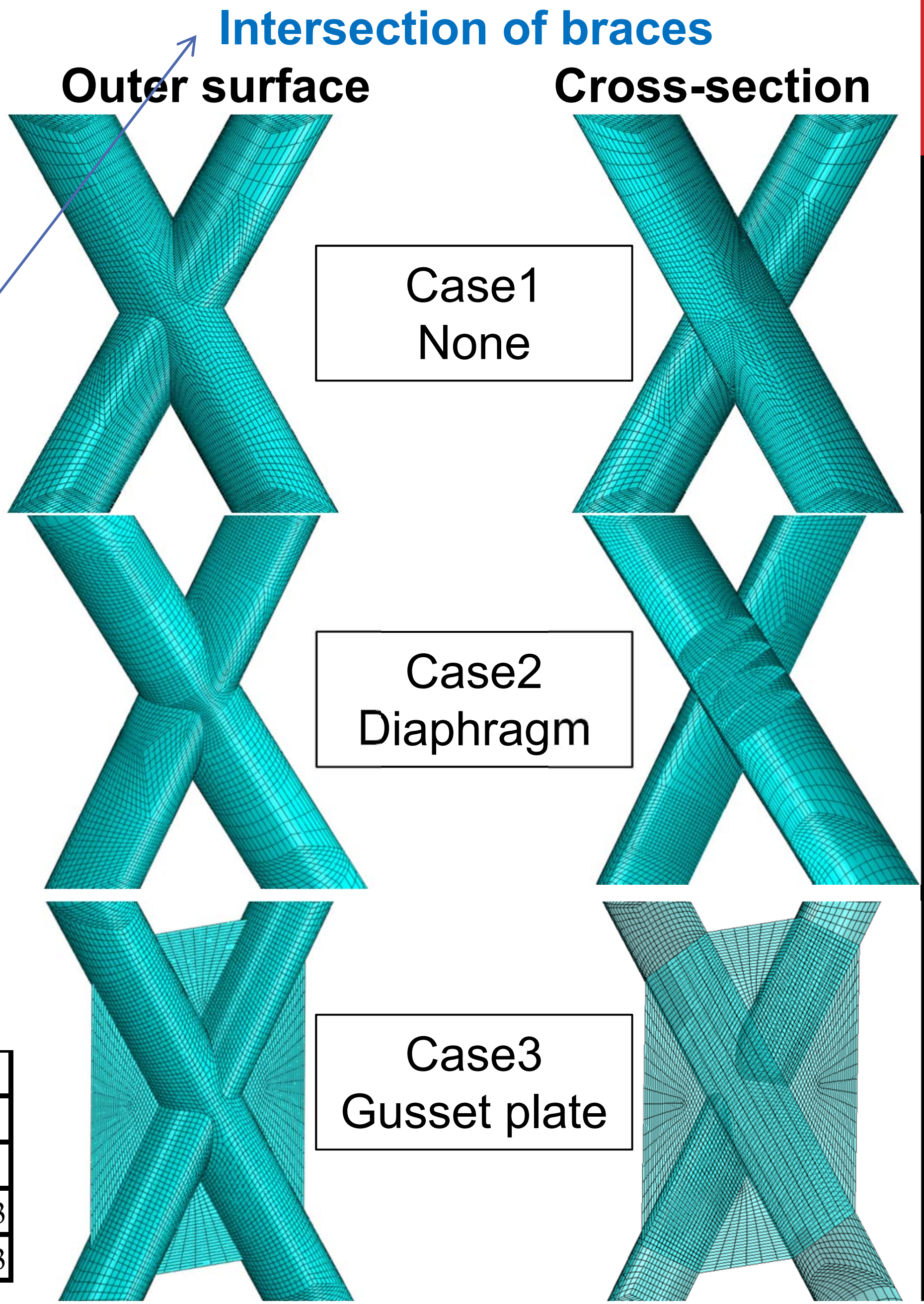
after shock (15:15)
Columns buckling and tank collapse

accident causation : strength poverty of intersection of braces
→need reinforcing intersection of braces

Objectives of this study
Validation:Fracture mechanism and deformation behavior
Study:Effectiveness of reinforcement and seismic capacity of spherical tank

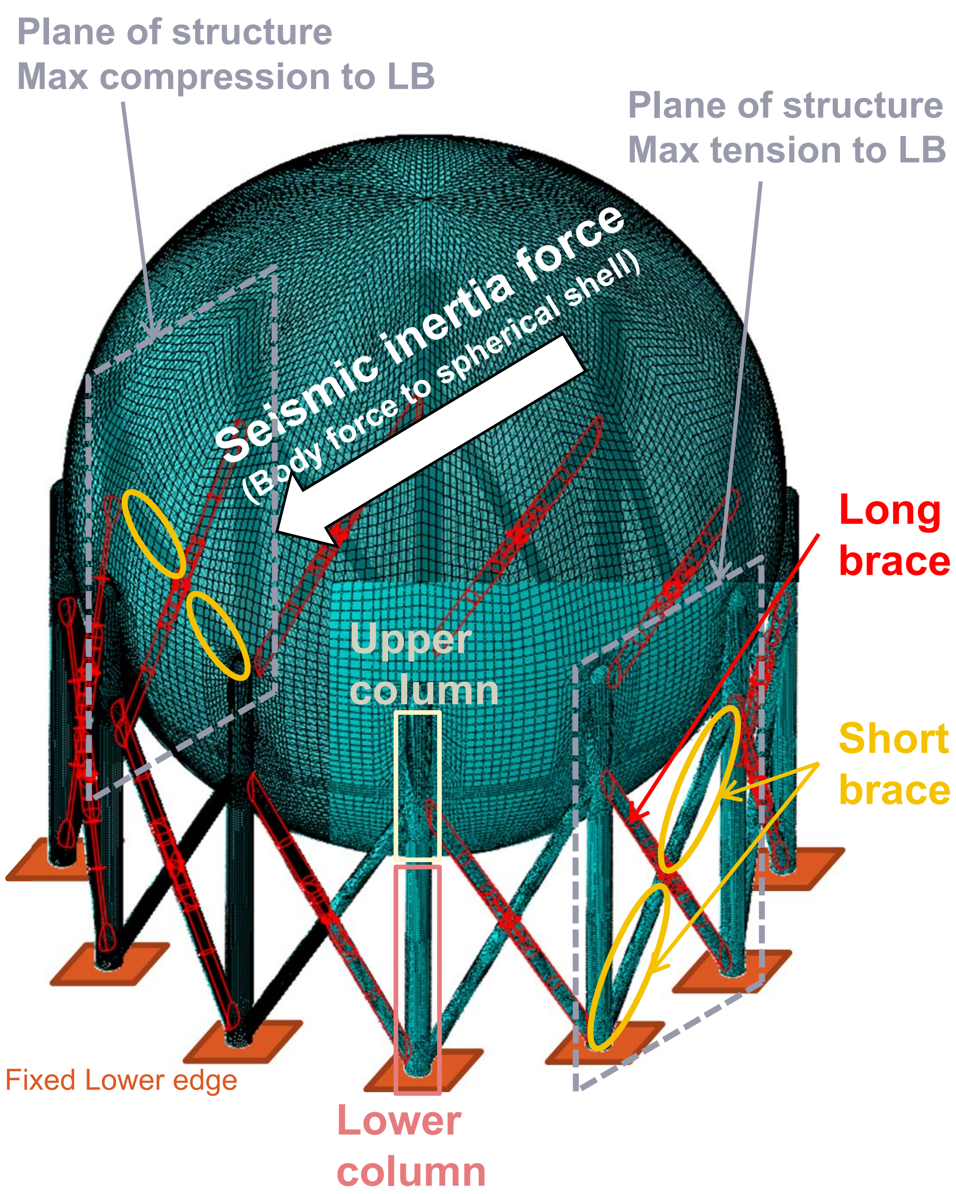
ANALYSIS MODEL OF SPHERICAL STORAGE TANK FOR FEA





Case No.	Case 1	Case 2	Case 3
Brace	without reinforce	with diaphragm	with gusset plate
Column	without reinforce	with diaphragm	with diaphragm
Number of nodes	936,447	757,064	774,693
Number of elements	313,785	254,734	261,433

ANALYSIS CONDITION FOR FEA



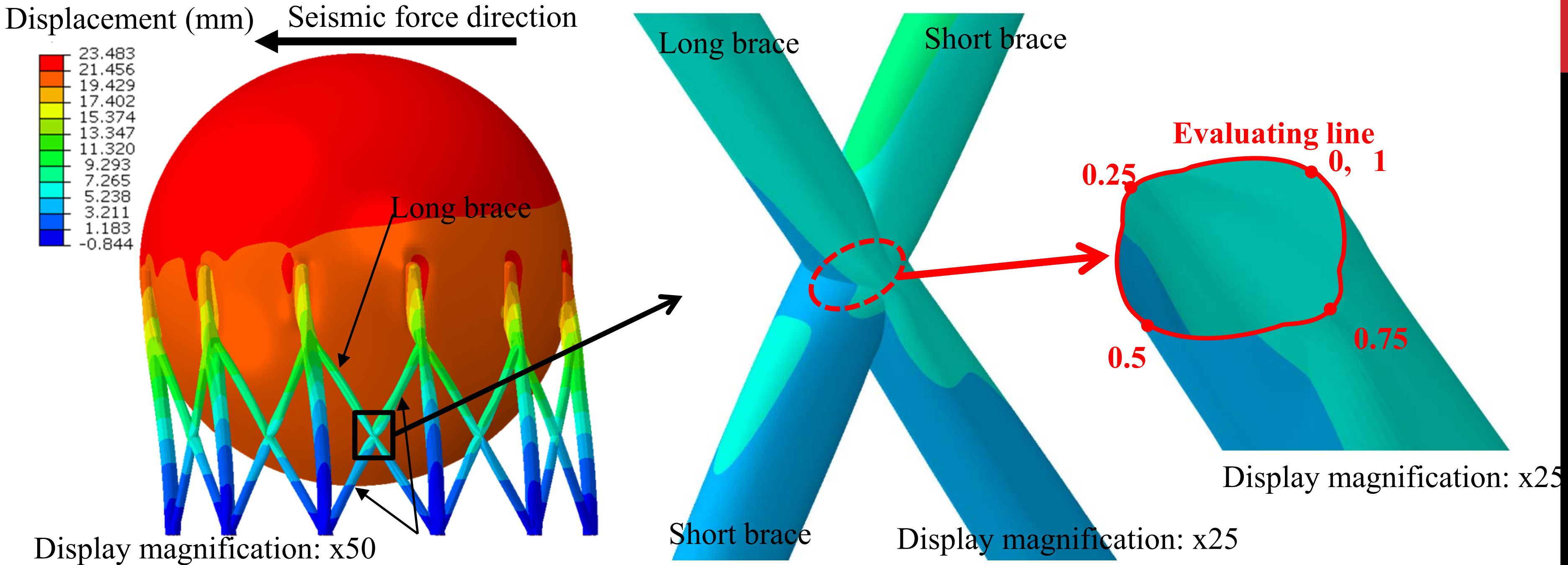
Elastic analysis

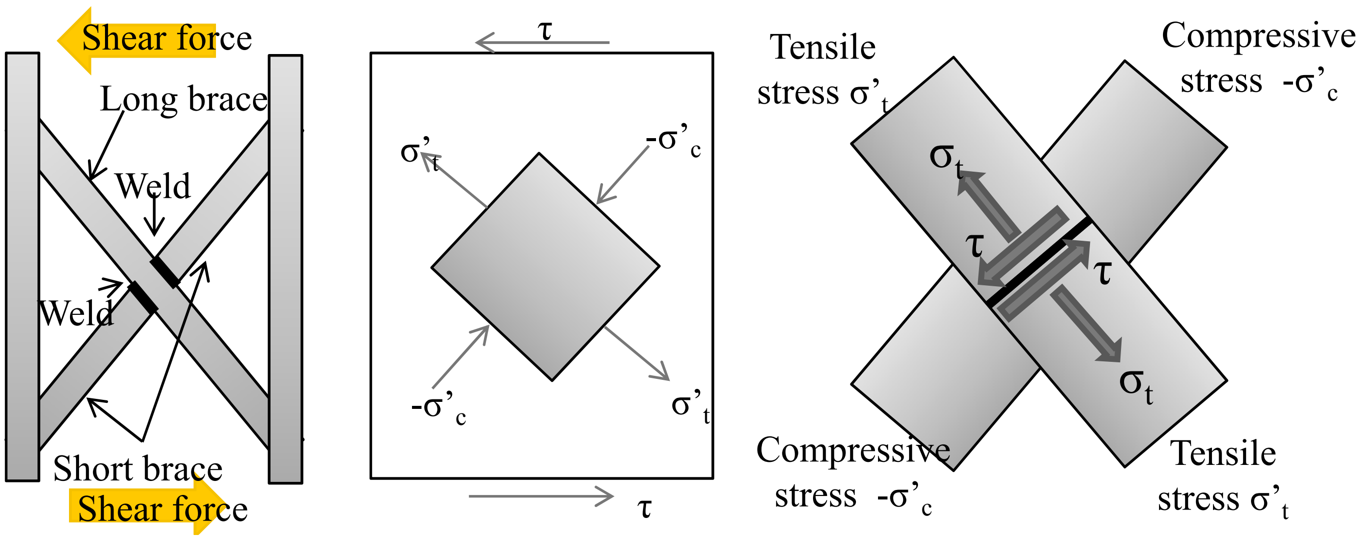
	Upper column	Lower column Brace	Spherical shell
Young's modulus E	**205 GPa**		
Poisson's ratio v	**0.3**		

Elasto-plastic analysis

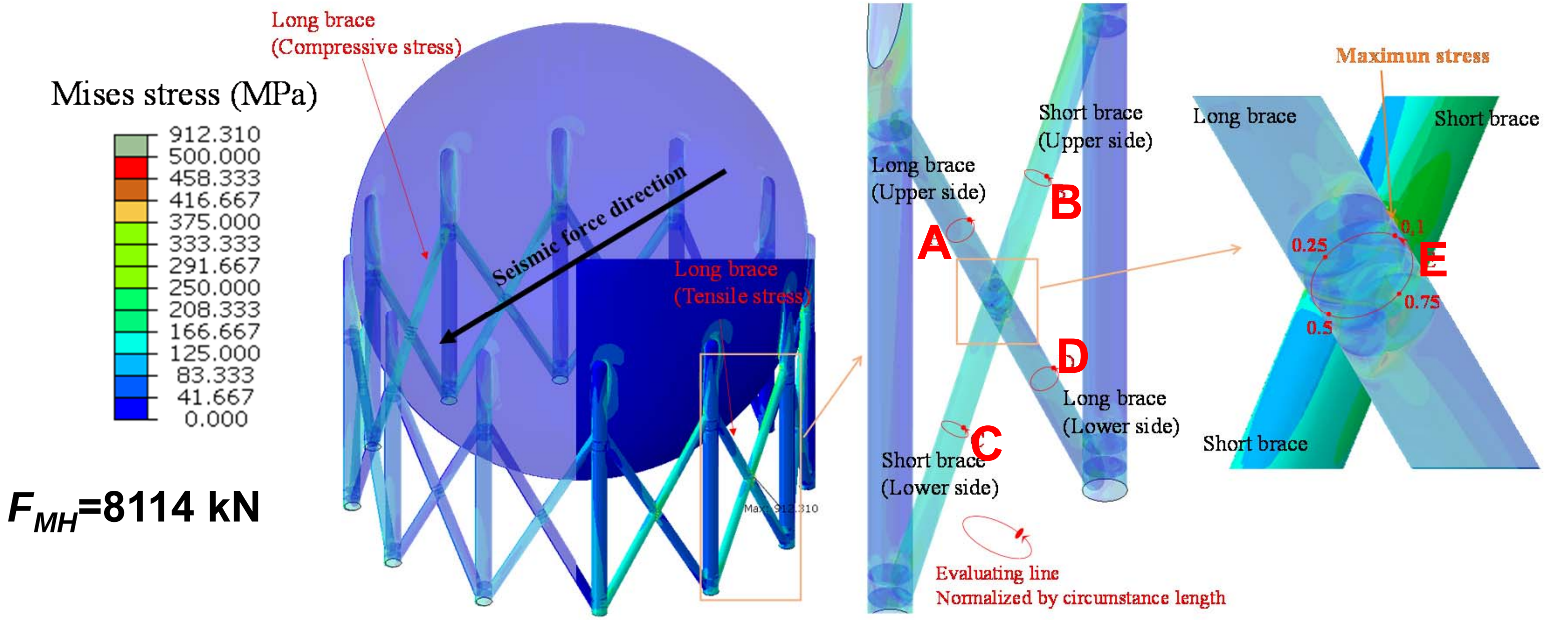
	Upper column	Lower column Brace	Spherical shell
Yield stress σ_{ys}	**470MPa**	**235MPa**	**— (Elastic)**
Ultimate Tensile strength σ_{uts}	**610MPa (ε_P=0. 2)**	**400MPa (ε_P=0. 3)**	
S – S Curve model	**2-liner**	**2-liner**	

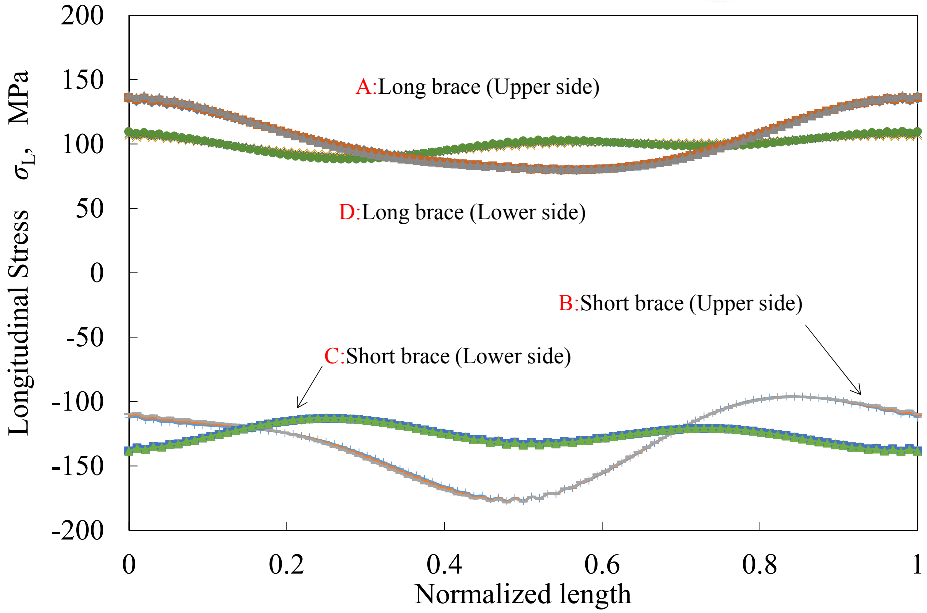
DEFORMATION OF INTERSECTION OF BRACES BY ELASTIC ANALYSIS

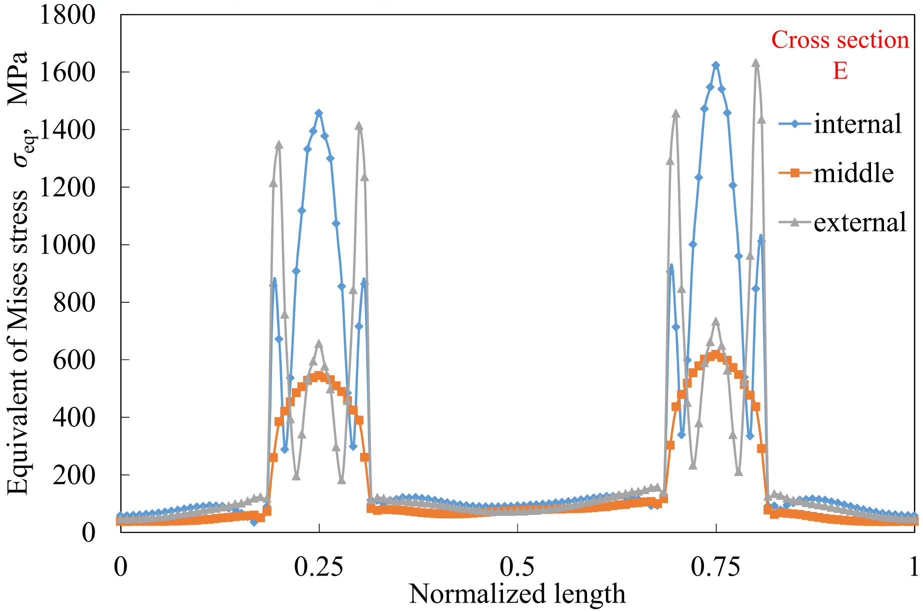




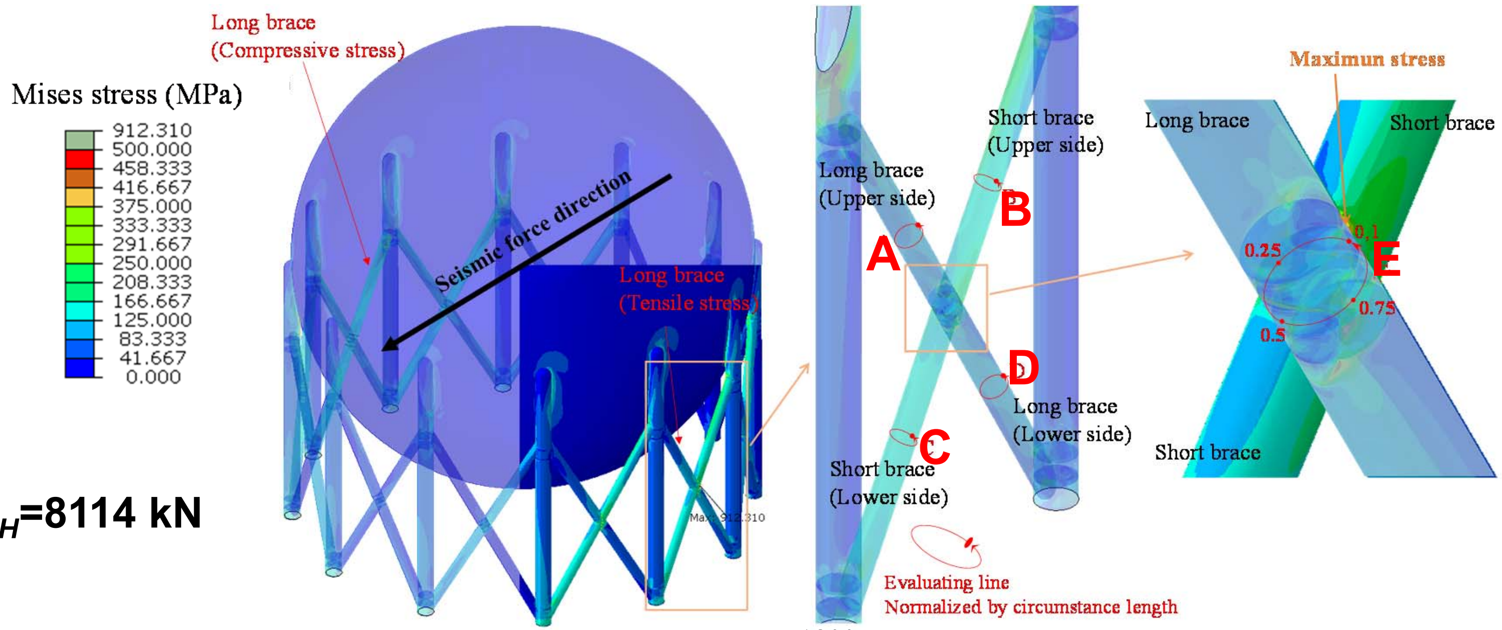
STRESS EVALUATION OF INTERSECTION OF BRACES BY ELASTIC ANALYSIS CASE1 (UNREINFORCEMENT)



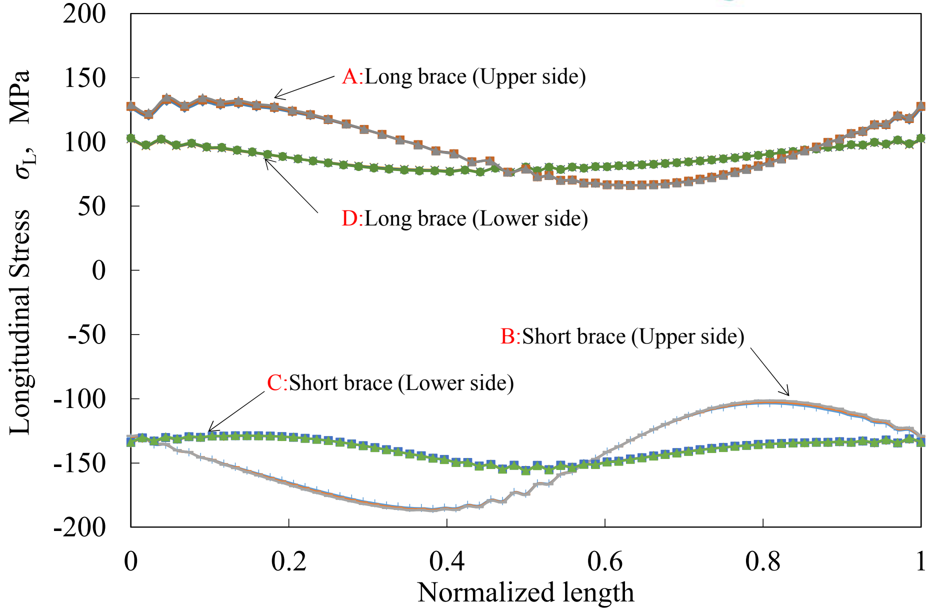


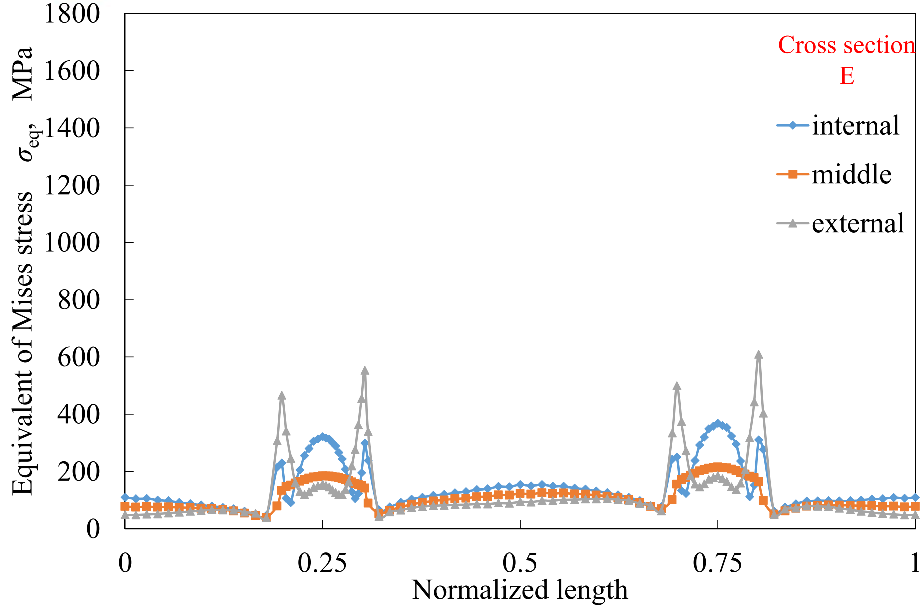


STRESS EVALUATION OF INTERSECTION OF BRACES BY ELASTIC ANALYSIS CASE2 (DIAPHRAGM)

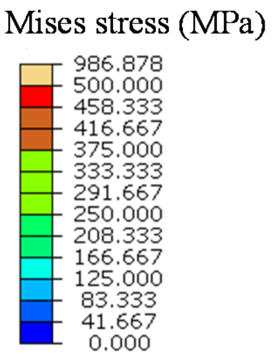


F_{MH}=8114 kN

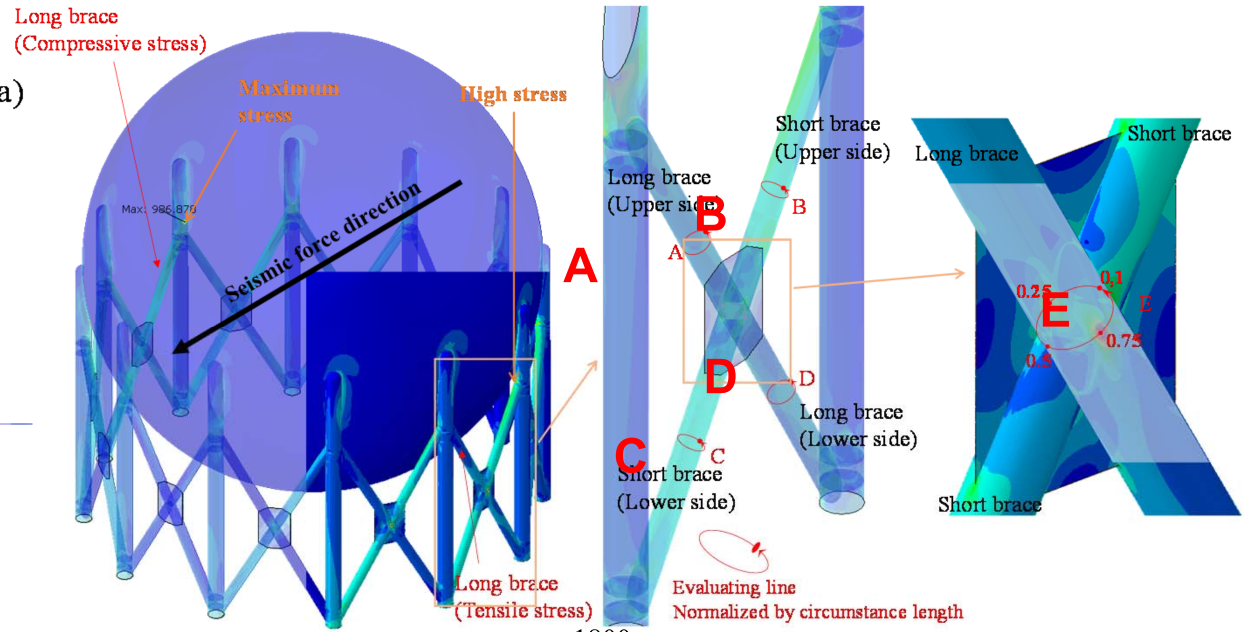


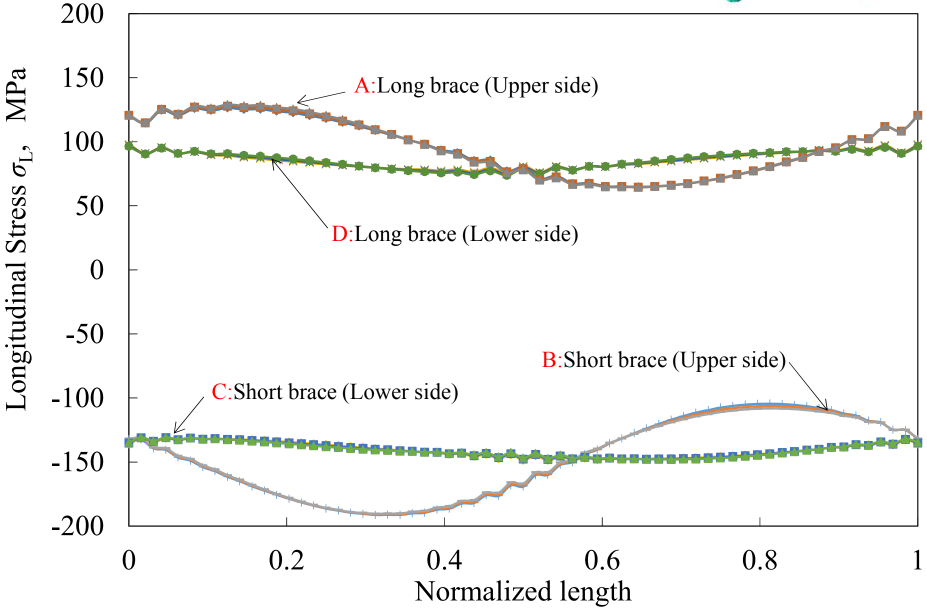


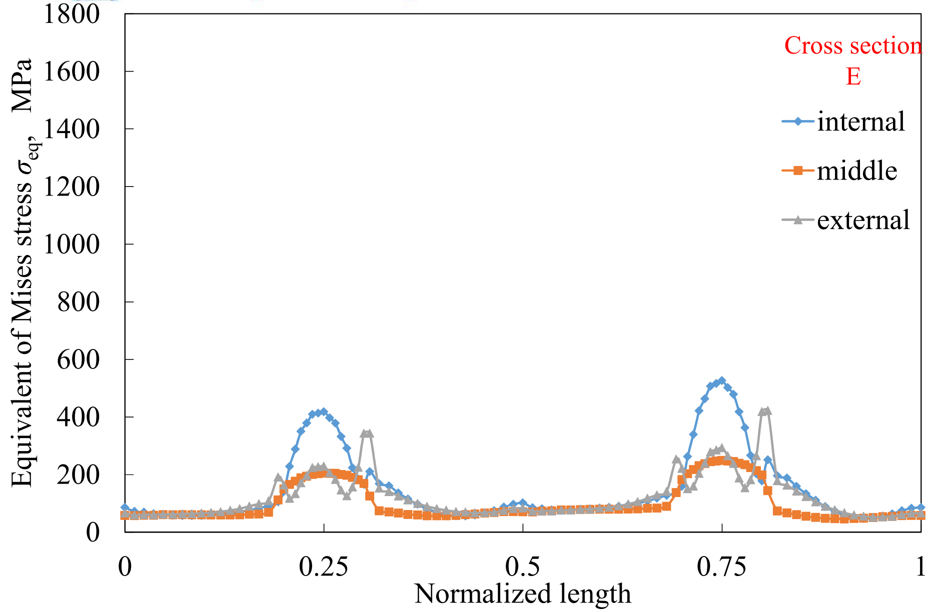
STRESS EVALUATION OF INTERSECTION OF BRACES BY ELASTIC ANALYSIS CASE3 (GUSSET PLATE)



F_{MH}=8114 kN

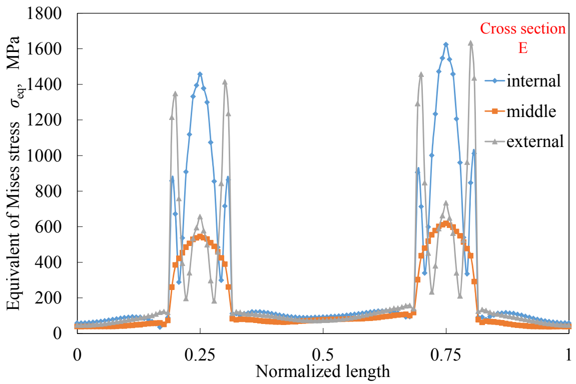


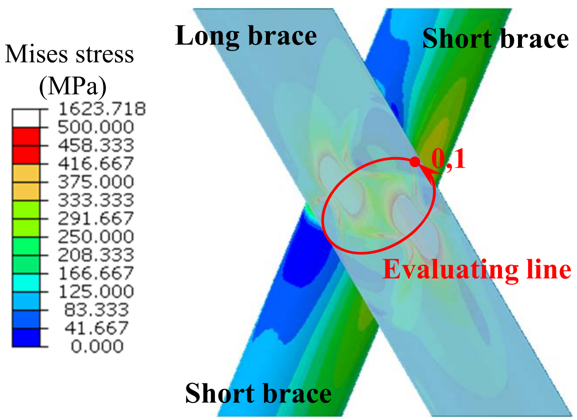




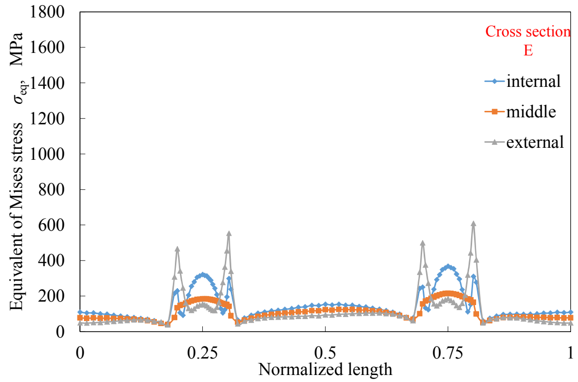
SUMMARY OF ELASTIC ANALYSIS ON EFFECTIVE OF REINFORCEMENT

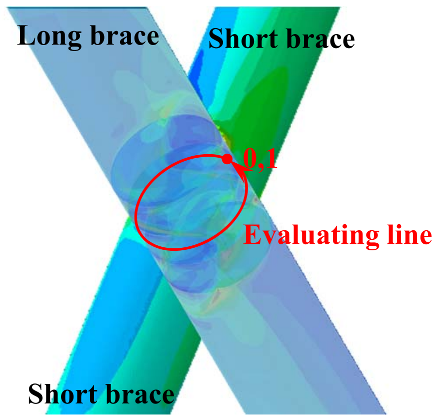
Case1 unreinforcement



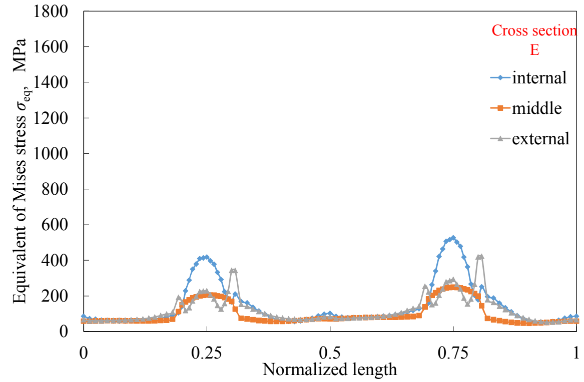


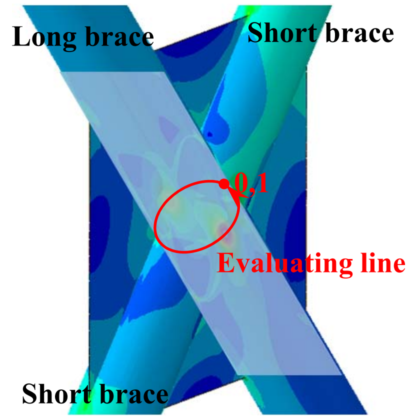
Case2 diaphragm





Case3 gusset plate



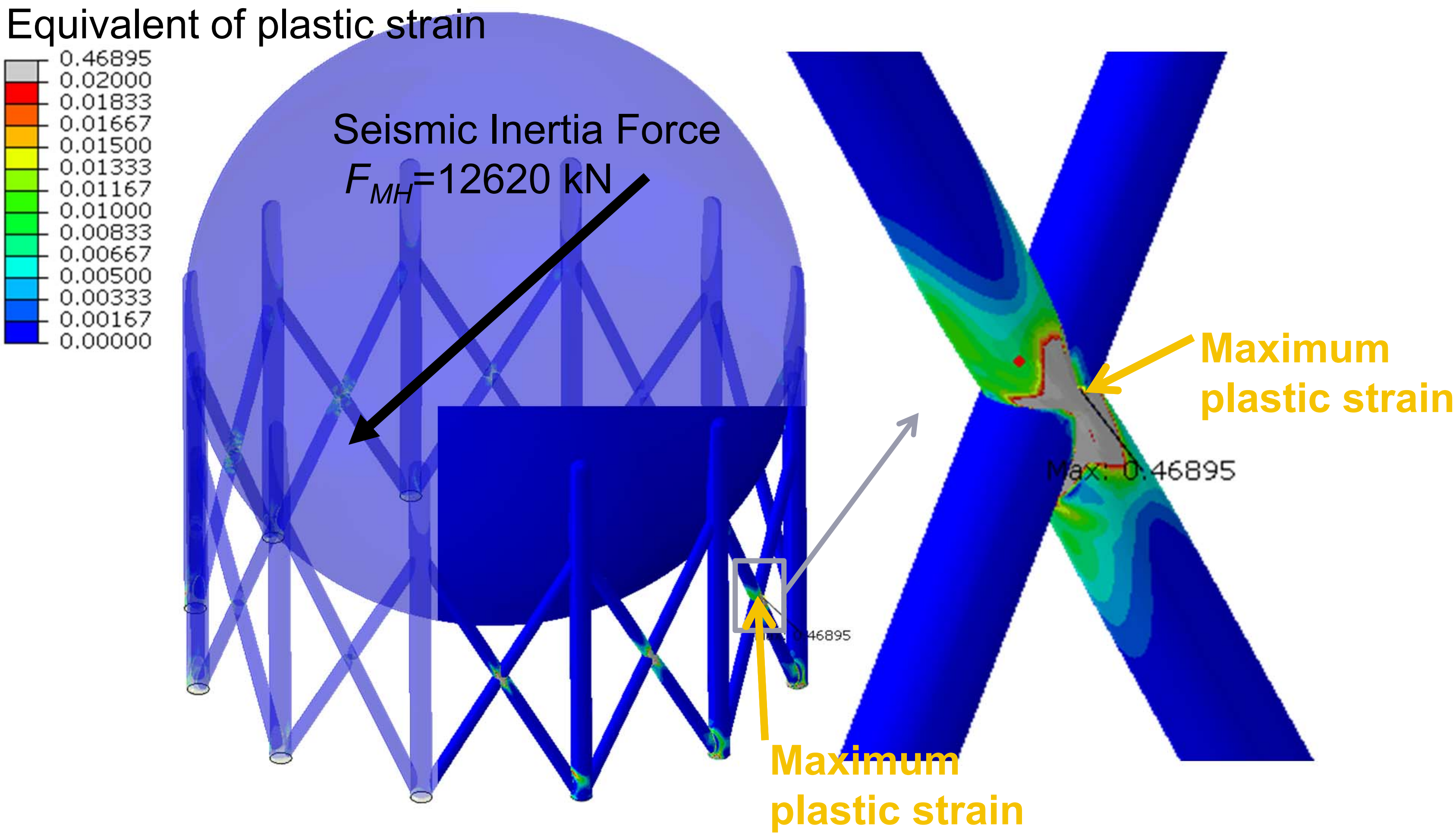


Reinforced type	Inner surface		Middle		Outer surface	
	average	max	average	max	average	max
without reinforce	308	1624	167	619	247	1633
with diaphragm	141	368	108	215	118	610
with gusset plate	145	526	98	249	122	423

Long brace
σ_t=100 MPa
Short brace
σ_c=130 MPa

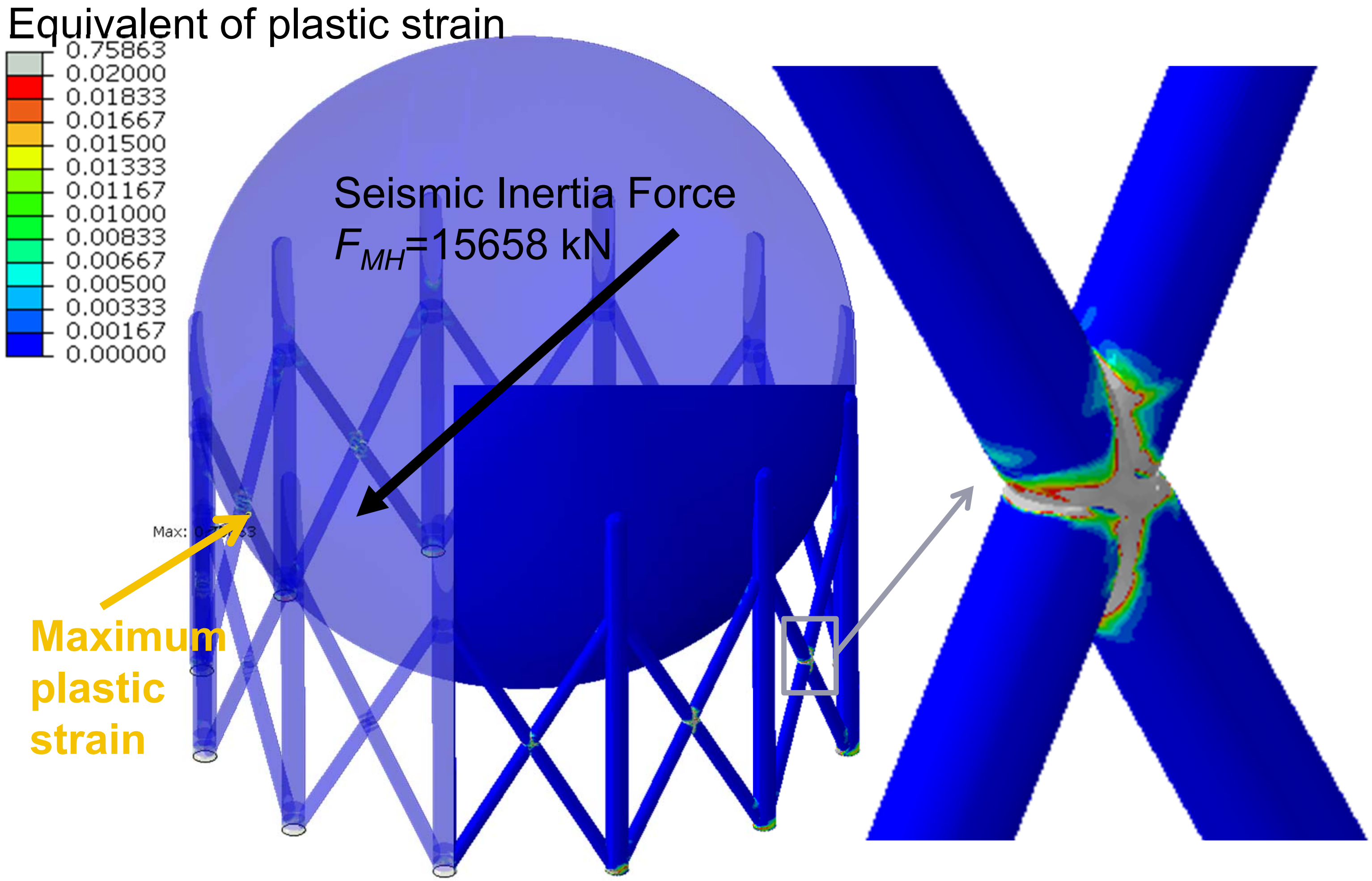
EVALUATION OF ULTIMATE STRENGTH BY ELASTO-PLASTIC ANALYSIS

Case1 Distribution of equivalent of plastic strain without reinforcement



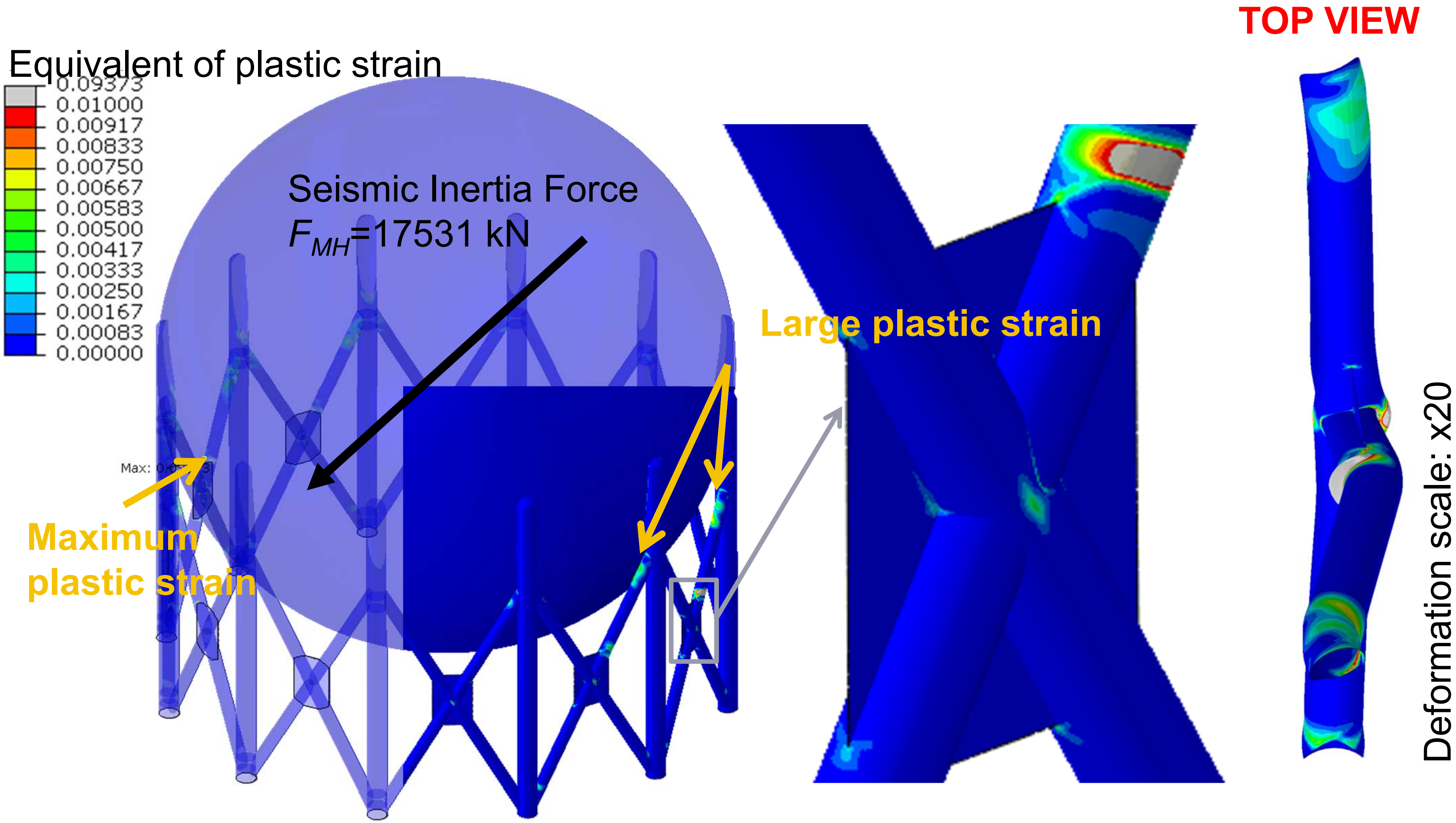
EVALUATION OF ULTIMATE STRENGTH BY ELASTO-PLASTIC ANALYSIS

Case2 Distribution of equivalent of plastic strain with diaphragm



EVALUATION OF ULTIMATE STRENGTH BY ELASTO-PLASTIC ANALYSIS

Case3 Distribution of equivalent of plastic strain with gusset plate



SUMMARY OF ELASTIO-PLASTIC ANALYSIS ON EFFECTIVE OF REINFORCEMENT

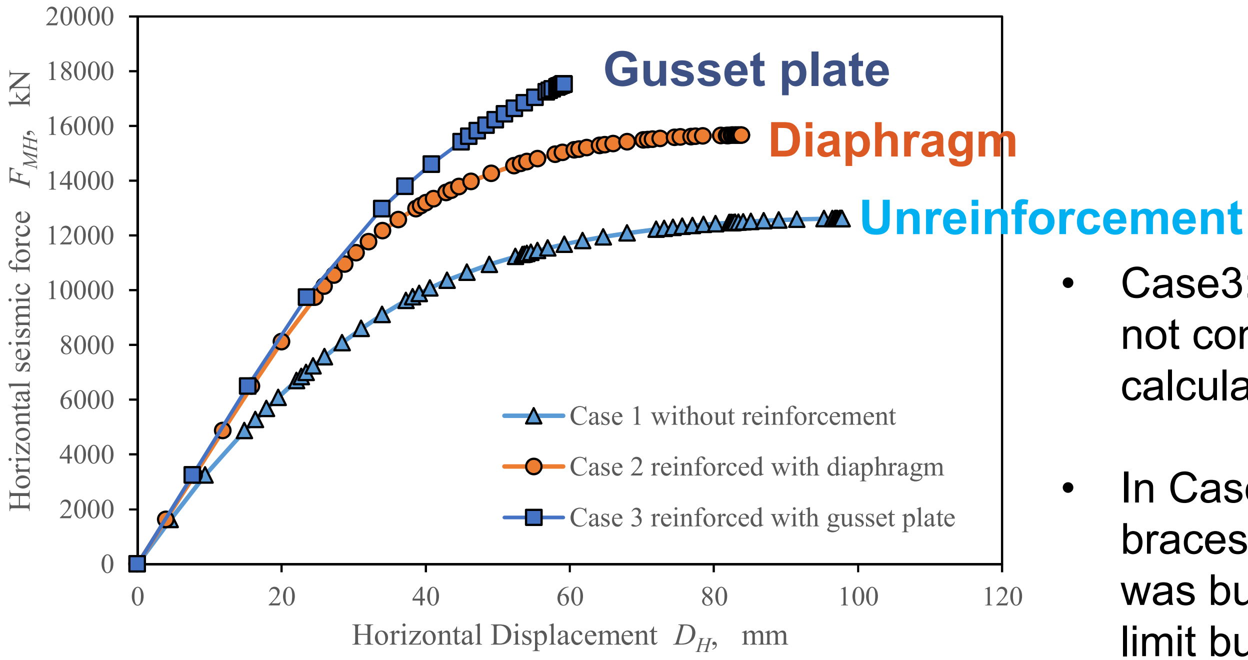


Fig. Relationship of Force and displacement

- Case3:Seismic horizontal Force was not constantly increasing at calculating limit.
- In Case3 it was considered that braces reinforced by gusset plate was buckled, 18,000kN is brace limit buckling load.

Case	Maximum horizontal seismic force kN	Effectiveness of reinforcement
Case1 (unreinforcement)	12620	-
Case2 (diaphragm)	15658	1.25 times
Case3 (gusset plate)	17531	1.39 times

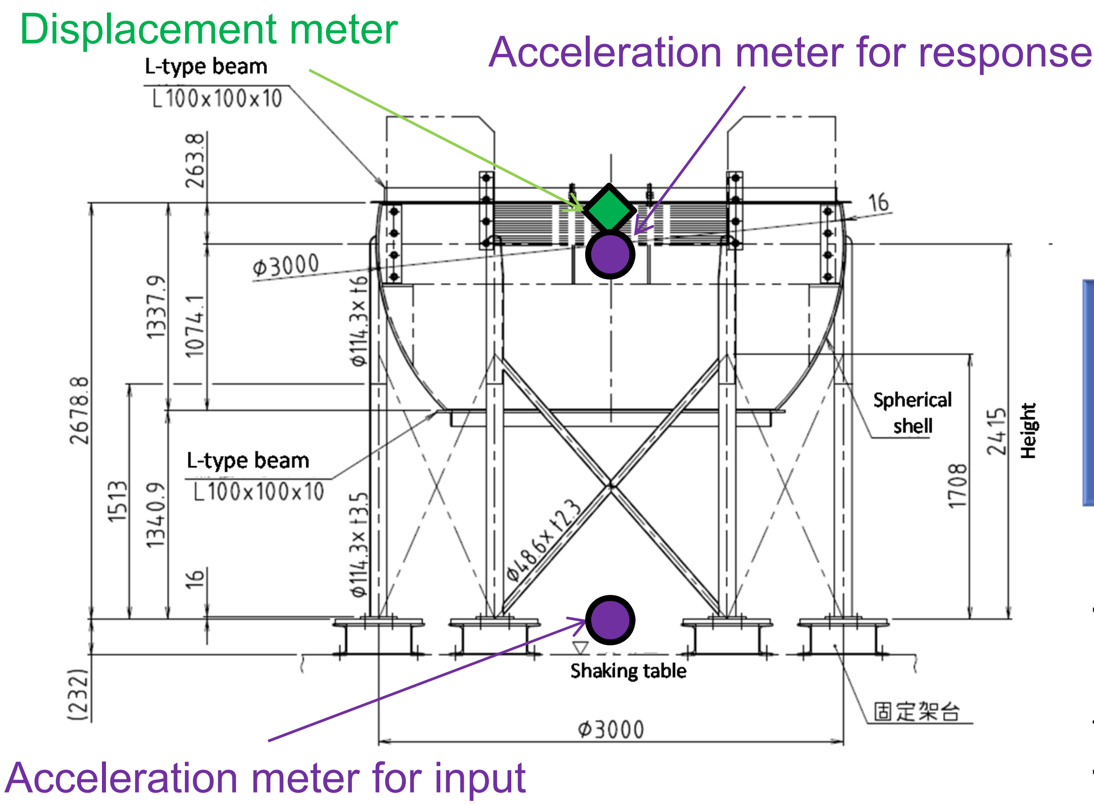
SHAKING TESTS

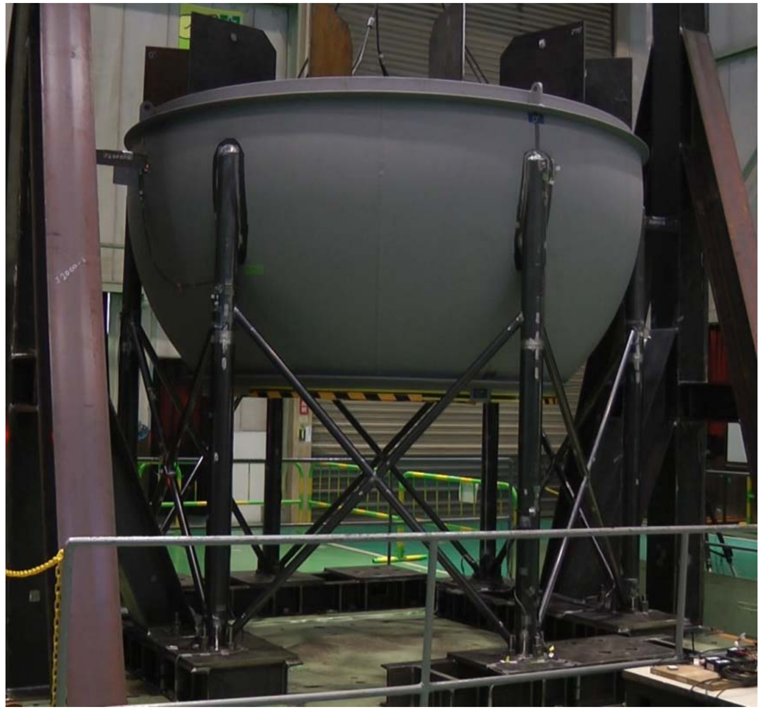
Test models specs

Dimensional ratio for real equipment 1/1.896

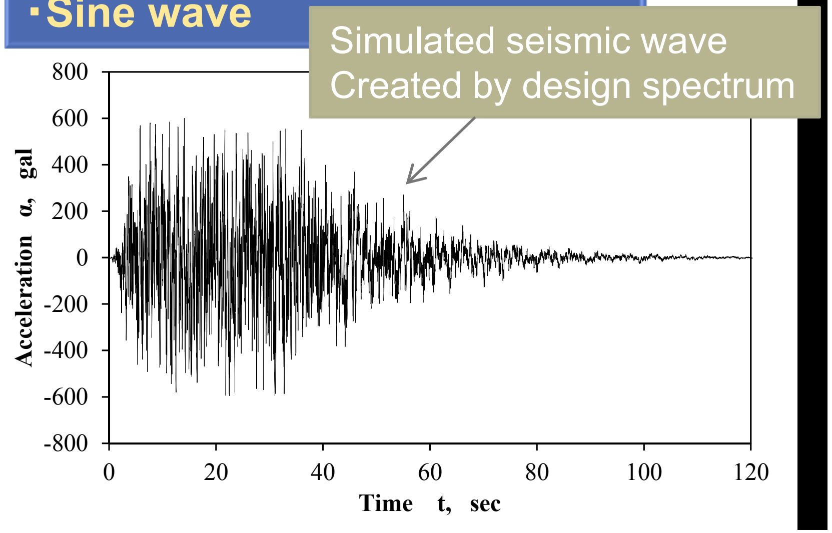
Tank A：Unreinforced model

Tank B：Reinforcement model with gusset plate same as FEA model





Input seismic wave
- JMA Kobe NS wave
- Simulated seismic wave
- Sine wave



- Acceleration. and duration time with similarity rule
- Cut off long term period with high pass filter(2.8Hzz)
- Simulated seismic wave fit on acceleration spectrum for design

TEST CASES

Similarity rule
Acceleration: original ×1.896
Time : original / 1.896

JMA Kobe NS

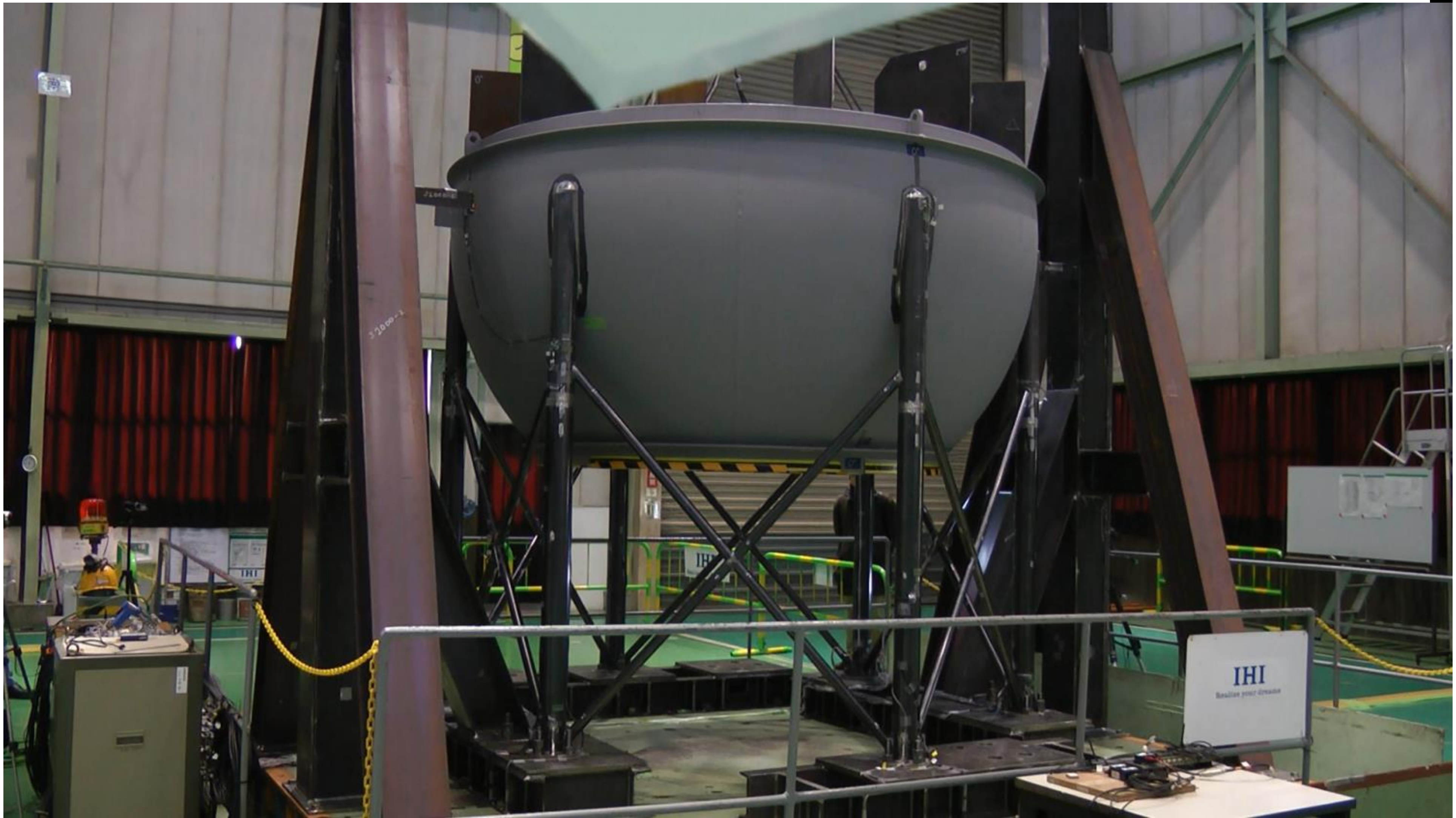
Without reinforce		Reinforced with gusset plate	
Tank A		Tank B	
Acceleration amplification ratio β	Maximun Input Acceleration α_{imax} (gal)	Acceleration amplification ratio β	Maximun Input Acceleration α_{imax} (gal)
10%	158	25%	340
15%	227	50%	745
100%	1062	100%	1065

Simulated seismic wave

Without reinforce			Reinforced with gusset plate		
Tank A			Tank B		
Wave shape	Acceleration amplification ratio β	Maximun Input Acceleration α_{imax} (gal)	Wave shape	Acceleration amplification ratio β	Maximun Input Acceleration α_{imax} (gal)
Simulated Sismic Wave	5%	55	Simulated Sismic Wave	10%	103
	10%	107		20%	201
	15%	158		35%	335
	30%	295		70%	693
	70%	699		100%	981
	100%	986		138%	1362
	138%	1343		200%	2036
	200%	2008		260%	2648
-	-	-	sin wave (11.2Hz 200gal)		175
-	-	-	sin wave (11.0Hz 800gal)		800

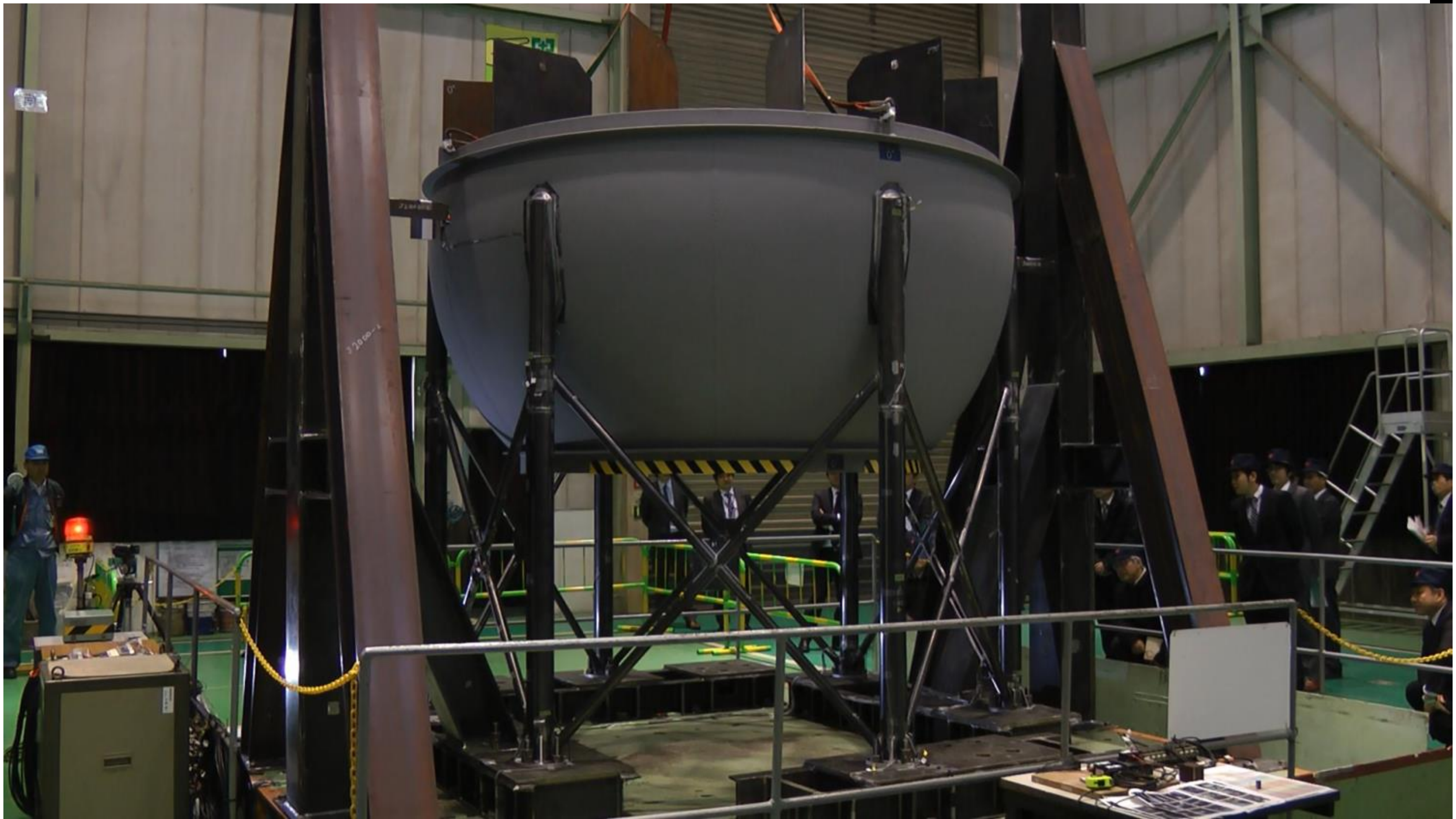
MOVIE DURING SHAKING TEST
OF SPHERICAL TANK WITHOUT REINFORCEMENT

Tank A

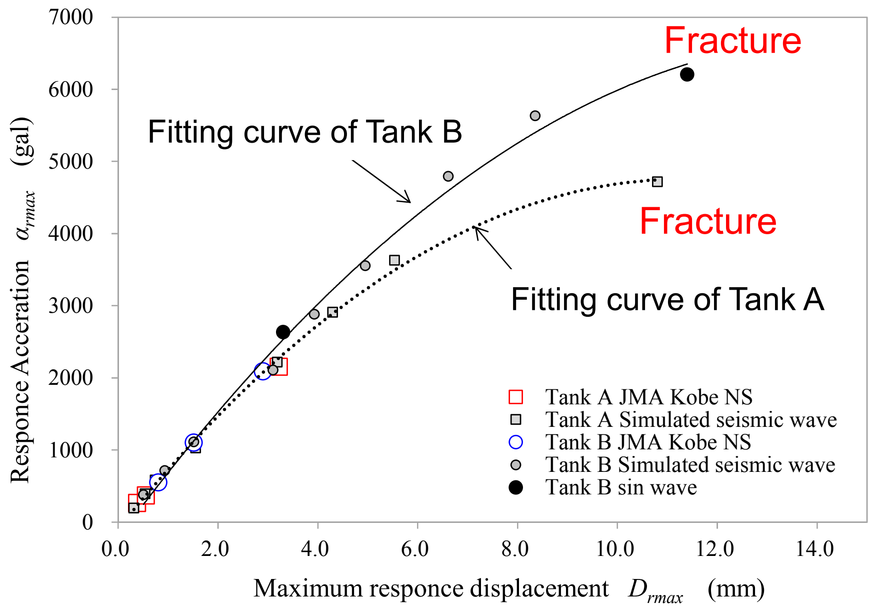


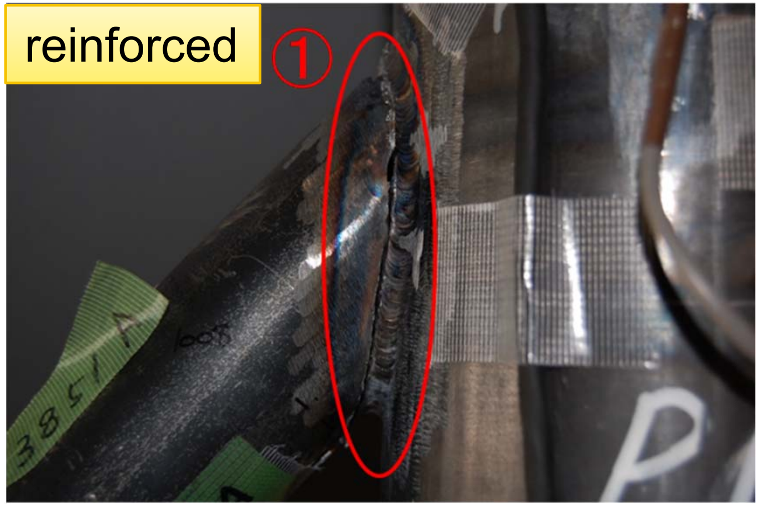
MOVIE DURING SHAKING TEST
OF SPHERICAL TANK WITH REINFORCEMENT

Tank B

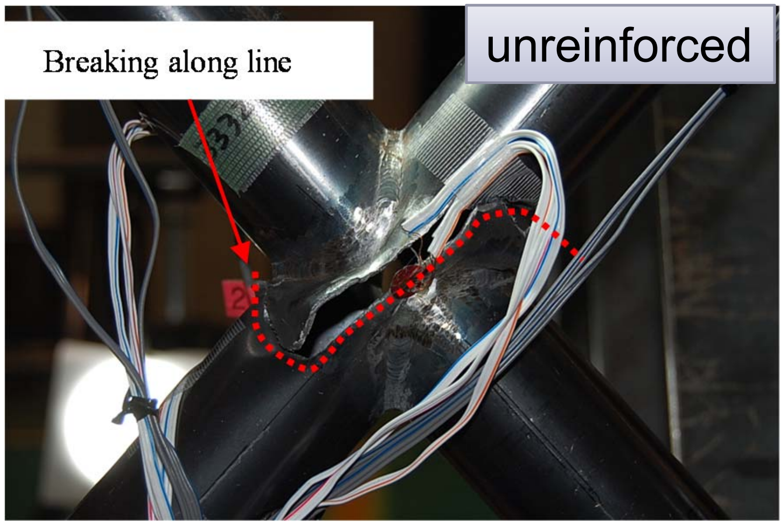


RESULT OF SEISMIC CAPACITY AND FRACTURE MODE

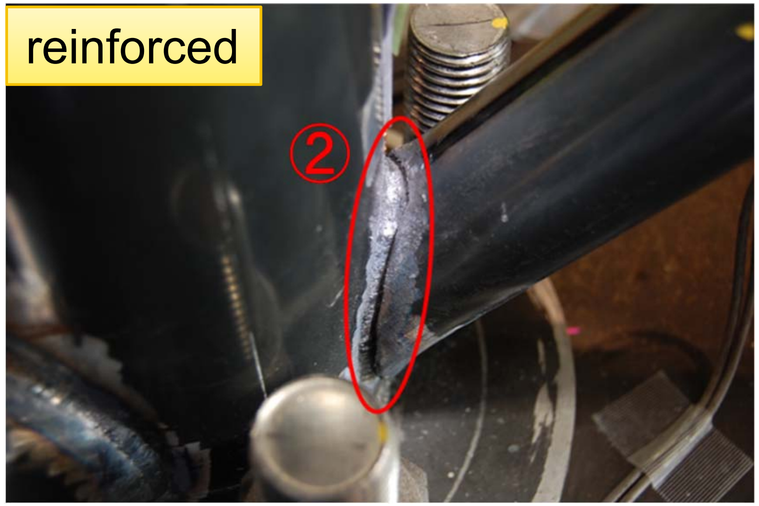




Broken brace around weld joint with upper column



Broken intersection of braces



Broken brace around weld joint with lower column

SUMMARY（1／2）

The failure mechanism of the steel pipe brace structure of a spherical tank were clarified by the elastic and elastic-plastic FEA.

From FEA results (with respect to the accident report), it was concluded the failure mechanism of spherical tank as follows

(1) Seismic capacity of spherical tank with steel pipe brace, the intersection of braces is the weakest point.

(2) The intersection of braces is in a multi-axial stress state due to the structural characteristics of pipe brace configuration when seismic inertia force is applied. This induces the fracture by plastic deformation.

(3) In case of long brace member is in tension, the intersection of long brace member is received compression force from short brace members, locally bending stress from cross-sectional deformation. In consequence, the intersection of braces is deformed very large.

(4) The effect of the reinforcement by diaphragm and gusset plate were discussed from FEA result of reinforcement models. by reinforcing the intersection of braces, seismic resistance capacity were increased to 1.25 times by diaphragm, and to 1.39 times by gusset plate.

SUMMARY(2／2)

Non-linear response characteristics and failure mode of a spherical tank were clarified by shaking tests using small models of spherical tank.

From the test results, it was concluded the effectiveness of reinforcement and the response characteristic of the pipe braced supporting frame of a spherical tank as follows;

(1) In a case of brace intersection was reinforced, the maximum response acceleration increased at collapse.

(2) In a case of there was reinforced there is no reinforcement to brace intersection, structural strength indicated the lowest at the load direction acting tensile force on long brace, cross section of long brace were deformed largely.

ACKNOWLEDGMENT

This study used the results to verify the seismic performance of the spherical tank in Research Committee of the Ministry of Economy, Trade and Industry commissioned project in 2014. Advice and comments given by IHI Corporation has been a great help in shaking tests. We would like to express the deepest appreciation to committee members and participator.

THANK YOU FOR YOUR KIND ATTENTION.