Proceedings of the IASS 2024 Symposium
Redefining the Art of Structural Design
August 26-30, 2024, Zurich Switzerland
Philippe Block, Giulia Boller, Catherine DeWolf,
Jacqueline Pauli, Walter Kaufmann (eds.)

Research on the TSUNAMI shelter using the polyurea resin

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Abstract

In Japan, earthquakes occur frequently, and tsunamis caused by earthquakes bring huge damage to humans. According to the reports of the Great East Japan Earthquake of 2011, about 90% of the victims died from drowning due to tsunamis. In order to protect people from the tsunami, Onoda Industry proposed tsunami shelters to prevent damage caused by tsunamis. These shelters are made from Styrofoam applying polyurea resin to increase strength of the structure. This study constructed FEM models of 2 types of tsunami shelters proposed by Onoda Industry to analyze the characteristics of the tsunami shelters. Using the constructed FEM model, this study calculates and analyzes responses of the tsunami shelters under static load on different directions. Moreover, this study proposes a new shelter that is smaller type designed for family use that can be installed at a balcony. Simulation results shows the tsunami shelters proposed in this paper satisfies the design criteria. In reference to a conventional tsunami shelter, this study makes the tsunami shelter which changed the opening part. Furthermore, this study devises making with the tsunami shelter of the different form. Because the shelter is for home use, size is lowered. This study analyzes two shelters and prove that there are utility and checks how it changes whether paint with polyurea.

Keywords: hazard, TSUNAMI, optimization, shelter, analysis, polyurea resin

1. Introduction

Japan has long been plagued by natural disasters. In particular, Japan is known as an earthquake-prone country, and earthquakes occur frequently. Secondary disasters caused by earthquakes include fires, tsunamis, liquefaction, and landslides. In the Great East Japan Earthquake, 90% of the total damage from secondary disasters was caused by drowning due to tsunamis, so countermeasures against tsunamis are necessary.In this study, we will conduct a model analysis of SAM, SAMLIFE (hereinafter referred to as "tsunami shelter"), a shelter manufactured by Onoda Sangyo for protection against tsunami, as a joint research project.

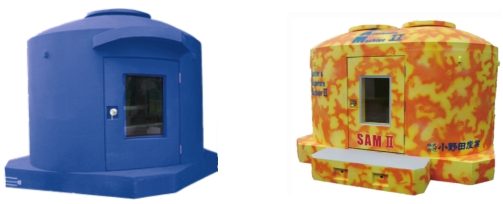


Figure 1: Tsunami shelters (left: SAM, right: SAMLIFE)

This tsunami shelter is made of styrene foam and coated with polyurea resin. The polyurea resin strengthens the outer surface of the polystyrene foam, making the shelter strong and able to rise from the water surface. In this paper, we prove the usefulness of the polyurea resin by analyzing the tsunami shelter. We also study and analyze a small tsunami shelter that can be easily placed in ordinary homes in order to popularize the tsunami shelter.

2. Analysis method

The model was created in the analytical space and analyzed using the finite element method. Figure 2 shows the plan view of the model tsunami shelter, Figure 3 shows the analytical model, and Table 1 shows the analytical parameters of the tsunami shelter.

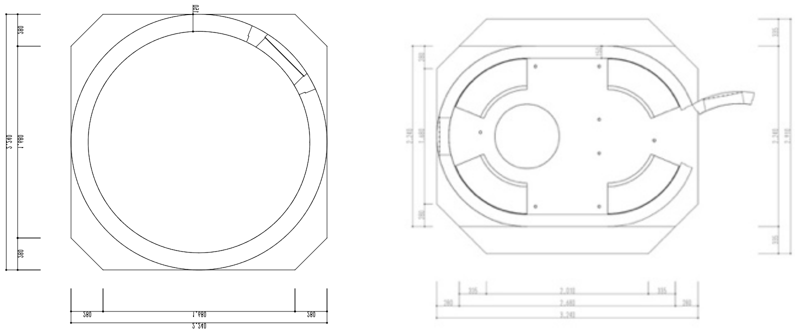


Figure 2: Tsunami shelters plan (left: SAM, right: SAMLIFE)

SAM SAMLIFEVer.1 SAMLIFEVer.2 SAMLIFEVer.3

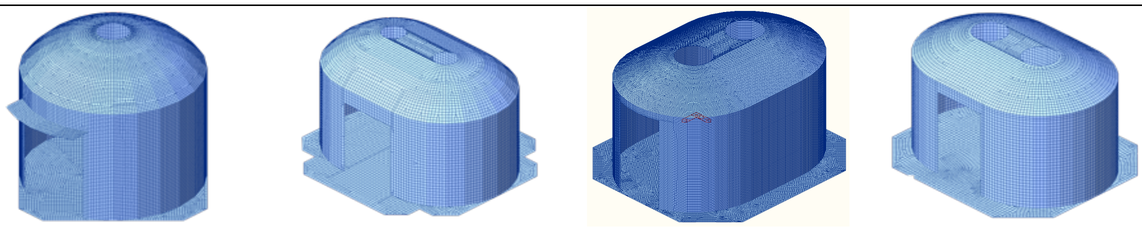


Figure 3: Tsunami shelter analysis model

Table 1: Tsunami Shelter Analysis Specifications

Analysis Software	MIDAS iGen (Ver. 920 R 1x)		
Element Type	Plate elements		
Element size (Number of elements)	SAM	20mm x 20mm (23159 elements)	
	SAMLIFE	20mm x 20mm (71790 elements)	
board thickness	Ceiling, wall: 150mm Floor: 300mm		
Material Properties	Board thickness	E_T^2 (N/mm^2)	ρ_T^3 (kg/m^3)
	Without polyurea	19.3	50.0
	With polyurea	51.2	73.4
Analytical Form	Static Linear Analysis		

The size of SAM is 2.24m x 2.24m x 2.25m (length x width x length), and the size of SAMLIFE is 3.24m x 3.24m x 2.25m (length x width x length). In addition, when analytical modeling of real objects is performed, items that do not serve as structural members (windows, chairs, etc.) are not considered, since they are not load-bearing members.

The loads applied to SAM and SAMLIFE are calculated by referring to an actual experiment conducted by Onoda Sangyo in which a car body was free-fallen from a height of 10 meters. The calculations are as follows.

$$\mathrm{F} = \frac{mv}{\Delta t} \tag{1}$$

F Impact load (N)
m Mass (kg)
v Velocity (m/s)
Δt Time to standstill (s)

The resulting impact load is 352.8 kN. This load is equally distributed to the nodes of the model, the analysis is performed, and the deformation and stress levels during the analysis are measured.

The measurement is made with the opening as the front, and the loads are applied to the sides, back, and roof.

For the material properties of styrene foam coated with polyurea resin, the experimental values obtained by loading styrene foam coated with polyurea resin are used as reference. The experimental site was a 55mm x 100mm x 1300mm specimen that was sprayed with polyurea resin, and stress levels were calculated from the loads and moments applied at that time.

The stress values for styrene foam alone and polyurea coated styrene foam are 0.27 N/mm^2 and 6.97 N/mm^2. Using these values as a reference, a comparison was made with the stress levels obtained from the analytical model, and if the values exceeded the values, the model was considered to have ruptured.

3. Analysis results

3.1. SAM analysis results

Load values obtained in (1) are placed in four patterns: roof (near the opening in the ceiling), front (opening with a door), back (opposite the door), and side (at 90 degrees from the door).The maximum displacement and stress results for the SAM are shown in Table 2, and the analytical results are shown in Figure 4.

Table 2: Maximum displacement and maximum stress in SAM

shock part	Maximum displacement (mm)		Stress intensity (N/mm^2)
	Without polyurea	polyurea	
roof	380.78	143.57	1.77
the front	408.74	154.07	8.46
back	246.89	93.06	1.95
side	302.90	114.17	5.92

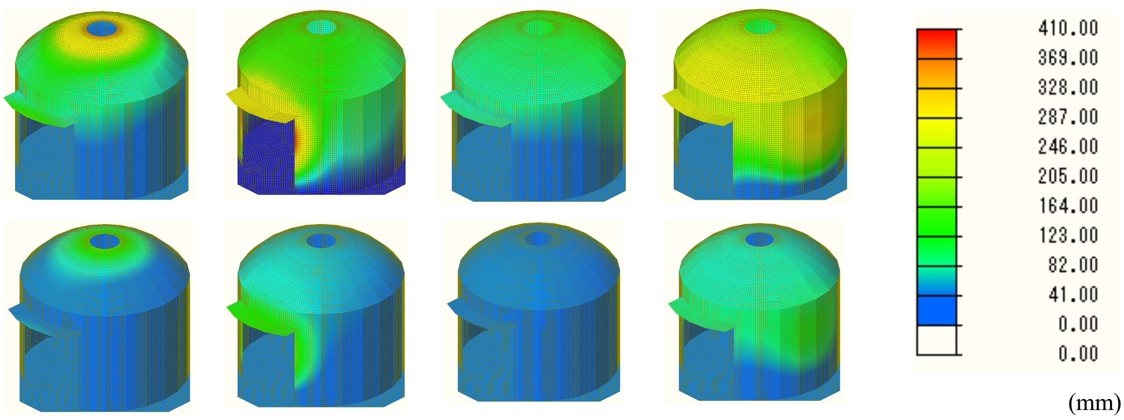


Figure 4: SAM_Analysis Results (From left to right: roof, front, side, back / Polyurea with top, without bottom)

The largest displacement occurred when the load was applied from the front without the polyurea resin coating. In this case, the deformation was about 2.65 times greater than when the polyurea resin was applied.

In the case of rupture, the polyurea-applied product did not rupture unless it was subjected to a frontal load, while the product without the polyurea coating ruptured when impact was applied from any direction.

3.2. SAMLIFE analysis results

A summary of the maximum displacement results for SAMLIFE is shown in Table 3, and the analytical results are shown in Figures 5.

Table 3: Maximum displacement and maximum stress in SAMLIFE

	With/Without polyurea	Roof	Front	Side	Back
SAMLIFE Ver.1	With	832	576	374	241
	Without	313	217	140	90
SAMLIFE Ver.2	With	1713	706	314	439
	Without	646	266	118	165
SAMLIFE Ver.3	With	783	551	437	246
	Without	295	207	164	92

(mm)

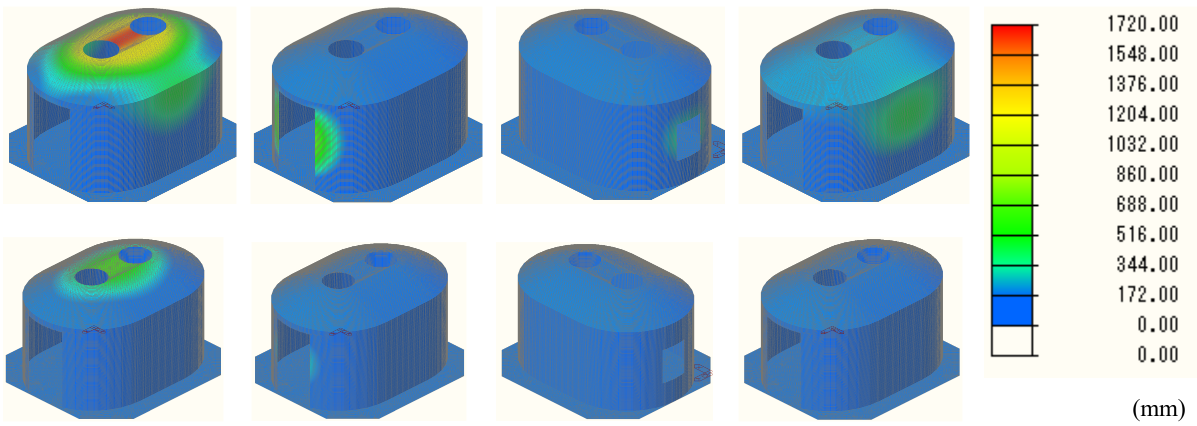


Figure 5: SAMLIFE_Analysis Results

(From left to right: roof, front, side, back / Polyurea with top, without bottom)

The largest displacement occurred when the load was applied from the front without the polyurea resin coating. In this case, the deformation was approximately 2.65 times greater than when the polyurea resin was applied.

The following results show that the openings have doors and windows and are more likely to be unbreakable than the actual analysis performed. However, they are not necessarily capable of absorbing sufficient impact because they are not designed to protect the interior. Therefore, it is considered that the use of apertures that are as small as possible will bring about a greater effect than before.

Therefore, we will examine the impact mitigation of SAMLIFE with a door as small as possible and with a circular human ventilation hole, which is less likely to bias the impact. (Hereafter referred to as SAMLIFE ver. 4) Table 4 shows the results of comparing the stress levels of SAMLIFEver.3 and SAMLIFEver.4.

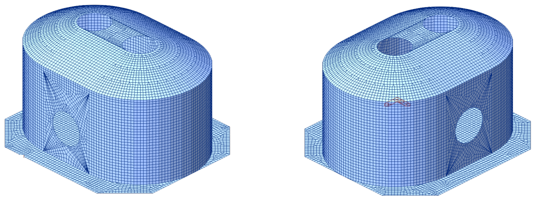


Figure 6: SAMLIFEver.4 analysis model

Table 4: Comparison of SAMLIFE Ver.3 and Ver.4

Load Description		Reproduction of experiments				See Ministry of Land, Infrastructure, Transport and Tourism			
Load Area		Roof	Front	Side	Back	Roof	Front	Side	Back
Stress intensity (N/mm^2)	Ver.3	3.22	5.79	4.32	4.63	0.25	1.80	0.33	0.36
	Ver.4	2.92	4.54	5.15	4.70	0.23	1.42	0.40	0.37

No rupture was observed in SAMLIFEver.4. Compared to ver.3, which has the closest geometry to SAMLIFE ver.4, SAMLIFE ver.4 showed lower stress in the case of roof loading and front loading, but higher stress in the case of side loading and rear loading. The reason for this is that the larger openings in the roof increase stress levels. The window on the back of SAMLIFEver.3 is about 0.37m^2 and 1.13m^2 for SAMLIFEver.4, which is thought to be the reason for the difference.

4. Study on a model

4.1. SAMFloat6

The tsunami shelter SAM is 2.24 x 2.24 x 2.25 (m) in size, which would be somewhat large if it were to be stationed in an ordinary home. Therefore, we consider a smaller sized tsunami shelter. The first step is to consider the shape of the shelter that is the most difficult to drift away from the land in the event of a tsunami. We created a simple model of a circle or a hexagonal shape, and tested it in running water.
As a result, a hexagonal model was the hardest to flow, so a model was created with a hexagonal base. In doing so, the model was created with a side size of 1.0 m and a height of 1.3 m.
The analytical model is shown in Figure 7. The shelter devised is shown in Figure 8. (Hereafter referred to as SAMFloat6).

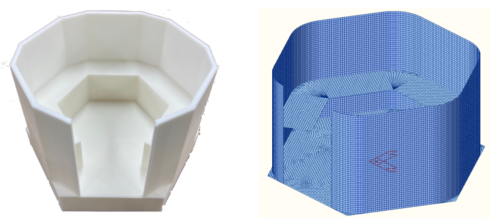


Figure 7: SAMFloat6 model and analytical model

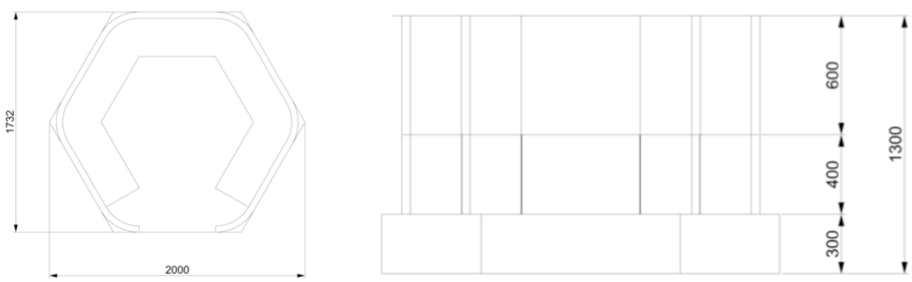
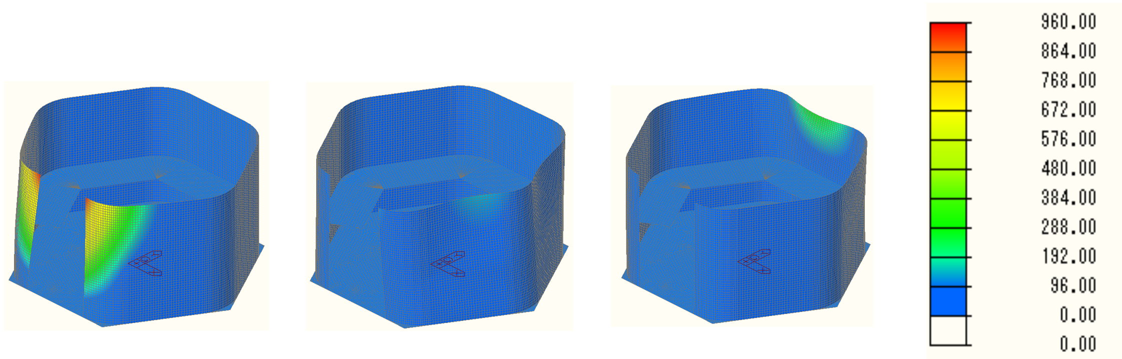


Figure 8: SAMFloat6 shelter plan

Let us add the impact load described earlier to SAMFloat6. In addition, referring to the tsunami lifeboat guideline[1)] defined by the Ministry of Land, Infrastructure, Transport and Tourism, the analysis is performed with the loads assuming a frontal impact at 10 m/s and a side impact at 5 m/s, which are the reference values for impact with a structure. The analysis results are shown in Figure 9.



(mm)

Figure 9: SAMFloat6_Analysis Results

Table 5: SAMFloat6_Analysis results for stress intensity

	Front	**Side**	**Back**
Stress (N/mm^2)	22.05	4.27	4.62

Table 5 shows that the product is unlikely to withstand frontal impacts, but can withstand side and rear impacts. Also, we consider that the placement of the SAMFloat6 door will reduce the stress level, and therefore, depending on future installation methods, the design may be able to withstand frontal impacts.

4.2. Spherical shelter

When setting up a shelter, transporting the shelter in an assembled state requires a variety of preparations and labor. A foldable or assembled shelter requires more time than an assembled one, but the advantages in terms of transportation are very significant. In earthquake-stricken areas, roads are often littered with obstacles, making it difficult for large vehicles to pass through. With this in mind, we will devise a shelter that can be carried in a disassembled state and easily installed. In recent years, the development of 3D printers using styrene foam has opened up various possibilities in construction technology. Therefore, we will devise a shelter that can be assembled using the polyurea resin in this study.

The shelter we devised is shown in Figure 10. （The shelter is divided into 23 parts, which are assembled to resemble a sphere.) This spherical shelter consists of 23 parts, which are assembled to resemble a sphere. The joints of each part are made of polyurea resin, and there is one opening for an entrance and two openings for windows.

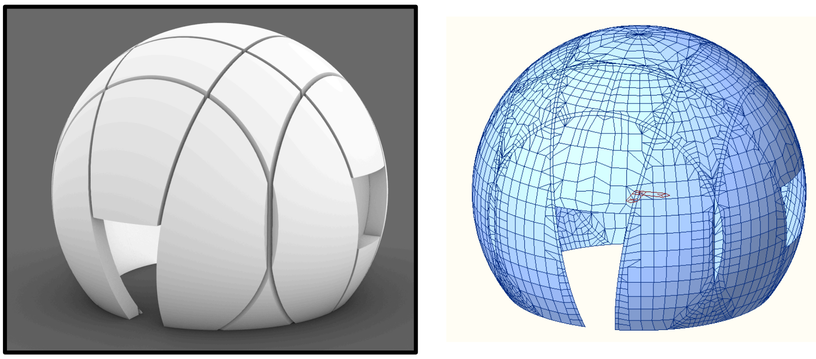


Figure 10: Model of a spherical shelter

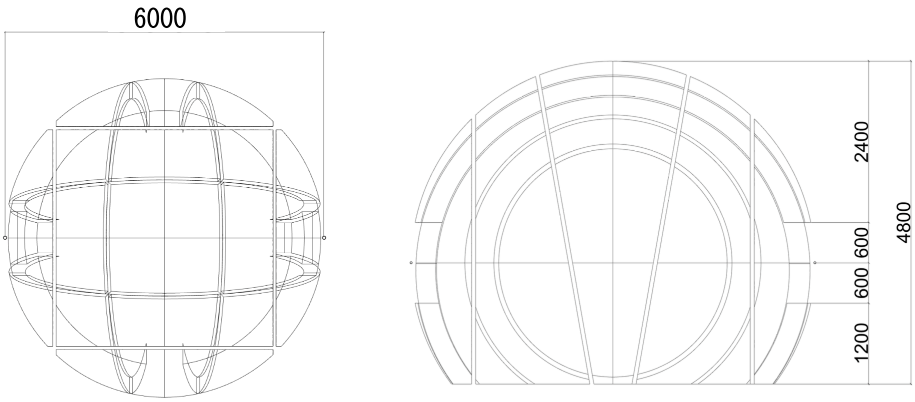
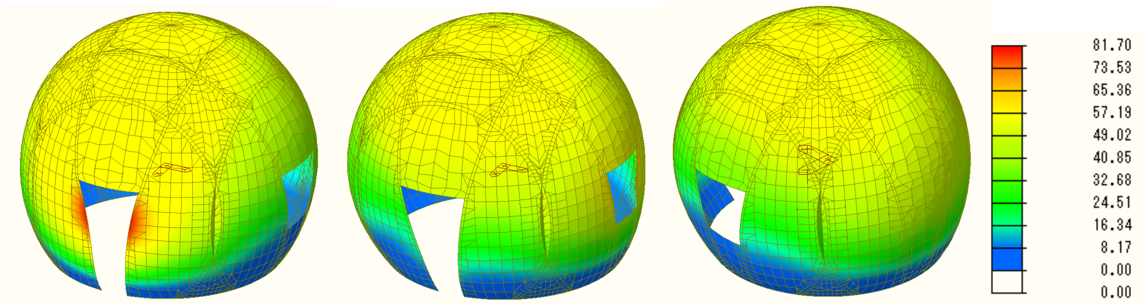


Figure 11: Floor plan of a spherical shelter

The analytical model is shown in Figure 12. In this analytical model, the thickness of the joint is 200mm and the thickness of the rest is 300 mm. Comparison with SAM and SAMLIFE is made by referring to the loads obtained in (1) on this sphere-shaped shelter. The displacement results of the spherical shelter are shown in Figure 12, and the stress analysis results are shown in Table 6.



(mm)

Figure 12: Spherical shelter _Analysis Results

Table 6: Spherical shelter_Analysis results for stress intensity

	Front	**Side**	**Back**
Stress (N/mm²)	1.36	1.23	1.17

Table 6 shows that the possibility of rupture is low even if the material is subjected to the referenced impact from all directions; compared to SAM and SAMLIFE, the stress level values are lower, and one of the reasons cited is that the impact area is spherical and the impact is dispersed.

5. Analysis by Tsunami wave pressure

This analysis is based on the assumption that the 1/50-scale tsunami shelter SAM at Tokai University was subjected to a simulated tsunami in a hydrographic experiment, and on a simulation in accordance with the Structural Design Method for Tsunami Evacuation Buildings. In both cases, the results of static loads applied in the horizontal direction are described.

The structural design method requires the input of trapezoidal distributed loads that vary with height, as shown in the figure. Since distributed loading is not possible in this analysis, a nodal loading method is used to concentrate the range of distributed loads between nodes at a single point.

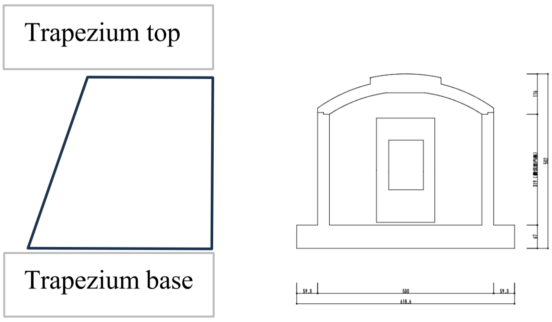


Figure 13: Drawing of 1/50 scale tsunami shelter

The results of the analysis in accordance with the structural design method for tsunami evacuation buildings are presented. The displacement contours are shown in Figure 14 and the values of the maximum displacement and stress values in Table 7.

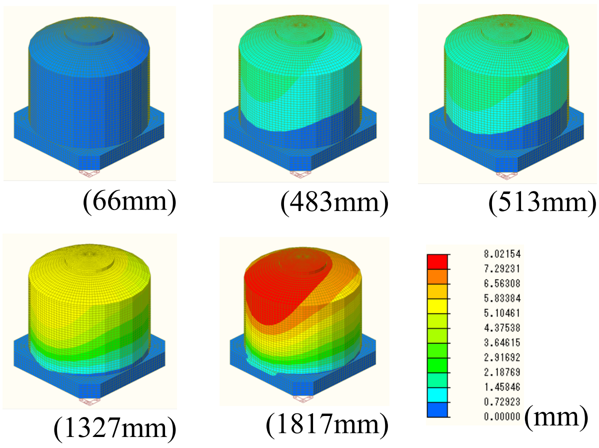


Figure 14: Tsunami wave pressure_displacement contours

Table 7: Load input conditions for 1/50 scale tsunami shelter

Height of inundation (mm)	Tsunami wave pressure (kN/m^2)	Maximum displacement (mm)	Stress (N/mm^2)
66	Trapezium top:1.3 Trapezium base:1.9	0.0040	0.0035
483	Trapezium top:9.3 Trapezium base:14.2	1.6103	0.3541
513	Trapezium top:10.2 Trapezium base:15.1	1.8117	0.3944
1327	Trapezium top:34.1 Trapezium base:39.0	5.7605	1.2333
1817	Trapezium top:48.5 Trapezium base:53.5	8.0215	1.7153

6. Conclusion

A summary of this study is presented below.
From the analysis, it was confirmed that the polyurea resin coating significantly reduces deformation and improves strength compared to when styrene foam is used as a stand-alone material.
The analysis shows that SAMLIFE is less likely to rupture than SAM. This is due to its structure that can easily disperse impacts.
The analysis shows that the area with the door on both SAM and SAMLIFE was structurally weak. It can be seen that the larger the impact area, the smaller the possibility of rupture. It was also found that the collision area was more resistant to impact if the collision area was not a flat wall, but an arc-shaped wall.
The analysis shows that SAMFloat6 is weak against frontal impacts but strong against side and rear impacts, and that the spherical shelter is strong against frontal impacts. In order to use the spherical shelter practically, we will make an actual model and conduct experiments in the future.

Acknowledgements

This research was made possible by the cooperation and generous assistance of Onoda Sangyo Co. We would like to express our gratitude to them.

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