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THE ROLE OF STRUCTURAL SIMULATIONS IN DEVELOPING INNOVATIVE SAFETY CAPSULES

Abstract: *Structural simulations play a crucial role in the development of new products, particularly in the early design phase, where insights into performance under different load conditions can significantly influence design choices. This paper explores the application of structural simulations in developing the " Emergencies Safety Capsules", an innovative housing solution, highlighting the necessity and benefits of these simulations in creating safe, reliable, and efficient designs.*

Key words: *Capsules, Design, Shelter, Solutions, Engineering, Industrial Engineering, CAD, CAE.*

1. INTRODUCTION

In the design and development of new products, particularly those intended for structural safety and load-bearing applications, such as the Emergencies Safety Capsules, understanding how materials and configurations behave under different conditions is essential. Traditional physical testing methods, while effective, can be costly and time-consuming and sometimes even dangerous. Structural simulations offer a cost-effective and efficient alternative, enabling designers to predict how a structure will respond to various forces and scenarios. This paper discusses the necessity of these simulations, illustrating how they can enhance product reliability, safety, and innovation. [1]

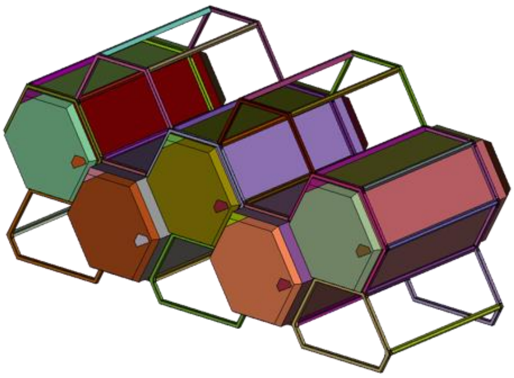

Figure 1 Assembly of Safety Capsules

2. OVERVIEW OF SAFETY CAPSULE DESIGN METHOD

The Emergencies Safety Capsule, designed to provide secure and durable shelter, comprises five PMMA (Polymethyl Methacrylate) [2] capsules supported by a honeycomb HDPE (High-Density Polyethylene) [3] structure. PMMA is chosen for its clarity and impact resistance, making it suitable for creating a secure and transparent enclosure. HDPE, known for its strength, stiffness, and chemical resistance, is used to construct the supportive honeycomb structure, ensuring durability and safety under various conditions. The combination of these materials promises to offer a reliable and efficient shelter solution, especially when considering as well the recyclability of the materials. [4]

Figure 2 PMMA

3. IMPORTANCE OF STRUCTURAL SIMULATIONS

3.1. Predicting Structural Performance

Structural simulations allow to predict how the entire assembly will behave under different loading conditions, such as vertical and angular loads. Both load cases were build using a rigid plane which would push on the structure with a specific load. The plane is also fixed in all directions except the one in which the force is applied. [5]

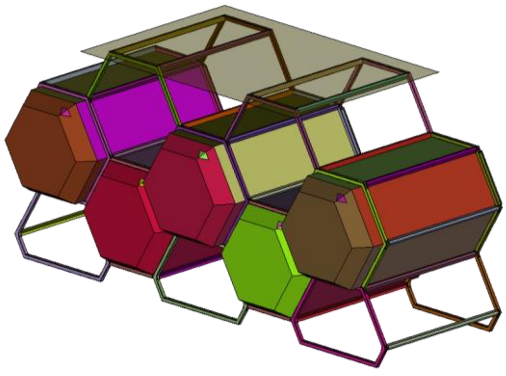

Figure 3 Vertical Load

The type of load used was dynamic because:

- dynamic load, even with the same weight, is more damaging than a static load.
- dynamic loads involve movement and changing forces, which can cause greater stress and strain on materials and structures compared to stationary loads

Since the maximum weight of the fully loaded assembly is 3250kg the load applied in the vertical load test is 31882.5N. For the angular test, the load applied is 24525.0N which is equivalent to 2500kg.

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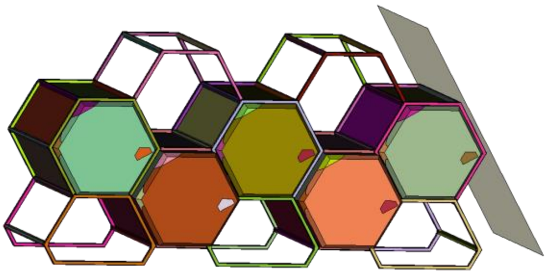

Figure 4 Angular Load

In the CAE model, the area which would be in contact with the ground was modelled as a rigid part with blocked translation and rotation (red highlights).

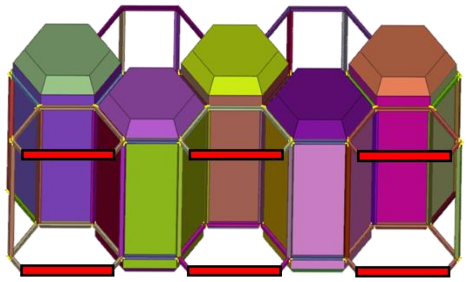

Figure 5 Fixing Points

By using computer-aided engineering (CAE) tools, such as Ls-Dyna [6], designers can model these scenarios, assessing how the pod and its supporting structure respond to stresses and strains. This predictive capability is crucial for identifying potential weaknesses in the design before physical prototypes are built

3.2. Identifying critical load cases

In the case of the Safety Capsule Assembly, simulations were conducted for both vertical and angular load cases.

The simulation was run for 100 msec.

When applying the load, the intention was for the force to also reach a plateau. The following curve was used:

TIME (msec)	LOAD (N)
0.0	0.0
0.75	1
1	1

Then for each specific load case (vertical and horizontal) the Y-axis was scaled according the loads mentioned above.

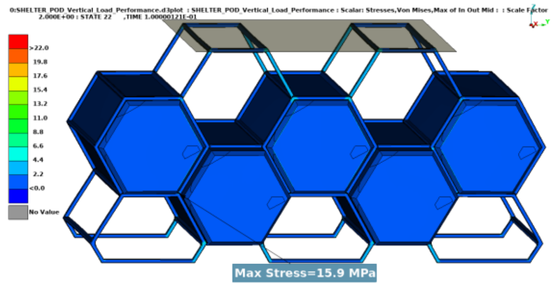

Figure 6 Results Vertical Load

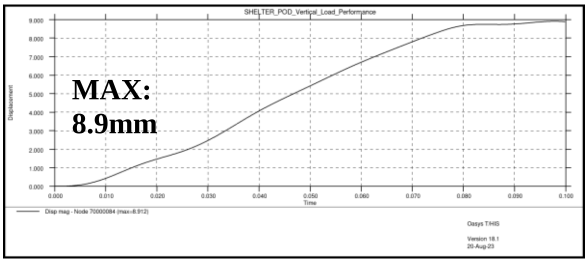

Figure 7 Graphic Vertical Load Stress

The Yield stress for HDPE and PMMA is 22 and 65 MPa respectively. As it can be seen in the angular load case a max stress of 21.3 MPa can be observed on the structure which indicates that in that region the material is close to its elastic limit. However, since the limit of 22 MPa is not passed there is no plastic strain (all deformations are still in the elastic range).

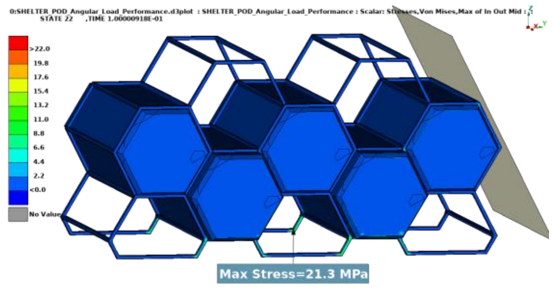

Figure 8 Results Angular Load

Additionally, as expected, the angular load case is more disfavored since the rigid plane moved 10.4mm while in the vertical load case the impactor plane only moved 8.9mm

Understanding these critical load cases allows designers to implement necessary design reinforcements, such as adding longitudinal braces, ensuring the structure can handle unexpected loads in real-world scenarios.

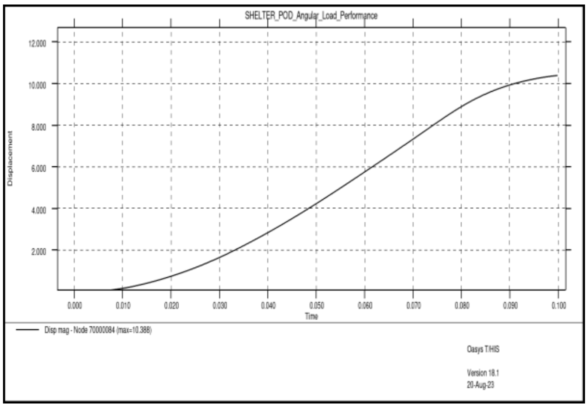

Figure 9 Graphic Angular Load Stress

3.3. Ensuring Safety and Compliance

Simulations provide a detailed view of stress distribution within the pod and its supporting structure. The analysis showed that the maximum stress levels were close to the material's yield point but did not exceed it, indicating that the design would remain within safe elastic limits under expected loads.

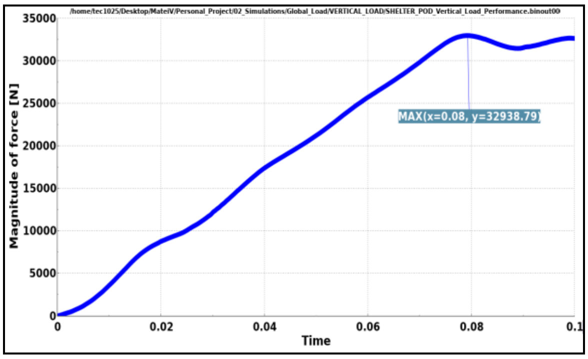

Figure 10 Magnitude of Vertical Load

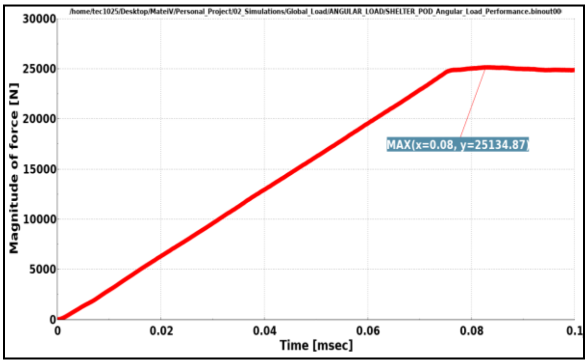

Figure 11 Magnitude of Angular Load

Due to the deformations that occur in the model during the run it is expected to see some fluctuations in the contact force although the force applied on the impactor had a linear increase and a plateau.

The aim was to assure the fact that the required force is applied on the model and that we observe a stabilization of the force towards the end of the simulation.

In both cases, even if fluctuations are observed, we see that the expected load is achieved with even some peaks which are higher

This insight is critical for ensuring that the product meets safety standards and regulations, reducing the risk of structural failure and enhancing user safety.

4. ENHANCING DESIGN EFFICIENCY AND INNOVATION

4.1. Cost Reduction and Time Efficiency

By using simulations, the need for numerous physical prototypes is reduced, saving time and resources. This efficiency allows for faster iterations of the design, where modifications can be tested virtually before physical models are made. [7]

Simulations have helped creating the ideal frame for the capsules. The structure is constructed out of box sections (10mm wall thickness) with chamfered edges while keeping the hexagonal pattern.

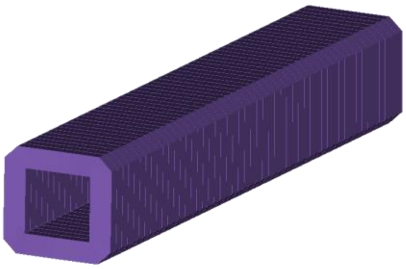

Figure 12 Frame Section

The reasons of which a box section was used instead of a solid were:

- The ability of passing several electrical wires
- Weight reduction
- Cost reduction

There are also some elements form the full CAD model that are not present in the CAE model. However, those were represented by adding the respective mass to the model in order to keep the same weight and COG (center of gravity) in the CAE as in the CAD model.

The overall mass of the assembly is 2500kg.

Each pod was then assumed to hold another 150kg (person + luggage), thus brining the overall mass of the fully loaded assembly to 3250 kg.

This approach not only accelerates the development process but also reduces costs associated with material wastage and labor.

4.2. Optimizing Material Use

Simulations enable designers to experiment with different materials and configurations, optimizing the use of materials without compromising structural integrity. [8] For the Emergencies Safety Capsules, the use of HDPE and PMMA was validated through simulations to ensure they provided the necessary strength and durability while being lightweight and cost-effective.

Knowing therefore the maximum weight of the assembly after the detailed design was completed, we can estimate the material costs to be at best for:

- basic model – 3600 euros;
- extra space model - 4000 euros;
- energy independent model – 5800 euros;

This optimization is crucial for sustainable design, minimizing environmental impact, and maximizing resource efficiency.

5. REAL-WORLD APPLICATIONS AND FUTURE DIRECTIONS

The insights gained from simulations are directly applicable to the real-world deployment of the Emergencies Safety Capsules Assembly. By confirming that the design can withstand various load conditions, manufacturers can confidently produce and test one of these assemblies in real-life situations to compare the results with the simulations.

If the data correlate, it will validate the effectiveness of the simulations, providing a strong foundation for mass production. This validation process ensures that the assembly can reliably perform as expected, making it suitable for deployment in diverse environments, from disaster relief zones to urban housing solutions for homelessness.

Leveraging simulation-based optimization not only validates designs but also drives innovation by enabling rapid prototyping and iteration.

6. CONCLUSIONS

Structural simulations are indispensable tools in modern product development, providing valuable insights into the behavior of materials and structures under different conditions.

The case study of the Emergencies Safety Capsules demonstrates how simulations can guide the design process, ensuring safety, reliability, and cost-effectiveness. As simulation technologies continue to advance, their role in engineering will become even more critical, enabling the creation of innovative new products that meet the evolving needs of society.

Bibliography

[1] J. D. S. David N. Forda, *Dynamic modeling of product development*, System Dynamics , vol. 14, 1998.

[2] Procurement Resource, *High_Density Polyethylene(HDPE) Price Trent and Forecast*, Procurement Resource, 2024. [Online]. Available: https://www.procurementresource.com/resource-center/high-density-polyethylene-hdpe-price-trends. [Accessed 2024].

[3] By Team Xometry, *Everything You Need To Know About Acrylic (PMMA)*, 4 May 2022. [Online]. Available: https://www.xometry.com/resources/materials/acrylic-pmma/.

[4] G. C. J.-l. D. Hugo Festjens, *A numerical tool for the design of assembled structures under dynamic loads*, International Journal of Mechanical Sciences, vol. 75, 2013.

[5] British Plastic Federation, "Polyethylene (High Density) HDPE," British Plastic Federation, [Online]. Available: https://www.bpf.co.uk/plastipedia/polymers/HDPE.aspx.

[6] https://lsdyna.ansys.com/, ANSYS, [Online]. Available: https://lsdyna.ansys.com/.

[7] PTC, S*imulation-Led Design: Democratizing the Power of Simulation*, PTC, [Online]. Available: https://www.ptc.com/en/resources/cad/white-paper/simulation-led-design.

[8] D. Z. P. W. S. K. C. S. S. Poulikidou, *Materials & Design*, Science Direct, vol. 83, pp. 704-712, 2015.

[9] Advanced Plastiform, *Types of Plastic Molding*, Advanced Plastiform, [Online]. Available: https://advancedplastiform.com/6-types-of-plastic-molding/.

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