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STRUCTURAL PERFORMANCE OF A GEODESIC DOME AGAINST FLOODS: EVALUATION OF A PNEUMATIC LIFTING SYSTEM

DESEMPENHO ESTRUTURAL DE UM DOMO GEODÉSICO FRENTE A INUNDAÇÕES: AVALIAÇÃO DE UM SISTEMA PNEUMÁTICO DE ELEVAÇÃO

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ABSTRACT

The loss of homes due to natural disasters and floods collapses quality of life globally, demanding resilient emergency shelters. This article aims to report the empirical evaluation of a temporary shelter (geodesic dome) integrated with a manual pneumatic lifting mechanism. The methodology encompassed structural sizing via 3D CAD software and the physical fabrication of a 3V geodesic mesh with 75 modular panels. The prototype was positioned on an expanded polystyrene platform associated with a 50-liter tank to simulate floods, using four volumetric pneumatic actuators as the lifting apparatus. Three flood-depth scenarios, calibrated against parallax errors, were simulated: 0-2.0 cm, 2.0-4.5 cm, and 4.5-7.0 cm. Results demonstrated that staged actuation stably elevated the dome, operating within a 0.2 cm safety margin at each threshold, keeping the superstructure emerged and the internal zone isolated. In conclusion, integrating active lifting mechanisms yields highly efficient protection against flooding and technical feasibility for socio-environmental risk mitigation.
Keywords: Natural Disasters; Geodesic Dome; Temporary Housing; Floods; Pneumatic System.

RESUMO

A perda de lares por desastres naturais e inundações colapsa a qualidade de vida globalmente, exigindo a construção de abrigos resilientes. Este artigo objetiva relatar a testagem experimental de um abrigo temporário (domo geodésico) equipado com sistema pneumático de elevação manual. A metodologia englobou o dimensionamento em software CAD 3D e a construção física de uma malha 3V com 75 painéis modulares. O protótipo foi posicionado sobre uma plataforma de poliestireno expandido associada a um aquário de 50 litros para simular inundações,

utilizando quatro atuadores pneumáticos volumétricos como mecanismo de elevação. Simularam-se três cenários hídricos corrigidos contra erros de paralaxe: 0-2,0 cm, 2,0-4,5 cm e 4,5-7,0 cm. Os resultados demonstraram que o acionamento escalonado elevou o domo de forma estável, operando com margem de segurança técnica de 0,2 cm em cada nível, mantendo a estrutura emersa e o ambiente interno isolado. Conclui-se que a integração de estruturas levadiças ativas oferece proteção eficiente contra alagamentos e viabilidade técnica para mitigar riscos socioambientais.
Palavras-chave: Desastres Naturais; Domo Geodésico; Habitação Temporária; Inundações; Sistema Pneumático.

1. INTRODUCTION

Annually, extreme meteorological events—particularly severe inundations and river basin overflows—inflict catastrophic structural damage on urban centers, triggering the forced displacement of vulnerable communities worldwide (ONU NEWS, 2020). The abrupt destruction of residential infrastructure not only destabilizes local economies but also precipitates profound psychological and public health crises among affected families (FOLHA DE S.PAULO, 2023).

This phenomenon is heavily driven by socio-environmental vulnerability, a condition wherein marginalized social strata intersect with areas of severe ecological degradation, such as floodplains and deforested regions (FREITAS *et al.*, 2014; ALEKSIĆ *et al.*, 2016). Driven by the rapid acceleration of climate change, the demand for adaptive and resilient emergency housing has become unprecedentedly urgent (HENRIQUES; LOPES, 2019). Consequently, exceptional flood crises require immediate, technologically advanced interventions from both state authorities and the private sector to safeguard human lives (KOBIYAMA *et al.*, 2006).

Projections delineate an alarming trajectory: Spink (2014) highlights that the population exposed to catastrophic flooding could reach two billion by 2050. In response, modern engineering and construction sectors are increasingly prioritizing the development of rigorously tested, reliable habitability solutions (CASA E MERCADO, 2023).

Within this context, the present study addresses a critical engineering challenge: is it mathematically and structurally feasible to design a temporary shelter that actively mitigates the impacts of rising water levels? To address this, this article presents the experimental validation of a geodesic dome prototype integrated with a pneumatic lifting foundation. The primary objective is to evaluate the structure's hydrodynamic performance and mechanical buoyancy within a simulated flow bench across three severe flood stages.

2. THEORETICAL FRAMEWORK

Designing emergency housing for flood-prone regions necessitates a rigorous intersection of architectural geometry, hydrodynamic engineering, and proactive disaster mitigation (ANDERS, 2007; NAPPI; SOUZA, 2017). Historically, conventional emergency shelters have prioritized rapid deployment and economic feasibility — a paradigm that frequently overlooks the structural resilience required to withstand prolonged aquatic exposure and intense hydrodynamic drag (HONG, 2017).

The implementation of a geodesic dome yields intrinsic mechanical advantages; its spherical, triangular-based mesh efficiently dissipates external stresses and facilitates fluid bypass, thereby preventing catastrophic structural collapse (RESENDE *et al.*, 2022). Nevertheless, even an aerodynamically and hydrodynamically superior superstructure is rendered ineffective if its underlying foundation becomes submerged.

To mitigate the specific threat of severe inundations, contemporary engineering paradigms emphasize the imperative of dynamic foundations. Integrating mechanical actuators or pneumatic elevation platforms represents a pivotal technological shift, enabling the habitable space to physically elevate above hazardous water levels and rushing debris. Consequently, validating these active defense mechanisms demands rigorous empirical testing in scaled flow benches to establish reliable Flood Damage Curves (FDC). Such laboratory protocols ensure that the lifting apparatus can smoothly and securely sustain the structural load during critical inundation peaks.

3. METHODOLOGY

This research is characterized as exploratory and experimental, employing a hypothetico-deductive approach grounded in direct empirical observation. The methodological framework was structured into two primary phases: the computational architectural design of the shelter, and the physical fabrication and subsequent empirical testing of the dynamic lifting apparatus.

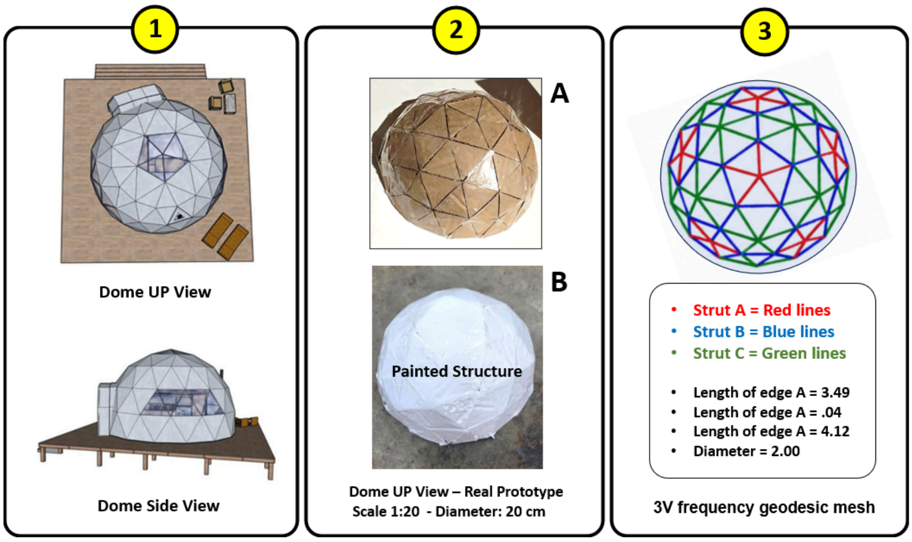
3.1. Physical model construction

To conduct the physical flood resistance assays, a scaled physical model of the dome was manually fabricated at a 1:20 scale. Subsequently, the project was modeled using Computer-Aided Design (CAD) software, proposing a shelter in the shape of a geodesic dome designed to comfortably accommodate up to four individuals.

For the construction of the geodesic model, a modular panel assembly methodology was adopted, utilizing a 3V frequency structural scheme as a reference. The structural sizing was based on three distinct typologies of linear elements, designated as struts A, B, and C. These struts were standardized with the following specifications: strut A was dimensioned with a length of 3.49 cm and 80.00° cuts; strut B with 4.04 cm and 78.30° angles; and strut C with 4.12 cm and 78.00° angles. The final configuration comprised the spatial assembly of 75 prefabricated panels (Figure 1 – item 3).

Regarding the materials utilized, the components were crafted from modeling cardboard (Figure 1 – item 2). Following the precise spatial positioning of the nodes, wood glue was applied as a permanent bonding agent. Finally, the surface of the prototype underwent a two-stage finishing treatment: a sealer was applied for waterproofing, followed by a homogeneous layer of white spray paint to ensure additional structural protection and aesthetic fidelity.

Figure 1. Construction sequence and structural assembly of the physical model.



Source: Elaborated by the author.

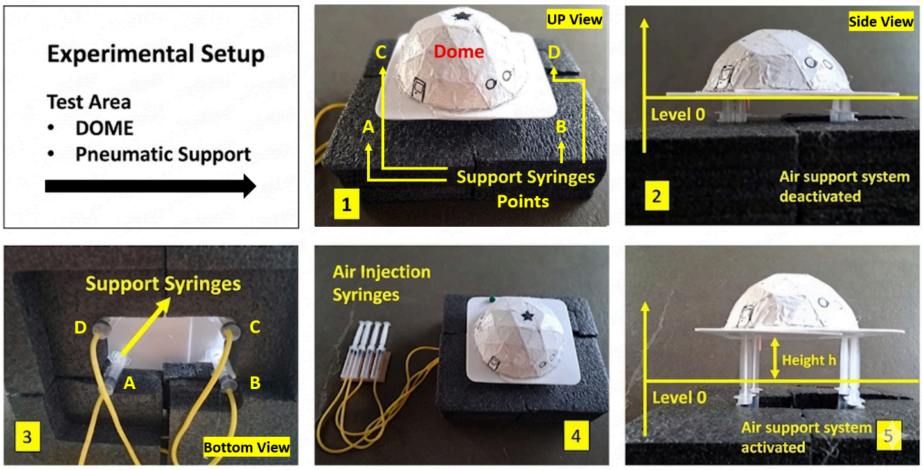
3.2. Experimental Flow Bench Setup

To execute the inundation and fluid flow assays, a specialized experimental apparatus was structured for hydrodynamic analysis. The fabricated geodesic dome was positioned onto a rectangular expanded polystyrene (EPS) platform, engineered to simulate the foundation of a real-scale residential floor. This comprehensive apparatus was subsequently positioned behind a glass tank with a volumetric capacity of 50 liters (Figure 2).

The instrumentation of the active lifting system comprised the installation of four (4) volumetric pneumatic actuators — modeled utilizing standardized 20 mL syringes — which were fixed vertically immediately beneath the supporting platform (Figure 2). These primary actuators served as the core of the pneumatic elevation infrastructure, mechanically coupled via pneumatic tubing to a secondary assembly of air injection cylinders situated outside the tank. The underlying mechanical principle dictates that the manual injection of air into the circuit expands the internal plungers, thereby promoting the stable vertical displacement of the platform and, consequently, of the overarching dome superstructure.

Figure 2 illustrates the layout of the experimental apparatus. In Figure 2 (Image 1), a top-down view depicts the geodesic dome resting on four mobile pneumatic structures, designated as Points A, B, C, and D. Figure 2 (Image 2) showcases the baseline condition (zero level) of the mobile pneumatic platform in its inactive state. Figure 2 (Image 3) displays the four attachment nodes for the syringes (Points A, B, C, and D), while Figure 2 (Image 4) provides a comprehensive view of the entire pneumatic assembly integrated with the dome. Finally, Figure 2 (Image 5) demonstrates the dome positioned at its maximum elevation with the pneumatic system fully activated.

Figure 2. Experimental setup detailing the pneumatic lifting system actuators.

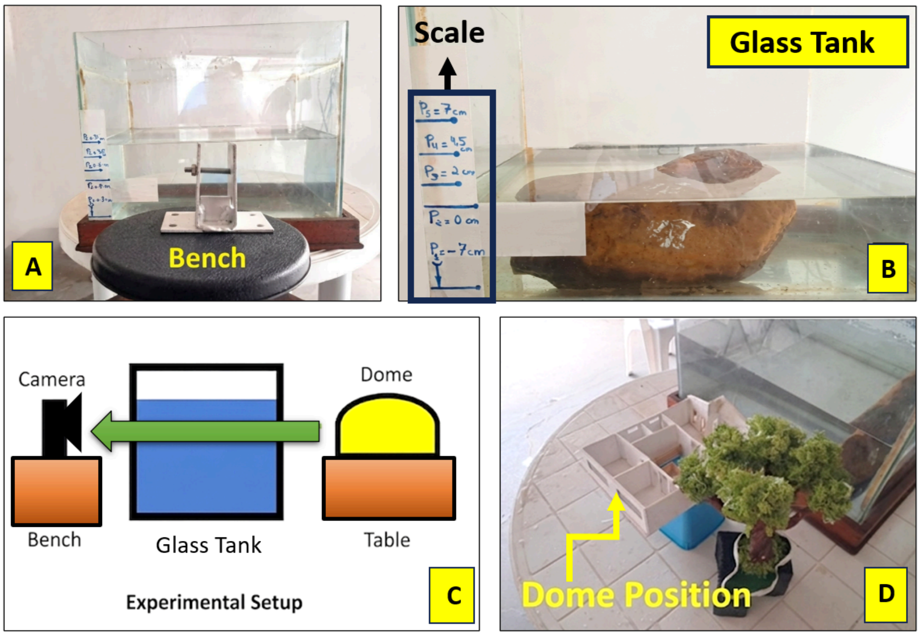


Source: Elaborated by the author.

To validate and control the inundation simulation, a metric graduation scale was securely affixed to one of the transparent faces of the glass tank (Figure 3). This volumetric delimitation enabled the execution of the empirical assays across three precise stages of flood depth: ***0 to 2.0 cm (Level 1), 2.0 to 4.5 cm (Level 2), and 4.5 to 7.0 cm (Level 3).***

Figure 3A illustrates the camera mounting infrastructure (bench) utilized to record the comprehensive progression of the empirical assay. Positioned in front of the mount is the glass tank, into which water was introduced to simulate an inundation event, adhering strictly to the predefined levels indicated on the graduation scale (Figure 3B). The experimental apparatus was configured as depicted in Figure 3C, with the geodesic dome positioned behind the glass tank, which in turn is situated behind the camera assembly. This specific spatial arrangement creates a visual effect of fluid flow over the overarching dome superstructure. Furthermore, Figure 3D highlights the relative positioning of the dome, which, in this particular instance, is evaluated alongside an additional structure representing a conventional residential unit.

Figure 3. Filming setup configured to eliminate parallax errors during fluid progression.



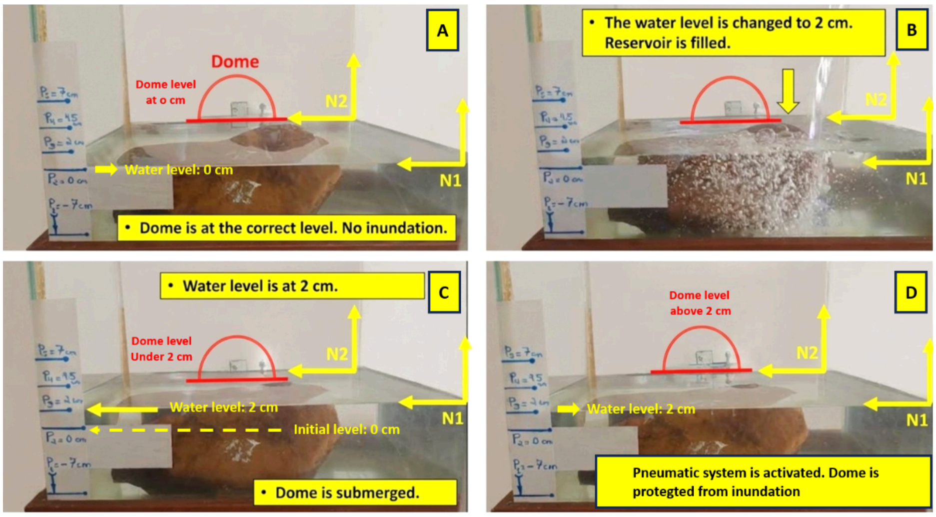
Source: Elaborated by the author.

4. RESULTS AND DISCUSSION

The empirical validation consisted of the sequential and continuous execution of controlled inundation events within the glass tank, combined with the responsive activation of the shelter's pneumatic lifting system at each critical threshold reached by the water level. The operational architecture was rigorously engineered to maintain a technical safety margin of 0.2 cm, thereby ensuring the structural floor remained safely and consistently above the water level throughout the entirety of the inundation hazard.

The first phase of the experiment evaluated the structural response across a depth profile ranging from 0 to 2.0 cm. Initially, the geodesic dome was positioned at the baseline elevation (zero level). During the visual recording process, the parallax error — an inherent optical distortion in lateral videography — was successfully mitigated by establishing a reference elevation N2 mathematically equivalent to the baseline coordinate N1 (Figure 4A). Following the initiation of reservoir filling, the water reached the 2.0 cm threshold, inducing the temporary submersion of the prototype's foundational support (Figure 4B). Immediately upon verification of this critical submersion, the pneumatic infrastructure was engaged in its first operational stage (Figure 4C). The manual air injection stably elevated the expanded polystyrene (EPS) platform, repositioning the overarching superstructure at an elevation superior to the water line, thereby perfectly isolating the internal habitable zone from the fluid medium (Figure 4D).

Figure 4. Stages of the pneumatic test against the 2.0 cm flood (Level 1).

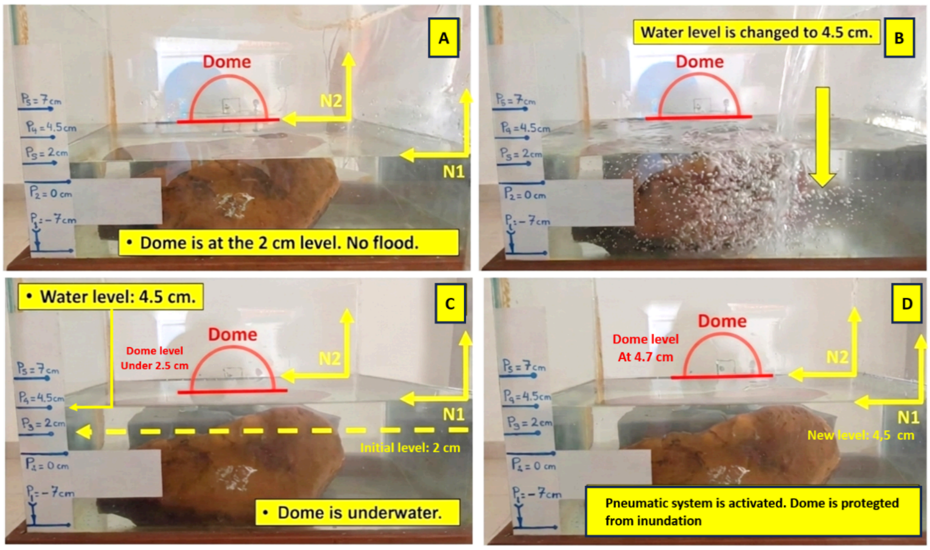


Source: Elaborated by the author.

In the second experimental scenario, the hydrodynamic stress was systematically intensified (Figure 5). The volumetric content within the glass tank was increased until the fluid level reached the secondary critical elevation of 4.5 cm (Figure 5C). In direct response to this milestone, which critically threatened the structural floor of the habitation unit, the second stage of the pneumatic actuators was engaged. The subsequent vertical displacement ensured, once again, that the geodesic dome seamlessly surpassed the new inundation threshold, thereby maintaining an entirely dry and secure internal microenvironment (Figure 5D).

In the third and final assay, representing the extreme simulation scenario, the fluid level was elevated to the maximum operational depth of 7.0 cm, completely submerging the preceding technical safety margins (Figure 6). Faced with this severe inundation event, the third displacement stage of the pneumatic system was swiftly engaged. Across all visual and metric observations, it was unequivocally demonstrated that the structural elevation occurred continuously, stably, and entirely free of mechanical vibration. The habitation unit effectively returned to the optimal hydrodynamic isolation position, definitively validating the mechanical performance and structural reliability of the proposed apparatus (Figure 6C).

Figure 5. Stages of the pneumatic test against the 4.5 cm flood (Level 2).

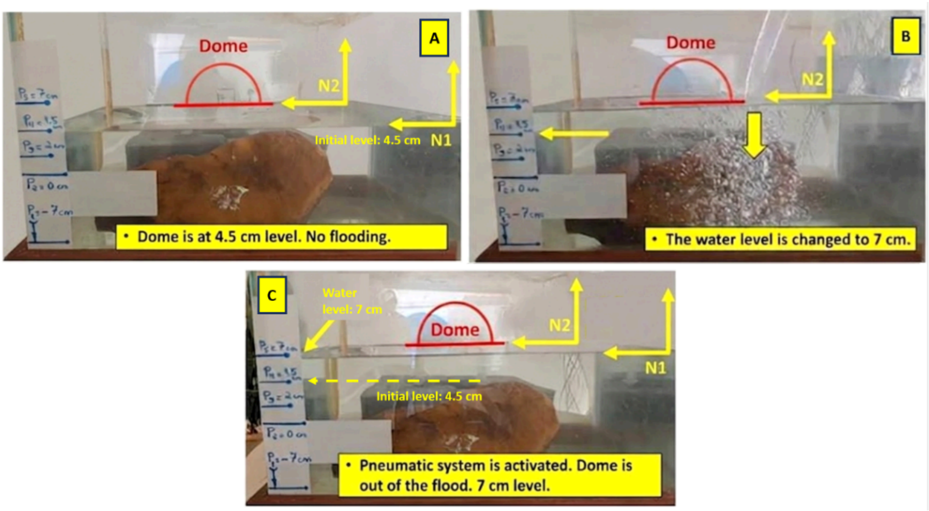


Source: Elaborated by the author.

The comprehensive compilation of empirical data facilitated the derivation of an operational characteristic curve, which correlates the vertical displacement height of the structure with the safety levels prescribed for disaster mitigation. The resulting graphical analysis demonstrated a precise, direct correlation incorporating the predefined 0.2 cm structural safety margin: Level 1 accommodated a maximum permissible flood depth of 1.8 cm, triggering a preventive elevation to exactly 2.0 cm; Level 2 sustained severe inundation events up to 4.3 cm, inducing an elevation to 4.5 cm; and Level 3 withstood extreme inundation depths of 6.8 cm, establishing the peak spatial positioning at a safe altitude of 7.0 cm.

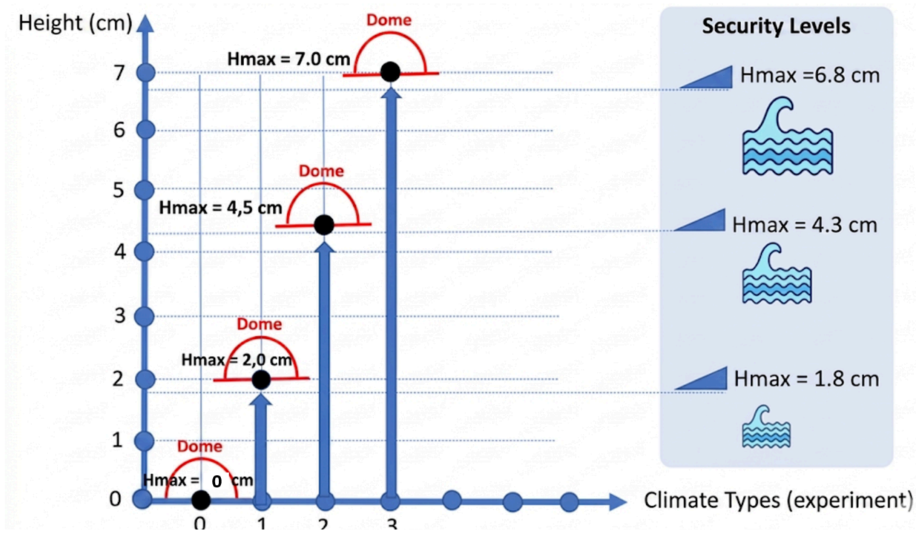
The continuous, highly responsive nature of the mechanism demonstrates that the rapid transition across these altimetric profiles effectively mitigates external environmental risks. Crucially, this dynamic response is achieved without generating destructive internal mechanical stresses or compromising the structural integrity of the overarching spherical geodesic superstructure (Figure 7).

Figure 6. Stages of the pneumatic test against the critical 7.0 cm flood (Level 3).



Source: Elaborated by the author.

Figure 7. Operational curve relating pneumatic elevation to flood levels.



Source: Elaborated by the author.

4.1. Comparative analysis

From the perspective of mechanical and structural engineering, the selection of a geodesic geometry yields intrinsic advantages regarding the uniform dissipation of external stresses and the facilitation of fluid bypass. However, the primary merit of this structural arrangement lies in the transformation of a static foundation into a dynamic interface via four volumetric pneumatic actuators (modeled utilizing 20 mL syringes). This staged actuation —evaluated across three progressive water depth thresholds (up to 7.0 cm at a reduced scale) — demonstrated that the mechanical thrust induced by air injection was capable of elevating the expanded polystyrene (EPS) platform continuously, stably, and entirely free of structural vibration. The system operated strictly within a technical safety margin of 0.2 cm, thereby effectively isolating the habitable zone from direct contact with the fluid medium. Although the study presents inherent methodological limitations arising from the manual fabrication of the physical model (1:20 scale) rather than the originally conceptualized 3D printing via FabLab infrastructure, the subsequent kinematic validation — grounded in the rigorous mitigation of parallax errors — confers high reliability upon the derived operational parameters.

The deployment of dynamic foundations and active lifting structures aligns closely with the contemporary international landscape of mitigation engineering, yet it expands the classical paradigm by proposing unconventional geometries. While this study focuses on spherical geometry and pneumatic actuation for temporary shelters, Kronenburg (2014) discusses at length the evolution of mobile and flexible architectures in disaster zones, emphasizing that the implementation of rapidly deployable modular systems is paramount to urban resilience. Nevertheless, the author indicates that most international solutions prioritize static, rectangular modular structures mounted on piles; consequently, the geodesic dome model integrated with active actuators emerges as a geometrically superior alternative regarding aerodynamic and mechanical stability when subjected to the lateral hydrodynamic pressures that frequently precipitate the collapse of conventional shelters.

Conversely, the active lifting mechanism proposed in this manuscript for inundation isolation finds a real-scale parallel in the studies by Aquilino (2011) regarding global post-disaster reconstruction methodologies. Aquilino (2011) documents amphibious and floating housing initiatives across Asia and North America, arguing that structures responding dynamically to fluctuating water levels drastically mitigate Flood Damage Curves (FDCs). The fundamental divergence, however, is that the geodesic hydrodynamic arrangement relies on an active pneumatic system (driven by air pressure and vertical displacement actuators), whereas the conventional amphibious systems reviewed by Aquilino depend exclusively on passive buoyancy (Archimedean principle). This characteristic grants the model developed at UNESP superior predictive control, thereby enabling a coordinated, preemptive lift before the fluid medium establishes physical contact with the superstructure.

A highly prominent international scientific paper validating the use of adapted pneumatic mechanisms for flood protection is the study by Lee *et al.* (2013). In this work, the authors developed and tested an active pneumatic lifting system designed to protect low-lying power transformers against severe floods and typhoons. The industrial system developed by Lee *et al.* (2013) was sized for real-world urban scenarios, achieving a maximum vertical lift of 120 cm to elevate heavy enclosures housing 22.9 kV transformers. In contrast, their geodesic dome physical model operated at a reduced laboratory scale (1:20) within a 50-liter flow tank, exhibiting a controlled maximum vertical displacement of 7.0 cm in its extreme scenario (Level 3).

The Lee *et al.* (2013) system required a robust industrial mechanical compressor operating at a high pneumatic pressure of 6.5 bar to overcome the inertia of the metal structure. The geodesic dome model in this paper demonstrated high design efficiency by requiring an estimated circuit pressure of 1.0 bar, achieved through the manual actuation of 20 mL syringes connected to a lightweight expanded polystyrene (EPS) floating platform.

Pneumatic activation of the geodesic dome proved highly responsive, stabilizing the superstructure at its maximum height within 15 seconds, whereas the Lee *et al.* industrial system took 180 seconds (3 minutes) due to the actual mass load. The geodesic dome's predictive technical safety margin was calibrated with millimeter precision to 0.2 cm above the waterline — a stark contrast to the macro-industrial approach of Lee *et al.*, who adopted a 15.0 cm clearance tolerance to mitigate the effects of sudden waves and typhoon-force winds.

5. FINAL CONSIDERATIONS

The present study successfully achieved its primary objective by comprehensively demonstrating the technical viability and high-level effectiveness of a temporary shelter in the shape of a geodesic dome, ingeniously equipped with active mechanical defenses against water disasters. The progressive flow and flood tests, meticulously performed in the 50-liter test aquarium across three severe operational stages (supporting water levels up to 7.0 cm on a reduced scale), proved that adopting a pneumatic system directly in the foundation acts as a high-performance preventive tool.

The manual automation of the vertical displacement ensured that the structure remained fully emerged, preserving the physical integrity of the complex modular geometry and keeping the internal environment completely isolated and safe from moisture and water contact. The pneumatic mechanism acted constantly and without structural trepidations, operating precisely within the established 0.2 cm safety margin for each progressive stage. This performance robustly validates the hypothesis that the integration of active lifting structures offers concrete, measurable protection against flooding and significantly overcomes the traditional vulnerabilities associated with conventional fixed constructions in disaster zones.

Regarding methodological limitations, it is crucial to document that logistical constraints required adaptations to the original research scope. The three-dimensional printing of the scale model proved to be economically unviable due to commercial budgets. Consequently, the researchers adapted by employing the meticulous manual construction of a modular physical prototype. Similarly, constructing a 1:1 scale test facility with real pneumatic foundations proved financially unviable for the scope of this project. However, the rigorous geometric assembly of the physical model and the sophisticated application of parallax error correction techniques met all the stringent demands of the kinematic analysis, successfully delivering precise and highly reliable parameters.

For developments and future scientific work, the full electronic automation of the studied mechanical system is strongly suggested. The implementation of an advanced environmental sensor network, directly connected to local weather stations, would allow the predictive and autonomous activation of the pneumatic lifting system. In this proposed framework, a flood climate alert (e.g., a Level 2 severity forecast issued by authorities) could preventively elevate the housing unit to its corresponding safe elevation without the absolute need for human physical intervention. Furthermore, investigations into sustainable, low-carbon construction materials, such as bamboo, alongside foldable origami-based deployment methods, represent the next frontier for this research. Ultimately, the proposed model provides a solid technological base for the definitive mitigation of socio-environmental vulnerability in high-risk areas globally. The transition to an automated deployable system aligns directly with Alexander's (2016) guidelines for disaster management and smart civil engineering applications. Alexander (2016) argues that the effectiveness of active mechanical defenses in emergency shelters depends intrinsically on eliminating the need for human intervention during severe crises. Thus, integrating a network of automated environmental sensors with predictive weather alerts validates Alexander's thesis that real-time automation transforms temporary housing from a purely passive protective element into an active, resilient node within a smart urban infrastructure network focused on safeguarding vulnerable lives.

REFERENCES

ALEKSIĆ, Julija *et al.* Housing and climate change-related disasters: a study on architectural typology and practice. Procedia Engineering, [S. l.], v. 165, p. 869-875, 2016.

ALEXANDER, David. **How to Study Disasters:** A Guide to the Essential Literature. London: Routledge, 2016.

ANDERS, Gustavo Caminati. Abrigos temporários de caráter emergencial. 2007. Tese (Doutorado em Arquitetura e Urbanismo) – Universidade de São Paulo, São Paulo, 2007.

AQUILINO, Marie J. **Beyond Shelter:** Architecture and Human Dignity in a World of Climate Change. New York: Metropolis Books, 2011.

CASA E MERCADO. Soluções de engenharia podem amenizar desastres naturais. Casa e Mercado, [S. l.], 2023. Disponível em: https://casaemercado.com.br/solucoes-de-engenharia-podem-amenizar-desastres-naturais/. Acesso em: 12 fev. 2025.

FOLHA DE S.PAULO. Perda de moradia por desastres ambientais gera danos à saúde, mostra estudo. Folha de S.Paulo, São Paulo, 2023. Disponível em: https://www1.folha.uol.com.br/ambiente/2023/06/perda-de-moradia-por-desastres-ambientais-gera-danos-a-saude-mostra-estudo.shtml. Acesso em: 3 fev. 2025.

FREITAS, Carlos Machado de *et al.* Desastres naturais e saúde: uma análise da situação do Brasil. Ciência & Saúde Coletiva, Rio de Janeiro, v. 19, p. 3645-3656, 2014.

HENRIQUES, Daniel de Miranda; LOPES, Isabela Canônico. Abrigo temporário para vítimas de desastres. [S. l.: s. n.], 2019.

HONG, Yan. Um estudo sobre as condições das habitações temporárias após desastres: foco nas habitações em contentores.

Fronteiras da Pesquisa Arquitetônica, [S. l.], v. 3, p. 374-383, 2017.

KOBIYAMA, Masato *et al.* Prevenção de desastres naturais: conceitos básicos. Curitiba: Organic Trading, 2006.

KRONENBURG, Robert. **Architecture in Motion:** The History and Development of Portable Building. London: Routledge, 2014.

LEE, S. H. *et al.* The Development of a Flood Protection System for Pad Transformers Using Pneumatic Pressure in Areas Prone to Floods. **Journal of Electrical Engineering & Technology,** v. 8, n. 4, p. 892-899, 2013.

NAPPI, Manuela Marques Lalane; SOUZA, João Carlos. Temporary shelters: an architectural look at user-environment relationships. Arquitetura Revista, São Leopoldo, v. 13, n. 2, p. 112-120, 2017.

ONU NEWS. ONU: desastres forçam mais pessoas a saírem de suas casas que conflitos e violência. ONU News, Nova York, 2020. Disponível em: https://news.un.org/pt/story/2020/02/1702842. Acesso em: 25 fev. 2025.

RESENDE, Camila *et al.* Entre: proposta de abrigo temporário adaptável. Revista Projetar - Projeto e Percepção do Ambiente, [S. l.], v. 7, n. 1, p. 162-167, 2022.

SPINK, Mary Jane Paris. Viver em áreas de risco: tensões entre gestão de desastres ambientais e os sentidos de risco no cotidiano. Ciência & Saúde Coletiva, Rio de Janeiro, v. 19, p. 3743-3754, 2014.

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