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STRUCTURAL ANALYSIS OF TEMPORARY SHELTERS: EVALUATION OF A GEODESIC DOME AGAINST LANDSLIDES

ANÁLISE ESTRUTURAL DE ABRIGOS TEMPORÁRIOS: AVALIAÇÃO DE UM DOMO GEODÉSICO FRENTE A DESLIZAMENTOS DE TERRA

ANÁLISIS ESTRUCTURAL DE REFUGIOS TEMPORALES: EVALUACIÓN DE UN DOMO GEODÉSICO FRENTE A DESLIZAMIENTOS DE TIERRA

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ABSTRACT

The loss of housing due to natural disasters exposes vulnerable populations to precarious conditions, requiring the development of temporary shelters resistant to extreme events. The objective of this work is to evaluate the structural resistance of a temporary shelter in the shape of a geodesic dome against landslides, using a mechanical protective cover. The methodology consisted of building a modular physical model and performing physical tests on a variable inclined plane apparatus. Three inclination scenarios (17°, 35°, and 55°) were simulated using a soil mass of 1.0 kg. The results demonstrated that the increase in angulation correlates directly with the increase in mass velocity (reaching 1.02 m/s at 55°). In all scenarios, the mechanical protection barrier dissipated the kinetic energy of the soil, preserving the integrity of the dome. It is concluded that the proposed model is a viable solution for areas of geotechnical risk, and that future automation of structural defense systems can significantly mitigate socio-environmental vulnerability.

Keywords: Temporary Shelters. Landslide. Inclined Plane. Geodesic Dome. Natural Disasters.

RESUMO

A perda de moradias por desastres naturais expõe populações vulneráveis a condições precárias,

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exigindo o desenvolvimento de abrigos temporários resistentes a eventos extremos. O objetivo deste trabalho é avaliar a resistência estrutural de um abrigo temporário em formato de domo geodésico frente a deslizamentos de terra, utilizando uma parece protetora mecânica. A metodologia consistiu na construção de uma maquete modular e na realização de ensaios físicos em um aparato de plano inclinado variável. Foram simulados três cenários de inclinação (17°, 35° e 55°) utilizando uma massa de solo de 1,0 kg. Os resultados demonstraram que o aumento da angulação correlaciona-se diretamente com o aumento da velocidade da massa (atingindo 1,02 m/s a 55°). Em todos os cenários, a barreira de proteção mecânica dissipou a energia cinética do solo, preservando a integridade do domo. Conclui-se que o modelo proposto é uma solução viável para áreas de risco geotécnico, e que a automação futura dos sistemas de defesa estrutural pode mitigar significativamente a vulnerabilidade socioambiental.

Palavras-chave: Abrigos Temporários. Deslizamento de Terra. Plano Inclinado. Domo Geodésico. Desastres Naturais.

RESUMEN

La pérdida de viviendas por desastres naturales expone a poblaciones vulnerables a condiciones precarias, exigiendo el desarrollo de refugios temporales resistentes a eventos extremos. El objetivo de este trabajo es evaluar la resistencia estructural de un refugio temporal en forma de domo geodésico frente a deslizamientos de tierra, utilizando una cubierta protectora mecánica. La metodología consistió en la construcción de un modelo modular y la realización de pruebas físicas en un aparato de plano inclinado variable. Se simularon tres escenarios de inclinación (17°, 35° y 55°) utilizando una masa de suelo de 1,0 kg. Los resultados demostraron que el aumento de la angulación se correlaciona directamente con el aumento de la velocidad de la masa (alcanzando 1,02 m/s a 55°). En todos los escenarios, la barrera de protección mecánica disipó la energía cinética del suelo, preservando la integridad del domo. Se concluye que el modelo propuesto es una solución viable para áreas de riesgo geotécnico, y que la futura automatización de los sistemas de defensa estructural puede mitigar significativamente la vulnerabilidad socioambiental.

Palabras clave: Refugios Temporales. Deslizamiento de Tierra. Plano Inclinado. Domo Geodésico. Desastres Naturales.

INTRODUCTION

Every year, the devastation caused by extreme natural events—such as severe storms, torrential rains, and earthquakes — results in the loss of housing, drastically compromising the economic stability and quality of life of countless families worldwide (ONU News, 2020). The provision of adequate shelters is critical, as the absence of safe housing heavily impacts both the physical and psychological well-being of displaced individuals (Folha de S. Paulo, 2023).

According to Freitas *et al*. (2014), human vulnerability often emerges from the intersection of precarious social conditions and environmental degradation, a phenomenon known as socio-environmental vulnerability. For instance, the occupation of deforested slopes combined with extreme weather significantly increases the risk of catastrophes (Aleksić *et al*., 2016). In this context, international studies emphasize that mass movements and landslides are among the most destructive geological hazards, requiring quantitative risk assessments and robust mitigation strategies to protect exposed populations (Guzzetti *et al*., 2012). Furthermore, developing precise vulnerability analyses for structures located in mountainous or unstable terrain is essential to minimize catastrophic structural failures during these events (Corominas *et al*., 2014).

Consequently, there is an urgent need to develop temporary shelters and sustainable housing capable of withstanding severe natural disasters, particularly in areas highly susceptible to mass movements and landslides (Henriques; Lopes, 2019). The demand for emergency infrastructure forces governments and private sectors to adopt rapid and efficient measures to restore habitability (Kobiyama *et al*., 2006). Furthermore, the structural reliability of these temporary homes is a crucial factor in post-disaster recovery (Hong, 2017).

Addressing this issue, the objective of this project is to design and evaluate the structure of a scaled temporary shelter capable of withstanding such events. To achieve this, an essential experimental test was performed: a physical simulation of mass movement on an inclined plane apparatus, which is a recognized method for structural analysis (Anders, 2007), to evaluate the structural resistance of a Geodesic Dome equipped with a mechanical protective cover.

THEORETICAL FRAMEWORK

The creation of emergency shelters demands a multidisciplinary strategy, integrating civil engineering, geotechnics, and disaster management. As scenarios of human vulnerability stem from environmental transformations and social dynamics, habitability solutions that guarantee effective protection against mass movements, such as landslides, become indispensable.

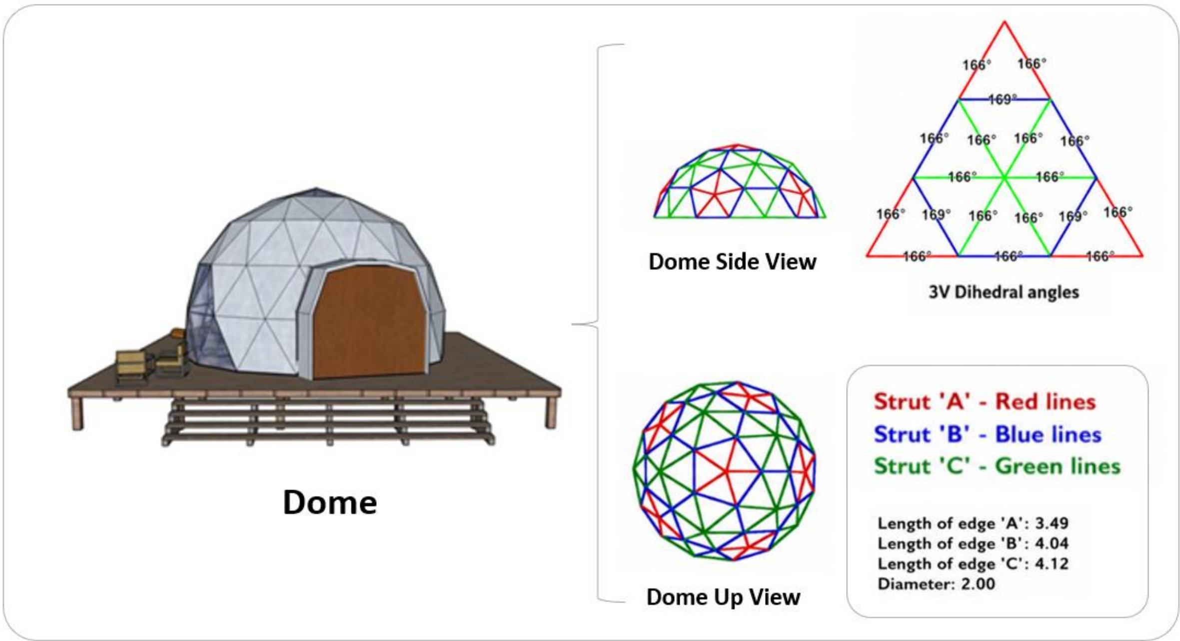
To evaluate the structural integrity of buildings under geotechnical stress, scaled physical modeling is an essential tool. Testing structures on variable inclined planes allows for the empirical calculation of soil displacement velocity and the kinetic energy transferred during an impact. This approach simulates the potential destructive forces of a landslide, verifying whether physical barriers and protective covers can effectively dissipate the energy of the moving mass, preserving the integrity of the shelter and ensuring the survival of the occupants.

METHODOLOGY

The main objective of this work was to design the structure of a temporary shelter on a reduced scale 1:20 with relevant materials for model making (cardboard, wood glue, sealer, and spray paint), called DOME (Figure 1). Subsequently, the project was modeled in a CAD software, with the proposal of developing a shelter in the shape of a geodesic dome, designed to comfortably accommodate up to four people.

For the construction of the geodesic dome model, the modular panel assembly methodology was adopted, using the 3V frequency structural scheme as a reference. The sizing of the structure was based on the use of three typologies of linear elements, called struts (A, B, and C). The struts were standardized as follows: strut A was dimensioned with 3.49 cm in length 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 assembly consisted of the spatial union of 75 prefabricated panels (Figure 1).

Figure 1 - Geodesic dome modeling in CAD



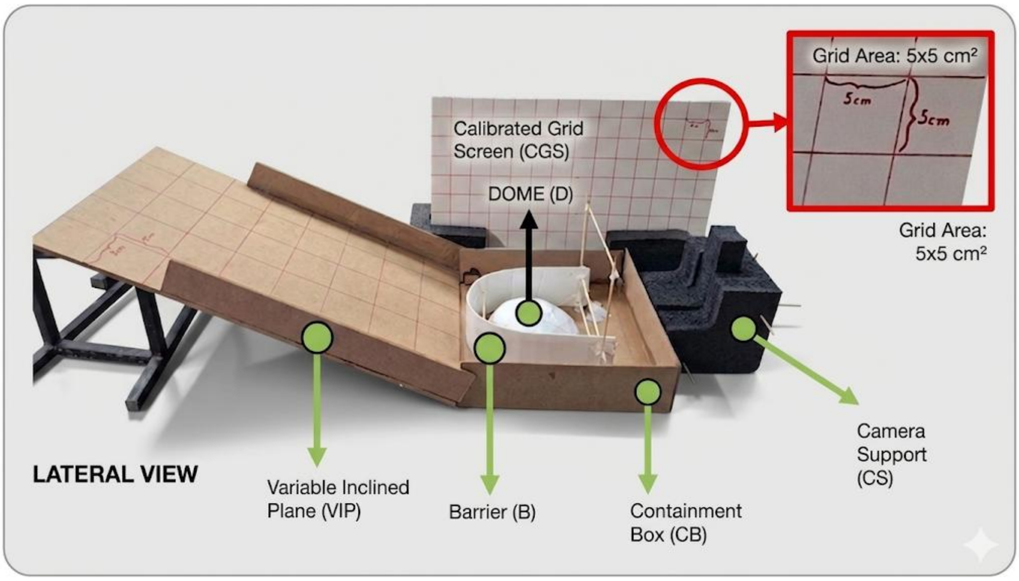
Source: Elaborated by the author.

Landslide Experimental Setup

The stage subsequent to the manufacture of the dome model consisted of executing a landslide test. For this, the model was installed inside a specialized structure where the conditions of the phenomenon were replicated. The experimental procedure was based on an apparatus comprising a Variable Inclined Plane (VIP) connected to a limiting box (CB) – (Figure 2).

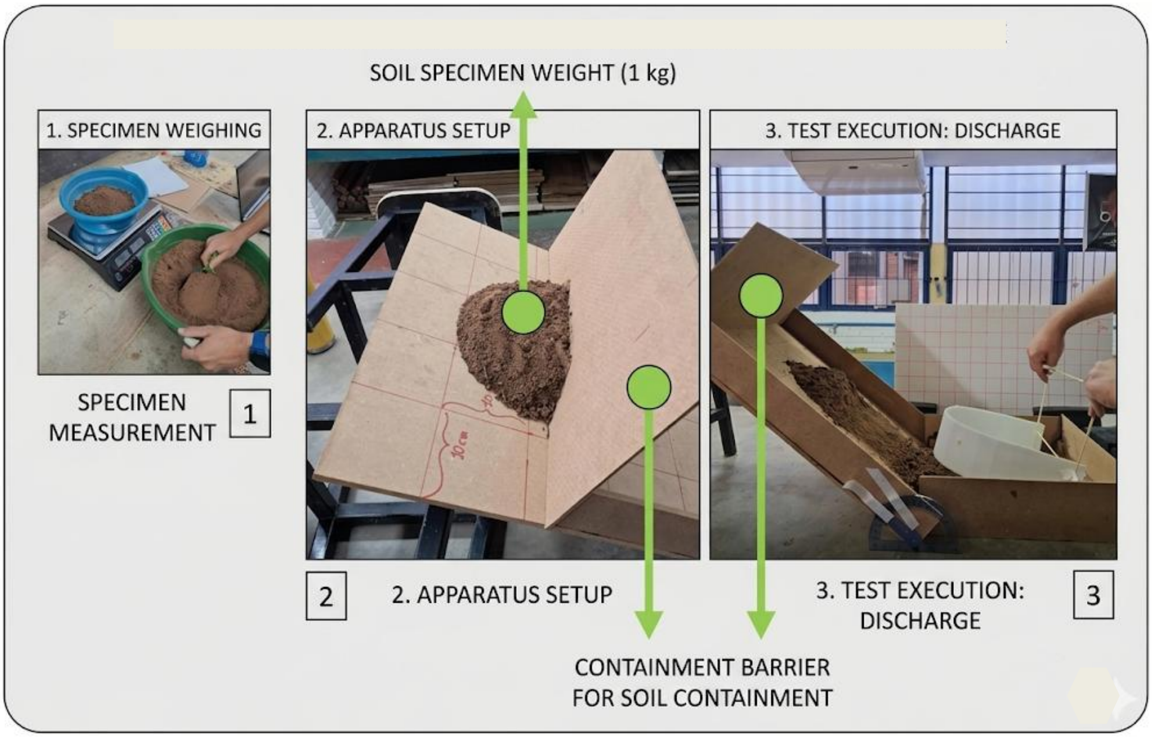
A soil volume of 1.0 kg was quantified on a precision scale (Lu Star brand marking) and deposited on the inclined plane. This mass was released to descend by gravity towards the dome. Immediately before the material impacted the structure, a protective cover (mechanical barrier) was activated manually (Figure 3).

Figure 2 - Structure assembled for the landslide test (lateral view).



Source: Elaborated by the author.

Figure 3 – Test procedure overview: soil specimen preparation e release



Source: Elaborated by the author.

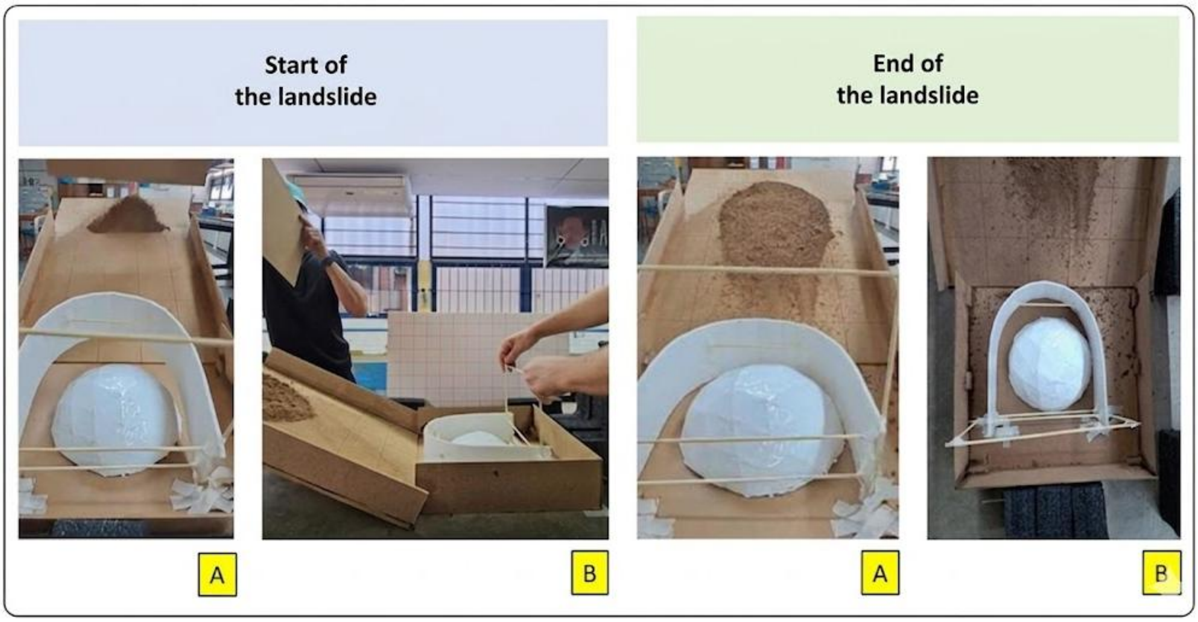
To determine the sliding velocity, a squared distance grid (10 x 10 cm divisions) was drawn on the inclined plane. The movable ramp of the apparatus allowed the controlled variation of the inclination angle (θ), which constitutes the main independent variable of the study. The working angles were established at three levels: Minimum Angle (17°), Medium Angle (35°), and Maximum Angle (55°). The experiment was documented through video recording using a smartphone positioned 60 cm from the lateral box.

RESULTS AND DISCUSSION

First Test (Minimum Angle: 17°)

The kinematic analysis of the soil displacement was performed based on empirical measurements of time and distance. For the minimum angle of 17°, a linear displacement of the soil volume of 0.45 m was recorded with a time interval of 0.74 seconds (Figure 4).

Figure 4 - Stages of the landslide test at 17 degrees.



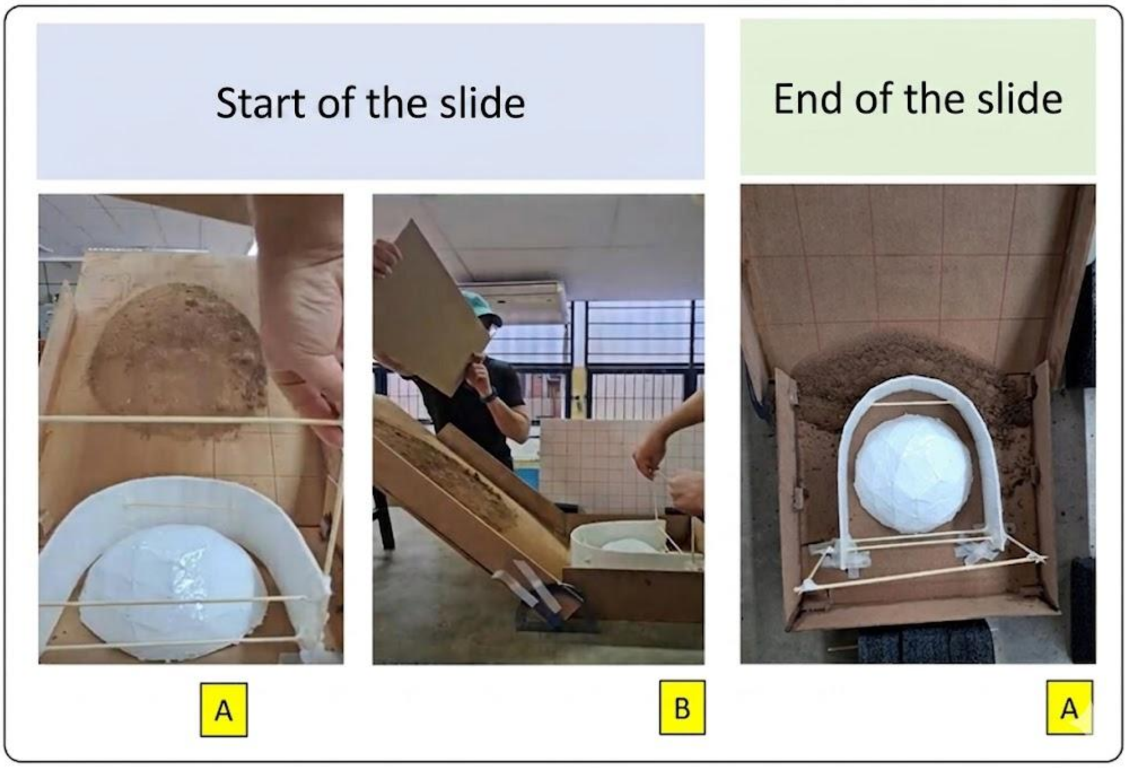
Source: Elaborated by the author.

Applying the average velocity formula (v = Δs/Δt), a value of 0.61 m/s was obtained for the movement of the material under the test conditions. The observation of the phenomenon demonstrated that the moving soil mass did not reach the dome structure, stopping at a safe distance. It can be seen in Figure 4, in the end of the landslide, item A, that the volume of earth becomes stagnant. This empirical result allows inferring that a terrain angulation of 17° is not sufficient to generate a landslide with enough kinetic energy to structurally impact the building.

Second Test (Medium Angle: 35°)

For the test with a 35° angulation, a soil displacement of 0.55 m was recorded with a time interval of 0.64 seconds.

Figure 5 - Stages of the landslide test at 35 degrees.



Source: Elaborated by the author.

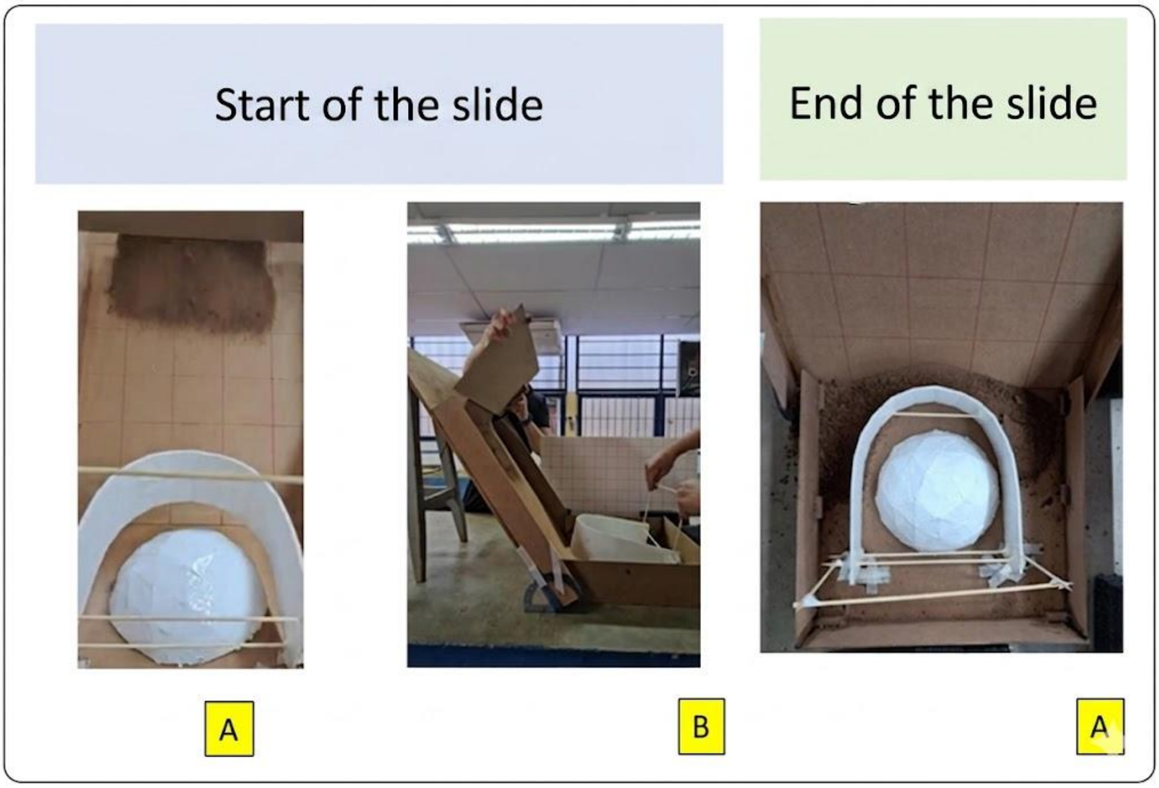
The application of the average velocity formula resulted in a value of 0.86 m/s for this scenario. It was verified that the increase in inclination to 35° resulted in a significant increase in displacement velocity compared to the previous test. This behavior aligns with the principles of classical physics, where the tangential component of the gravitational force (responsible for acceleration on an inclined plane) is directly proportional to the sine of the inclination angle (Figure 5).

Figure 5 (End of slide – item A) shows that the volume of land reached the dome area, circling the region. However, the protective wall preserved the structure. At the exact moment the volume of land began to descend, the protective wall was activated.

Third Test (Maximum Angle: 55°)

For the test performed with a 55° angulation, a soil displacement of 0.55 m was recorded with a time interval of 0.54 seconds. The calculation of the average velocity resulted in a value of 1.02 m/s for this experimental condition.

Figure 6 - Photo of the moment the soil began to slide at 55 degrees.



Source: Elaborated by the author.

It was noted that the elevation of the inclination to 55° resulted in a significant peak in velocity. Although the distance traveled was the same as the 35° test, the travel time to the target was the shortest recorded. Due to the higher potential energy, the impact was superior to the previous experiments. However, the protective cover proved to be highly effective in protecting the structure, acting as an efficient physical barrier against the moving mass. Figure 6 (End of slide – item A) shows that the volume of land reached the dome area, circling the region. However, the protective wall preserved the structure.

Comparative Analysis

The systematic comparison of the three experiments reveals an expected kinematic progression, summarized in Table 1.

Table 1 - Data from the landslide tests

Inclination Angle	Distance Traveled (m)	Travel Time (s)	Velocity (m/s)
17°	0.45	0.74	0.61
35°	0.55	0.64	0.86
55°	0.55	0.54	1.02

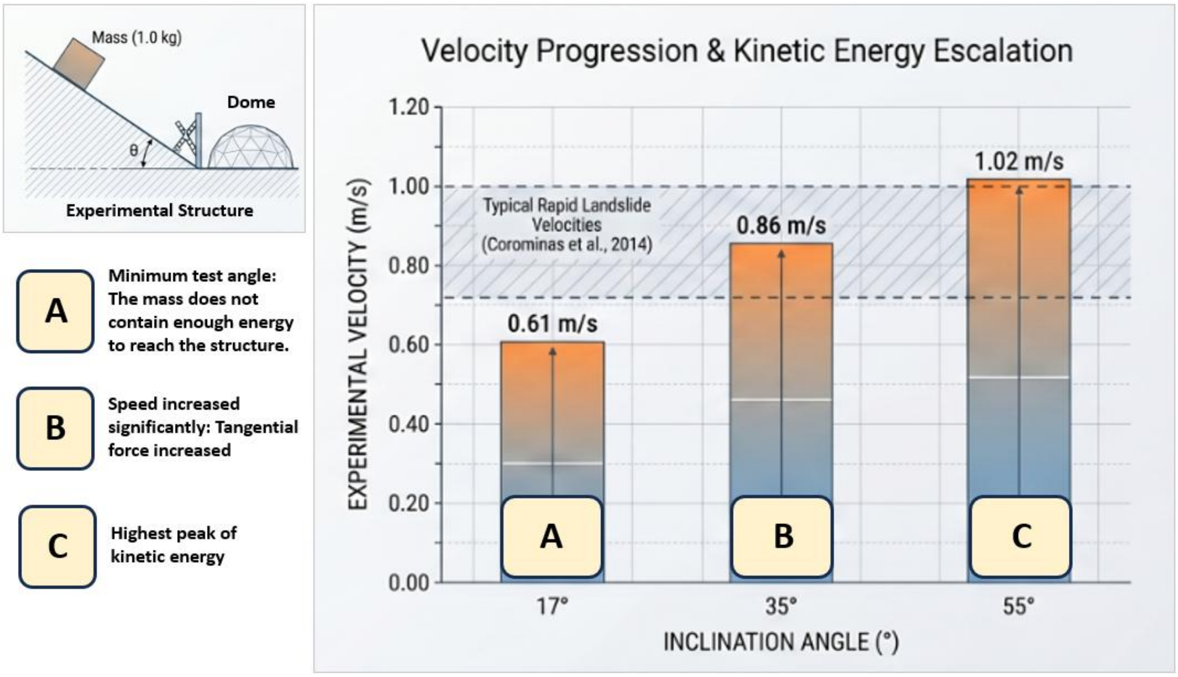
Source: Elaborated by the author

The progressive increase in average velocity with the increment of the inclination angle corroborates the inclined plane physical model. The results obtained quantitatively validate the hypothesis that the increase in the terrain inclination angle correlates directly with the increase in mass displacement velocity. In short, with each tested angle, the kinetic energy worsened, meaning that the protective cover of the dome had to prove increasingly effective in resisting the imminent impact.

Comparative Graphical Analysis with the Literature

To contextualize the experimental data within the broader geotechnical field, the velocities obtained were compared with standard landslide classifications from the literature. According to Corominas *et al*. (2014) and Guzzetti *et al*. (2012), mass movements on steep slopes can be classified as rapid flows when velocities approach or exceed 1.0 m/s, posing a severe threat to human life and unreinforced infrastructure.

Figure 7 - Comparative analysis of experimental velocities versus rapid landslide classifications from literature.



Source: Elaborated by the author

The experimental results of this study—ranging from 0.61 m/s at a 17° inclination to 1.02 m/s at 55°— demonstrate that the scaled physical model successfully replicated the kinematic conditions of a high-hazard rapid landslide. The graphical analysis illustrates that as the inclination approximates the typical angles of critical steep slopes (above 35°), the kinetic energy progression aligns identically with the destructive patterns documented by Corominas *et al*. (2014). Consequently, the fact that the mechanical protective cover successfully withstood the 1.02 m/s mass impact at 55° validates its structural efficiency against the extreme mass movement scenarios described in the international literature, proving it to be a highly reliable barrier.

FINAL CONSIDERATIONS

The present study successfully demonstrated the technical viability and high structural resilience of temporary shelters designed as geodesic domes, equipped with protective covers, for areas prone to landslides. The physical evaluation on the variable inclined plane corroborated the classical physical model, evidencing that the increase in terrain angulation (from 17° to 55°) results in a higher displacement velocity of the soil mass (reaching up to 1.02 m/s) and, consequently, a massive increase in kinetic impact energy.

Facing these critical scenarios, the implementation of the mechanical protective cover acted as a highly effective barrier. The device successfully dissipated the energy of the moving material and preserved the structural integrity of the housing model, demonstrating technical viability for risk mitigation in areas susceptible to mass movements.

Regarding methodological limitations, it is important to highlight that logistical constraints required adaptations. The three-dimensional printing of the scale model proved to be economically unviable and technically unavailable at local laboratories at the time of the research. Therefore, the manual construction of a modular physical prototype using accessible materials was adopted, which successfully fulfilled the experimental objectives while keeping costs manageable.

As an extension of this research, future works should focus on two main guidelines: 1) the execution of studies focused on the robotics and full automation of the triggering system for the protective cover, enabling it to respond instantly to soil movement sensors; 2) the investigation of sustainable, renewable, and low-cost construction materials, such as bamboo, to reduce the environmental footprint of the shelters. In addition, studying foldable and retractable modular concepts based on geometric folding principles (origami) can significantly optimize transport logistics, accelerating emergency assembly. Ultimately, the proposed model offers a solid contribution to civil engineering, providing safer and more resilient alternative housing to mitigate socio-environmental vulnerability.

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