Proceedings of the 21st ICSMGE, Vienna, Austria, 14 – 19 June 2026. Pistrol, Adam & Schweiger (eds.)
Published by: ÖGG, Austrian Society for Geomechanics, Salzburg, Austria, ISBN 978-3-9503898-4-5
https://doi.org/10.53243/ICSMGE2026-288

Guidelines for resilient infrastructures in the Amazon Region, Brazil

Gisleine Campos, Felipe Santos, Claudio Gomes
Institute for Technological Research of Sao Paulo State, SA, Sao Paulo, Brazil, gisleine@ipt.br

ABSTRACT: Brazil has faced frequent and severe weather-related natural hazards in recent years. Events that were once considered unusual or unprecedented have affected many regions across the country, from the North to the South. These events include heatwaves, heavy rains, floods, and droughts. The Amazon Region, one of the most biodiverse ecosystems in the world, has been significantly impacted by these phenomena, experiencing historic floods and droughts in its major river systems in 2023. Alongside these environmental changes, numerous infrastructural issues have emerged, particularly affecting ports and bridges, some of which have partially or completely collapsed. This situation has led to increased research into soil behavior, especially regarding a phenomenon known as Fallen Lands. This term refers to the processes of riverbank erosion and the subsequent transport of materials, making the area more vulnerable to landslides. Researchers are focusing on how these factors influence the stability of riverbanks and nearby structures, as well as the design and construction characteristics of both existing and newly planned projects. In this scenario, this article examines the impacts of climate change on the worsening and intensification of the Fallen Lands phenomenon, as well as its effects on the stability and safety of infrastructure in river flood areas. Recent cases of bridge and port collapses highlight key factors that contributed to these failures during their service life. It is essential to recognize that certain issues may be directly related to project design and the construction methods used. The article provides technical guidelines for the design of future civil construction projects in this region, focusing particularly on geological-geotechnical and hydrodynamic aspects. These guidelines aim to create more resilient urban infrastructure with a reduced likelihood of failure and improved safety for users.

KEYWORDS: Amazon Region, resilient infrastructures, fallen lands, geotechnical characteristics.

1 INTRODUCTION

The phenomenon known as Fallen Lands, which involves the collapse of the banks of Amazon Rivers, warrants significant attention due to its destructive force. This occurrence not only underscores the power of nature but also highlights the risks that users, residents and built structures in these areas face over time.

Among the impacts of this phenomenon, several key effects emerge:

- riverside communities may be forced to abandon their homes due to landslides, resulting in the loss of both their properties and personal belongings;
- buildings and other structures, such as ports and bridges located near riverbanks, can suffer destruction or damage;
- erosive processes can alter the landscape, negatively affecting water quality and biodiversity in the region;
- riverine communities may lose their sources of livelihood, such as fishing and agriculture, due to the destruction of productive areas;
- highways and urban roads may experience traffic interruptions, impacting urban mobility and the transportation of raw materials and products; and
- landslides can lead to tragic outcomes, resulting in fatalities and injuries, while also exacerbating feelings of insecurity within affected communities.

Figure 1 to Figure 5 depict recent incidents that have significantly compromised the functionality of vital infrastructure, including ports and bridges. These events have resulted in the destruction of communities situated along riverbanks and have tragically led to the loss of several human lives.

There are numerous cases currently being analyzed by the owners of the works and researchers focused on the theme of Fallen Lands. However, there is a lack of public data that clearly identifies the primary factors contributing to both partial and total collapses of these structures. Despite this, evidences suggest that some signs of deterioration were observed in these works prior to their collapses, particularly during successive periods of flooding and ebb of rivers.

Figure 1. Collapse in Solimoes riverside, Amazon Region in Brazil (Ribeiro, 2018, *apud* Rodrigues, 2024).

It is essential to underscore the fluvial dynamics of the rivers within the Amazon region, which indicate substantial sediment transport and erosive processes occurring along their banks (Souza, 2022). Recent observations suggest that these erosive processes have intensified, likely because of increasingly severe and prolonged rainfall events, followed by extreme drought conditions that have impacted the area.

Figure 2. Collapse of a port enterprise in Manacapuru city, Amazon Region, Brazil (CNN, 2024).

To mitigate the risks associated with the partial or total collapse of infrastructure works, it is imperative to reevaluate the fundamental principles of design, execution, and maintenance with the objective of enhancing resilience.

Figure 3. Collapse of a port enterprise in Itacoatiara city, Amazon Region, Brazil (Globo, 2023).

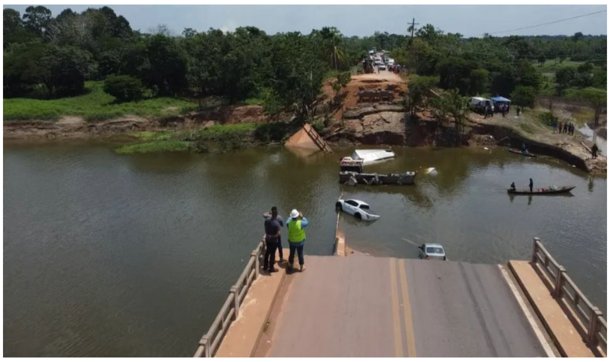

Figure 4. Total collapse of a bridge in BR 319 road, near Manaus city, Brazil (Globo, 2022).

Figure 5. Fallen Lands phenomenon induces stepped terraces on the Amazon Rivers, Brazil.

This article defines resilience as the capacity of a structure to withstand and recover from adverse events, such as natural disasters, while retaining its essential functions. It is insufficient for a structure to merely resist external forces; it must also possess the ability to adapt and recover expeditiously, thus ensuring the safety and operational integrity of civil works.

2 REGIONAL AND LOCAL GEOLOGICAL–GEOTECHNICAL ASPECTS

From a regional perspective, the Amazon Sedimentary Basin - where most of the aforementioned infrastructure projects are located - is primarily composed of Paleozoic and Mesozoic sedimentary rocks, as well as unconsolidated Tertiary sediments. These sedimentary rocks (considered soft rocks from an engineering standpoint) are deposited over a Precambrian basement composed of igneous, metamorphic, and sedimentary rocks (CPRM, 2010). The combined sedimentary and igneous fill of the basin exceeds 5,000 m in thickness at its depocenter (Wanderley Filho, 1991; Pereira et al., 2012).

Quaternary alluvial deposits are widely distributed along the main drainage networks and cover a significant portion of the surface of the sedimentary basin. These Quaternary sediments, along with the unconsolidated Tertiary deposits, constitute the materials most susceptible to processes associated with the "Fallen Lands" phenomenon.

In general, the Quaternary sedimentary materials consist of both recent and ancient alluvial deposits. The recent deposits are composed of layers of sands, silts, and clays distributed along river channels, while the ancient deposits are made up of layers of fine sandstones, mudstones, conglomerates, and siltstones, forming terraces characterized by flat reliefs near floodplains (Silva, 2003).

It should be noted that, in the description of the subsoil stratigraphy, the nomenclatures and classifications recommended by the Brazilian technical standards of ABNT (Brazilian Association of Technical Standards) are used in this paper.

A typical stratigraphy of the region exhibits the following distribution of layers and mechanical resistance, as inferred from Standard Penetration Tests (SPT) and piezocone static penetration tests with pore pressure measurement (CPTu – Cone Penetration Test with Pore Pressure Measurement):

- Surface layer, occasionally composed of black sand with organic matter or anthropogenic fill. In some locations, this surface layer may be absent, exposing the underlying stratum directly;
- Alluvial layer consisting of clayey-sandy silt or silty clay, over 20 m thick, dark gray in color, very often containing organic matter, and exhibiting very soft to soft consistency (N_{SPT} values ranging from 0 to 4 blows);
- Alluvial layer composed of clayey silt or silty clay, with consistency ranging from very soft to medium (N_{SPT} values between 2 and 10 blows), underlain by clayey-sandy silt extending to depths greater than 30 m. Interbedded sand lenses are common; and
- Alluvial layer predominantly sandy, with variable and increasing density with depth, transitioning into weathered soft rock formations from the Tertiary and Cretaceous periods, reaching refusal to percussion tools at approximately 50 m depth. This refusal layer may occur locally at shallower or deeper depths.

The Figure 6 and the Figure 7 provide graphical interpretations of the typical profile along the banks of Amazonian rivers. Figure 6 illustrates a scenario on the left bank of the Amazon River, where the channel depth can exceed 80 m; Figure 7 presents a typical cross-section of an Amazon River tributary, with a channel depth of approximately 20 m.

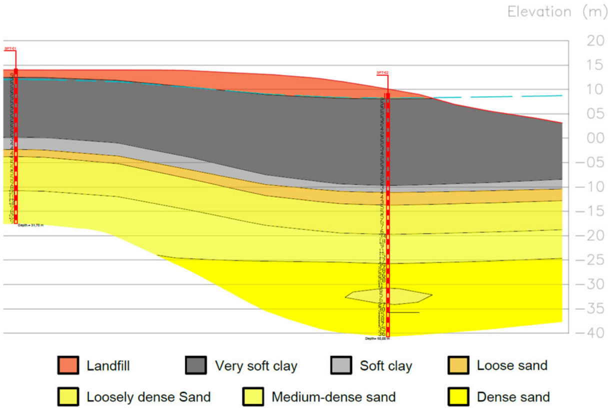

Figure 6. Left bank of the Amazon River, characterized by thick layers of soft soil, where the river channel can exceed 80 m in depth. The water level variation throughout a flood and ebb cycle can surpass 15 m.

Naturally, variations may occur; therefore, site investigation campaigns are essential to determine the thicknesses and geomechanical behavior of the strata, particularly the soft and very soft soils.

The groundwater level is generally shallow, typically less than 2 m deep, and depending on the rate at which the river level drops, it may result in high differential residual pore pressure values within the slope of the soil mass - a critical issue further addressed in the following section.

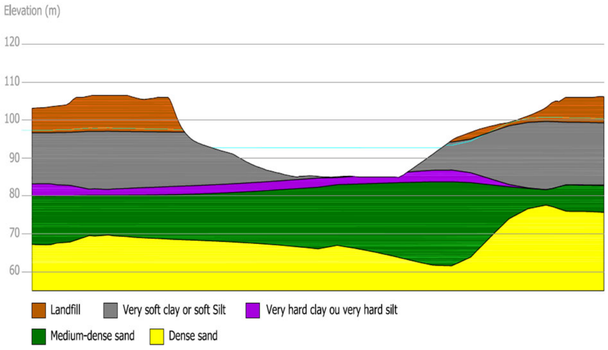

Figure 7. Typical cross-section of a tributary of the Amazon River, with a channel depth of approximately 20 m.

3 FALLEN LANDS PHENOMENON

A typical phenomenon observed along riverbanks—and occasionally affecting parts of the floodplains—is known as "Fallen Lands", a regional term widely used to describe fluvial erosion processes such as collapses and landslides that annually impact riverside communities and infrastructure (Souza & Campelo, 2020), posing risks even to river navigation. This phenomenon occurs especially during periods of drought, with increasingly frequent occurrences due to global climate change.

As previously mentioned, "Fallen Lands" predominantly occur in recent alluvial deposits composed of unconsolidated sand and clay layers, in conjunction with fluvial erosion processes during the dry season. Mass movement phenomena such as soil creep, rotational, and translational slides typically occur during the dry season, triggered by the rapid lowering of river water levels. In general, the initial stage of riverbank destabilization is characterized by a series of small subsidence steps, accompanied by a significant number of minor surface cracks.

In addition to serving as drainage channels, the fluvial systems of the Amazon Region play a significant role in sediment transport and exert considerable control over the long-term erosive action of rivers on the geological substrate. Riverbanks become increasingly susceptible to erosive processes due to the abrasion caused by flowing water and changes in hydraulic gradients during the successive flood and ebb cycles of the rivers (Gamba et al., 2017). Some authors (Souza & Campelo, 2020; Igreja & Franzinelli, 2006) suggest that neotectonic activity also contributes to the occurrence of the Fallen Land phenomenon, acting in conjunction with climatic factors (rainfall and wind), as well as lithological, sedimentological, hydrological, and hydraulic conditions.

Civil works, particularly infrastructure projects, can alter the natural functioning of drainage channels. A typical example is the construction of bridges, whose abutments often require earthworks that modify the local topography. In other cases, the roadways or railways themselves act as barriers to the normal flow of water during flood periods, altering the hydrodynamics of nearby rivers and accelerating erosive processes.

The phenomenon known as Fallen Lands generally results from progressive failures of marginal slopes. Understanding the mechanisms involved in slope destabilization is complex and typically depends on the specific geotechnical and hydrogeological conditions of the affected site, which significantly increases the level of difficulty in analyzing this process. Another challenge lies in defining the shear strength parameters of the destabilized soils, as these values are essential to support the design of stabilization and recovery measures for the affected area.

One approach that can aid in understanding the process and in parameterizing the involved soils is the application of back-analysis techniques, as proposed by Gomes (2003). An example of this methodology is the collapse of a bridge in the Amazon region (Figure 8), associated with the occurrence of the Fallen Lands phenomenon. In this figure, the subsidence steps (dotted lines) formed during the riverbank destabilization process can be observed.

Figure 8. Subsidence steps (dashed lines) next to a partially collapsed bridge.

Based on average soil parameters available in the literature for the predominant soils in the affected area, it was possible to apply back-analysis techniques, the results of which are presented in 0. It is worth noting that the parameters obtained through back-analysis proved to be highly consistent with those reported in the literature, particularly with the values proposed by Wolff (2014), presented in the same table.

Figure 9 illustrates the geological model of the destabilized area, the slope geometry, and the critical failure surfaces obtained through back-analysis, characterizing the retrogressive progression of the destabilization mechanism typical of the Fallen Lands phenomenon. It is evident that the failure surfaces R1, R2, and R3 accurately intersect the three main subsidence steps identified in the field, confirming the correlation between the analytical results and the field observations.

It is observed that the geometric variations of the slope between the stages represented by the yellow and orange colorations are minimal. This behavior may indicate a shortened time interval between failures R1 and R2, which is characteristic of the evolutionary dynamics of the Fallen Lands phenomenon.

In contrast, between failures R2 and R3, significant changes are noticeable in the toe region of the riverbank slope, suggesting a longer time interval between events. This longer interval would have allowed for more intense fluvial activity, promoting erosion of the previously failed soil mass. The results of the back-analyses performed are consistent with values reported in the technical literature. As an example, Table 1 presents also data from studies conducted in a region near the city of Manaus, Amazonas, in which undrained shear strength values were obtained through piezocone testing.

Table 1 - Geotechnical parameters.

Reference	Category	Cohesion (kPa)	Friction Angle (°)	Unit Weight (kN/m³)	Undrained Shear Strength (kPa)	Perm. (m/s)	N_{SPT}
Obtained from back-analysis	Landfill	10	25	17			
	Soft silt	15	10	16			
	Medium silt	10	25	16			
	Medium-dense sand	5	25	18			
	Dense sand	5	30	18			
Campos et al. (2024)	Landfill		25 – 35	17 – 19	-	10^{-6}	
	Silty Clay		5 – 15	16 – 17	50 – 70	10^{-7}	
	Clayey Sand		15 – 25	18 – 20	-	10^{-5}	
Wolff (2014)	Clayed Sand	<5	<25	<15			<10
		5 -15	25 - 30	15 - 17			10 - 20
		15 - 25	30 - 34	17 - 19			20- 30
		30	35	20			>30
	Sandy clay	<10	<15	<13			<10
		10 – 30	15 – 27	13 - 15			10 – 20
		30 – 55	15 – 27	15 - 18			20 – 30
		60	28	19			>30

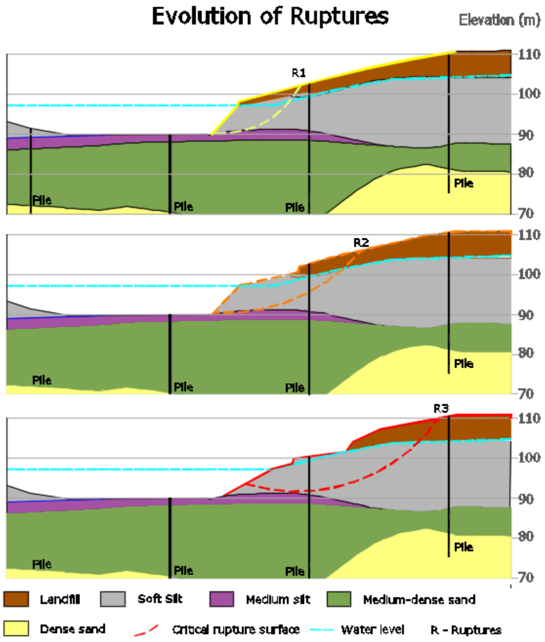

Figure 9. Geological model of the unstable area, slope geometry, and critical failure surfaces obtained through back-analysis, illustrating the retrogressive progression of the the Fallen Lands phenomenon.

4 RESILIENT INFRASTRUCTURES

The development of resilient infrastructure constitutes one of the Sustainable Development Goals (SDGs) established by the United Nations, specifically SDG 9 (United Nations, 2025). This goal is focused on the construction of resilient infrastructure, the promotion of inclusive and sustainable industrialization, and the encouragement of innovation. Achieving resilient infrastructure necessitates an integrated approach that incorporates strategic planning, innovative technologies, and a variety of practices. Resilience is defined as the capacity of infrastructure to absorb and recover from impacts, thereby minimizing disruptions to essential services.

Examples of resilient infrastructure include the following: drainage systems engineered to accommodate increased volumes of water, thereby mitigating the risk of flooding; containment structures designed to safeguard areas susceptible to landslides and flooding; robust constructions, including buildings and bridges, that are meticulously designed to endure high winds, earthquakes, and other severe environmental conditions; enhanced transportation systems, such as highways, tunnels, and railways, that possess greater capacity to withstand floods and landslides; and diverse energy generation systems that do not solely depend on a single source, such as solar or wind energy.

The construction of resilient infrastructure is essential for safeguarding lives and property, ensuring the continuity of critical services such as water and energy supply, and minimizing long-term maintenance costs. Additionally, it plays a significant role in mitigating environmental impacts and economic losses. Nevertheless, numerous existing structures were designed without integrating the principles of resilience, presenting considerable challenges for their maintenance and adaptation in the context of the current climate crisis. To transform these existing structures into resilient ones, it is imperative to adopt a multidisciplinary approach. This approach must encompass risk assessments, structural and foundational reinforcements, the utilization of advanced materials, the implementation of clean energy systems, and the incorporation of remote monitoring technologies. Furthermore, adaptations to landscaping and signage are necessary, alongside efforts to enhance user awareness by establishing escape routes and conducting simulation exercises. By employing such comprehensive strategies, the resilience of existing infrastructure can be significantly improved.

An outstanding illustration of resilient infrastructure is the Oman Gazi Suspension Bridge, located in Turkey, and inaugurated in 2016 (Figure 10).

Figure 10. Bridge in Turkey, with continuous monitoring (Cimento Itambé, 2025).

This impressive structure measures nearly 2,700 meters in length and is constructed from concrete and steel. Its innovative design features steel components interconnected in a manner akin to game pieces (Figure 11), enabling the structure to effectively withstand seismic activity. To ensure ongoing safety and structural integrity, the bridge is subject to continuous monitoring via sensors to detect vibrations.

Figure 11. Turkey bridge steel deck (Engenharia,2019).

The bridge is equipped with advanced sensors that monitor humidity levels and evaluate the risk of corrosion in its steel components. Each deck features climate stabilizers that ensure internal humidity does not exceed 40%. The design of both the steel and concrete pillars, which rest on concrete bases, has been strategically developed to withstand seismic activity. This is achieved by utilizing gravel beds beneath the pillars, which serve as shock absorbers during earthquakes, effectively transferring seismic energy to the bridge structure (Cimento Itambé, 2025). The construction of the bridge has resulted in a reduction of approximately 140 kilometers in the distance between Istanbul and Izmir.

In Brazil, Law No. 14,904/2024 establishes a regulatory framework for resilient infrastructure within the context of climate adaptation. This legislation delineates guidelines for the development of climate change adaptation plans designed to mitigate the vulnerability and exposure of environmental, social, economic, and infrastructure systems to the negative impacts of climate change. As a result, the formulation of new infrastructure projects is mandated to incorporate climate impact assessments and adaptive measures. The law underscores the necessity for engagement and collaboration among public authorities, civil society, and private stakeholders.

5 GUIDELINES FOR RESILIENT CONSTRUCTIONS

To develop resilient infrastructure, it is imperative to prioritize risk reduction, implement effective mitigation measures, raise public awareness, and enhance the preparedness of technical teams to address potential disasters. This comprehensive approach involves careful consideration of material selection and construction techniques, as well as urban planning that integrates effectively with the natural environment.

Recent studies indicate a notable deficiency in the design phase of construction projects, particularly concerning geological and geotechnical investigations, as well as assessments of river hydrodynamics (IPEA, 2018; CPRM, 2024. This lack of comprehensive preliminary analysis frequently results in project specifications that lack necessary detail. Additionally, it has been observed that the execution and technological oversight of these projects, along with routine maintenance activities, are hindered by a shortage of specialized teams trained in the various innovative technological solutions currently available.

The analysis conducted by the authors revealed several primary factors contributing to structural collapse. These factors include specific geotechnical characteristics of the site that were not adequately identified during the design and execution phases of the projects, insufficient periodic maintenance of the structures, and the neglect of underwater inspections. Additionally, these issues are often compounded by the occurrence of extreme weather events.

To address the technical deficiencies observed in civil construction projects while also enhancing their resilience, the following activities are proposed as guidelines:

- it is imperative to allocate additional time and resources to the initial stage of reconnaissance to improve the understanding of the area and the characterization of the subsoil. Investing in innovative field tests, alongside traditional percussion soundings, can yield valuable insights into the behavior of soils and rocks, thereby informing design solutions. Specifically, the thick layers of low-consistency soils require thorough characterization, particularly concerning the behavior of pore pressures during the flooding and ebbing phases of the rivers. Laboratory tests conducted on soil samples can significantly enhance the analysis of the stress state of the soil mass. Furthermore, it is important to highlight the advantages of geophysical tests that utilize promising and non-destructive methodologies;
- it must be considered the life cycle of a project during the design phase, with a focus on integrating concepts of sustainability and performance to develop resilient and cost-effective structures. An illustrative example related to bridge construction was provided by Hawarneh et al. (2025). Neglecting to account for predictive and corrective maintenance activities in the design phase can significantly impede and complicate this vital task, which is essential for ensuring the safety and longevity of the infrastructure;
- in the field of housing, modular construction is increasingly regarded as a more advantageous practice compared to traditional construction methods. This is particularly evident in terms of resilience, construction duration, resource efficiency, and sustainability (Kamali et al., 2025). Furthermore, the principle of modularity can be effectively applied to various infrastructure projects, such as smaller bridges and viaducts. In these instances, the utilization of precast steel or concrete elements is prevalent, as those found in conventional constructions;
- all drawings and records pertaining to the design, execution, interventions, and reinforcements of infrastructure projects (referred to as the project databook) must be systematically archived. This practice will facilitate the ongoing analysis of the operational and safety conditions of the structures involved. The absence of comprehensive documentation results in increased costs associated with investigation and maintenance;
- it is very important to conduct hydrodynamic studies in the design phase of new projects adjacent to watercourses. These studies facilitate the evaluation of environmental impacts, and the identification of risks related to flooding and erosion, which may compromise the functionality and integrity of future constructions. It is imperative that the recurrence periods of these studies be regularly reassessed in response to the climate crisis;
- it is necessary to implement a comprehensive Inspection and Maintenance Program for the infrastructure, ensuring compliance with current technical standards. This program should incorporate underwater inspections to detect any potential pathologies within the infrastructure elements;
- in the context of projects within the Amazon region, it is essential to evaluate the potential impacts of the Fallen Lands phenomenon on design considerations. This evaluation is critical for preventing issues related to support stability and minimizing the frequency of structural repairs. Implementing retro-analysis of previously occurred collapses can provide valuable insights for technicians to establish the necessary geotechnical parameters for future projects; and
- in the context of utilizing metallic structures, it is imperative to develop a comprehensive project that thoroughly addresses corrosive processes. This project

should employ multiple layers of defense to mitigate the corrosion of these components. Furthermore, as previously highlighted, contemporary technologies are available for the continuous monitoring of corrosion effects and moisture content in steel elements.

6 CONCLUSIONS

The investment in resilient infrastructure represents a strategic commitment to the future, safeguarding the security, economic stability, and sustainability of communities amid an increasingly uncertain climate and extreme events. Such infrastructure is engineered to endure severe conditions, facilitate rapid recovery following any damage, and mitigate adverse effects on both communities and economies.

To promote the growth of resilient projects, several actions are required, including:

- the training and qualification of engineering professionals and individuals in related fields are critical for both the design of new projects and the maintenance of existing infrastructure, with an emphasis on sustainability and resilience. Achieving this objective necessitates a comprehensive review of curricula and pedagogical approaches within higher education institutions. Such actions will ensure that the positive effects on professional practice are realized in both the medium and long term;
- an analysis and a proposal for regulations designed to promote the construction of resilient and sustainable infrastructure. Law nº 14,904 (Brazil, 2024) establishes clear guidelines for the development of climate change adaptation plans;
- the specific financing of resilient infrastructure projects is crucial, particularly through collaborations between the public and private sectors. Financial incentives, in conjunction with supplementary initiatives, can facilitate the urgent changes necessary within the country. This is especially pertinent in the Amazon Region, given the recent extreme weather events that have occurred in prior years; and
- the systematic implementation of data acquisition systems (instrumentation) in previously completed projects serves to enhance the reliability of numerical models that aim to accurately simulate extreme weather events and assess their impacts on existing structures. The evaluation of this data can offer valuable insights and act as a basis for the initiation of new projects. For future undertakings, where applicable, it is advisable to consider the integration of digital twins. This practice facilitates decision-making in a predictive manner rather than a reactive one.

Summarizing, the focus must be on striving for the best, which means quality, safety, and a long lifespan for the projects (Bogossian, 2025).

7 ACKNOWLEDGEMENTS

The authors would like to thank IPT – Institute for Technological Research of Sao Paulo State, Brazil, for funding and supporting the research carried out.

REFERENCES

Bogossian, F. 2025. Infraestrutura - visão de futuro sustentável e resiliente. Lecture (In Portuguese). In: ABMS 75 anos.

Brasil. 2024. LEI 14 904-2014. *Estabelece diretrizes para a elaboração de planos de adaptação a mudança do clima.* Brasil: DOU.

Campos, G. C.; Santos, F. S.; Gomes, C. L. R. 2024. Caracterização Geotécnica dos Solos da Região Amazônica, por Meio de Ensaios Piezocone, para Análise do Fenômeno de Terras Caídas. In: ABMS, *COBRAMSEG*, Camboriú – SC.

Cimento Itambé. 2025. Portal de Notícias. [Online] Available at: https://www.cimentoitambe.com.br/turquia-ponte-tecnologica-europa/
[Accessed July 2025].

CNN. 2024. Deslizamento de Terras atinge região do Rio Solimões no Amazonas. [Online]. Available at: https://www.cnnbrasil.com.br/nacional/deslizamento-de-terra-atinge-regiao-do-rio-solimoes-no-amazonas-veja-video/.
[Accessed June 2025].

CPRM – Serviço Geológico do Brasil. 2010. Geodiversidade do Estado do Amazonas, Manaus. CPRM.

CPRM - Serviço Geológico do Brasil. 2024. Avaliação técnica pós-desastre – Manacapuru/AM. Available at: https://rigeo.sgb.gov.br/bitstream/doc/25070/4/relatorio_terra_preta_avaliacao_pos-desastre.pdf. [Accessed July 2025].

Engenharia. 2019. Portal – Tecnologia. [Online] Available at: https://engenhariae.com.br/tecnologia/conheca-sman-gazi-a-ponte-mais-tecnologica-do-mundo
[Accessed July 2025].

Gamba, C.T.C.; Rosa, R.A.S.; Nogueira JR., J.B. 2017. Identificação de processos erosivos às margens do Rio Madeira (RO/AM) a partir da interferometria diferencial por radar (DINSAR). In: *UNICAMP, XVII Simpósio Brasileiro de Geografia Física Aplicada*. Campinas, 2017. Campinas: UNICAMP.

GLOBO. 2023. *Portal de Notícias*. [Online] Available at: https://g1.globo.com/am/amazonas/noticia/2023/10/11/video-parte-de-porto-cai-no-rio-em-itacoatiara-no-amazonas.ghtml.
[Accessed may 2025].

GLOBO. 2022. *Portal de Notícias.* [Online] Available at: https://g1.globo.com/am/amazonas/noticia/2022/09/28/queda-de-ponte-na-br-319-no-am-saiba-quem-sao-as-vitimas.ghtml
[Accessed June, 2025].

Gomes, C. L. R. 2003. *Retroanálise em Estabilidade de Taludes em Solo: Metodologia para Obtenção dos Parâmetros de Resistência ao Cisalhamento* [Dissertação de Mestrado]. Campinas: UNICAMP.

Hawarneh, A.A., Alam, M.S., Ruparathna, R., Pantaz, S.J. 2025. Life-cycle thinking and performance-based design of bridges: A state-of-the-art review. *Resilient Cities and Structures,* Elsevier, April, 2025.

Igreja, H.; Franzinelli, E. 2006. Aspectos das "terras caídas" na Região Amazônica. In: Proceeding, *IX Simpósio de Geologia da Amazônia.* Belém, Pará: 2006.

IPEA-Instituto de Pesquisa Econômica Aplicada. Governança da política de infraestrutura. Available at: https://portalantigo.ipea.gov.br/agencia/images/stories/PDFs/livros/livros/180705_livro_gover_politica_infra_condic_inst_invest.pdf. [Accessed June, 2025].

Kamali, M., Hewage, K., Rana, A., Alam, S., Sadiq, R. 2025. Advancing urban resilience with modular construction: An integrated sustainability assessment framework. *Resilient Cities and Structures,* Elsevier, April, 2025.

Pereira, E.; Carneiro, C.D.R.; Bergamaschi, S.; Almeida, F.F.M. 2012. Evolução das sinéclises paleozoicas: províncias Solimões, Amazonas, Paranaíba e Paraná. In: Hasuy, Y., Carneiro, C. D. R., Almeida, F. F. M. Bartorelli, A. (orgs.). *Geologia do Brasil*, São Paulo: Beca-Ball Edições Ltda.

Rodrigues, F.G.S. 2024. *Terras Caídas: Riscos e Desatres no município e na cidade de São Paulo de Olivença, AM* [Tese de Doutorado]. Ceará: Universidade Federal do Ceará.

Silva, J.M.L. 2003. *Levantamento de reconhecimento de alta intensidade dos solos do Município de Itacoatiara – Estado do Amazonas.* Belém, PA: Embrapa.

Souza, E.S.; Campelo, N.S. 2020. *Caracterização e modelagem geotécnica do fenômeno das Terras Caídas no ambiente amazônico*. Belo Horizonte, MG: Editora Dialética.

United Nations (2025). Goals 9. Available at: https://sdgs.un.org/goals/goal9 [Accessed July 2025]

Wanderley Filho, J.R. 1991. *Evolução estrutural da Bacia do Amazonas e sua relação com o embasamento* [Tese de Mestrado]. Pará: Universidade Federal do Pará.

Wolff, E. 2014. *Gerenciamento de risco geotécnico aplicado a infraestruturas portuárias* [Dissertação de Mestrado]. Brasília: Universidade de Brasília.