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Impulse wave in the Brazilian Lake of Capitólio

Onda de impulso no Lago Brasileiro de Capitólio

Geraldo de Freitas Maciel[1], João Batista Pereira[1], Yuri Taglieri Sáo[1], Fabiana de Oliveira Ferreira[2,3] & Laine Garcia Ferreira[1]

[1] Universidade do Estado de São Paulo, Ilha Solteira, SP, Brasil
[2] Centro Universitário Fundação Santo André, Santo André, SP, Brasil
[3] Universidade Federal do ABC, Santo André, SP, Brasil

E-mails: geraldo.f.maciel@unesp.br (GFM), jbpereira.eng@gmail.com (JBP), yuri.taglieri27@gmail.com (YTS), fabiana.oliveira@fsa.br (FOF), laine.g.ferreira@gmail.com (LGF)

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ABSTRACT

This note proposes a technical approach towards the disaster occurred on January 8, 2022, in the tourism region of Capitólio (Minas Gerais state, Brazil), where a massive quartzite rock broke from a cliff and toppled on to pleasure boaters drifting on a lake, leaving 10 people dead and 30 others injured. Even though the rockfall was decisive in the tragedy, it is reasonable to affirm that the submersion-wave impact certainly potentialized the accident. Along these lines, this work not only aims to videographically explore the geometric / kinematic characteristics of the solid block, but also to discuss the specificities pertaining the event. Lastly, with basis on the Noda Method (1970), this manuscript also estimates the resulting wave amplitude (near the impact) and the energy-transfer coefficient between the block and the body of water.

Keywords: Impulse wave; Capitólio rockfall; Noda method; Maximum amplitude wave.

RESUMO

Esta nota propõe uma abordagem técnica para o desastre ocorrido em 8 de janeiro de 2022, na região turística de Capitólio (MG), onde uma enorme rocha quartzítica se desprendeu de um penhasco e tombou sobre barqueiros de recreio à deriva em um lago, deixando 10 mortos e outros 30 feridos. Ainda que a queda da rocha tenha sido decisiva na tragédia, é razoável afirmar que o impacto da onda de submersão certamente potencializou o acidente. Nessa linha, este trabalho não só tem como objetivo explorar videograficamente as características geométricas/cinemáticas do bloco sólido, mas também discutir as especificidades pertinentes ao evento. Por fim, com base no Método de Noda (1970), este manuscrito também estima a amplitude de onda resultante (próxima ao impacto) e o coeficiente de transferência de energia entre o bloco e o corpo d'água.

Palavras-chave: Onda de impulso; Queda de rocha de Capitólio; Método de Noda; Onda de amplitude máxima.

INTRODUCTION

On January 8, 2022, in the tourism region of Capitólio (Minas Gerais state, Brazil), a massive quartzite rock broke from a cliff and toppled on to pleasure boaters drifting on a lake, leaving 10 people dead and 30 others injured (Oliveira et al., 2022). The international repercussion of the tragedy brought about a series of discussions entailing: 1) the concealment of risks associated to disasters triggered by natural hazards in tourism regions, especially in the absence of regulatory guidance and adequate monitoring; 2) the necessity to educate the local population and foreign visitors about such risks; and 3) the blind search for culprits after the accident.

From a strictly technical view, the physics of the waves produced by the rock falling on the lake resembles those of surface waves generated by mass movement or strong winds (Mao et al., 2016; Mattosinho et al., 2022). Examples of waves generated by the impact of different materials in the free surface are given in Figure 1. The waves result from the transfer of momentum of the sliding mass into the body of water, usually displacing huge volumes of water in distinct characteristic times. The displaced volume of water is propagated as gravitational waves, such as sinusoidal, cnoidal, solitary, bore and Stokes waves, whose mathematical classification depends on the nature of the impact, e.g. impact Froude number, displaced volume of water and water depth (Slingerland & Voight, 1979). Such waves may cause partial or total shore erosion, even resulting in the collapse of buildings and structures (like dams and harbors) (Prasad & Kumar, 2014; Wang et al, 2019a). Additionally, the displacement of large volumes of water and sediment can lead to an overtopping in downstream areas (Tessema et al., 2019), causing both loss of life and widespread damage to infrastructure. In this sense, the study of impulse waves generated by landslides (Fritz et al., 2009; Thuro & Hatem, 2010;

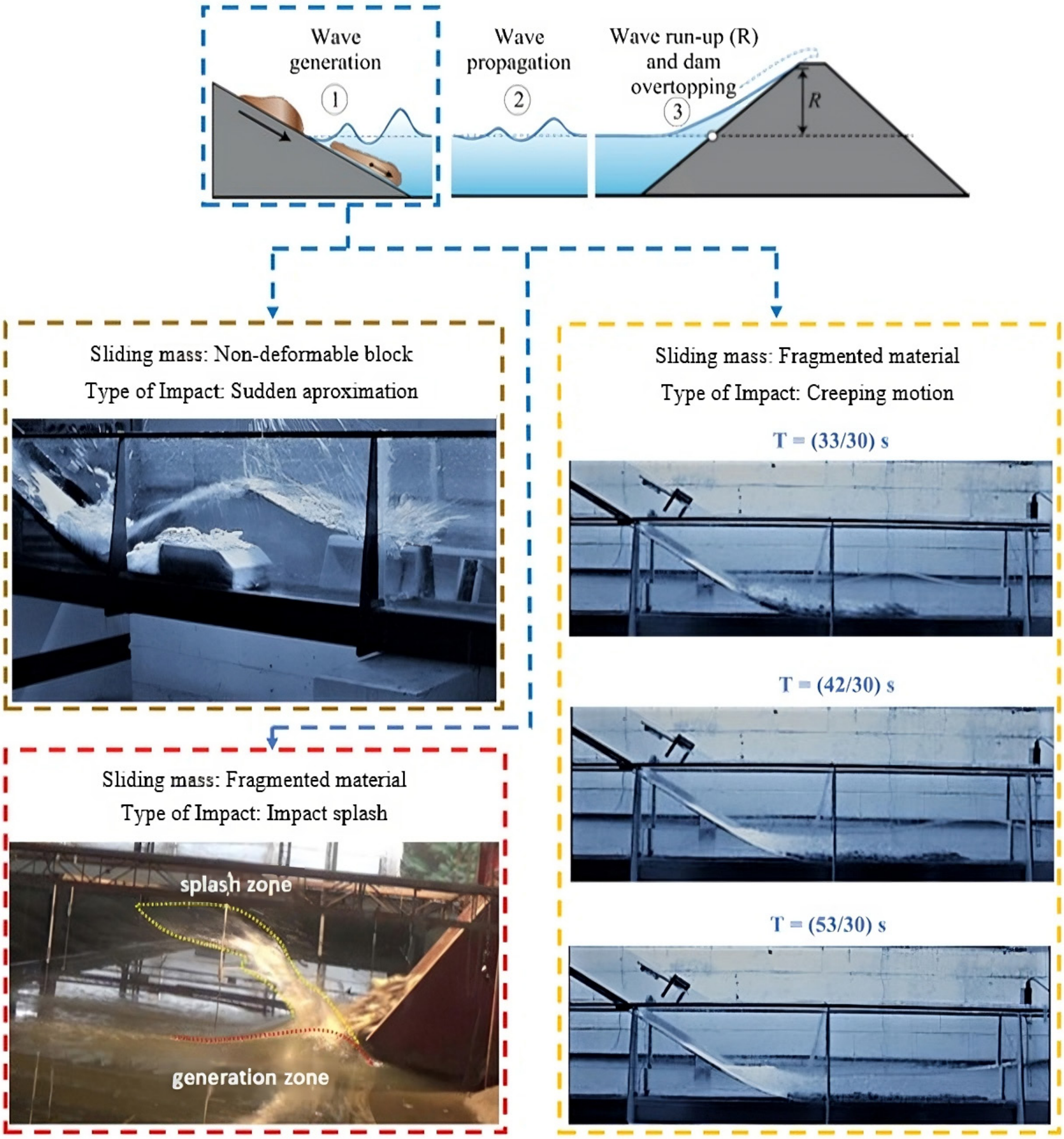


Figure 1. Phenomenon phases, with focus on wave generation caused by the impact of a non-deformable and fragmented material (adapted from Heller, 2007). Physical tests were carried out in the Hydraulics Laboratory of UNESP – Ilha Solteira, Brazil, with exception to the test done with fragmented material represented by the lower left image (adapted from Han et al., 2022).

Jansen, 2012; Crosta et al., 2015; Wang et al., 2019b) in natural lakes and dam reservoirs concerns not only hydraulic engineers but also managers of electric power concessionaires as well as the responsible for promoting the economic development of the tourism sector or adventure tourism of all kinds, since they can engender damage or accidents with people.

Scientific efforts have been aiming to establish physical, mathematical and numerical modellings of impulse waves in order to mitigate accidents caused by them (Raney & Butler, 1976, Maciel, 1991; Heinrich, 1992; Monaghan & Kos, 2000; Maciel & Nascimento, 2002b; Quecedo et al., 2004; Choi et al., 2007; Panizzo et al., 2005; Zweifel et al.2007; Pastor et al., 2009; Abadie et al., 2010; Bosa & Petti, 2011; Cremonesi et al., 2011; Tinti et al., 2011; Vasco et al., 2011, Yin et al., 2015; Shi et al., 2016; Wang et al., 2017; Si et al., 2018; Chen et al., 2020; Romano et al., 2020; Takabatake et al., 2020; Amaro et al., 2021; Cheng et al., 2021; Rauter et al., 2021; Zhang et al., 2021; Sabeti & Heidarzadeh, 2022). The first systematic studies related to the phenomenon were performed soon after the nuclear tests in the Bikini Atoll in 1946 (Hager & Evers, 2020). In the following years, theoretical works were published with basis on small-scale experiments performed in laboratory (Unoki & Nakano, 1953; Kranzer & Keller, 1959; Wiegel, 1955; Prins, 1958). Small-scale models can be reproduced through ideal two-dimensional geometries, in which waves are generated by the vertical fall of a solid block (Wiegel, 1955) or by sliding a deformable/non-deformable material over an inclined plane partially submerged in water (Mohammed & Fritz, 2012; Meng & Ancey, 2019; Heller, 2007). For instance, Han et al. (2022) carried out laboratory experiments by producing waves through the impact of fragmented material (concrete blocks) in a reservoir, as depicted in Figure 1. The authors observed highly non-linear impulse waves (large amplitude-depth ratio), which presented a large splash zone. The experiments also showed three types of waves: non-linear oscillatory waves, non-linear transitory waves and shallow-water bore waves. Combining experimental results with dimensional analysis, empirical and semi-empiric laws were formulated and vastly discussed in the literature (Kamphuis & Bowering, 1970; Slingerland & Voight, 1979,1982; Huber, 1980; Sabatier, 1983; Maciel, 1991; Watts, 1997, 2000; Maciel et al., 1990; Maciel & Nascimento, 2002a, 2002b; Watts & Grilli, 2003; Walder et al., 2003; Fritz et al., 2004; Zweifel, 2004; Watts et al., 2005; Ataie-Ashtiani & Malek-Mohammadi, 2007; Heller, 2007; Ataie-Ashtiani & Najafi-Jilani, 2008; Di Risio & Sammarco, 2008; Heller & Hager, 2010; Heller & Spinneken, 2013; Bolin et al., 2014; Fuchs & Hager, 2015; Heller & Spinneken, 2015; Evers & Hager, 2016; McFall & Fritz, 2016; Bullard et al., 2019; Evers et al., 2019), being useful for general estimation of impact-wave properties.

In this context, and taking into account the repercussion of the accident in Capitólio (2022), the aim of this manuscript is to employ the Noda's semi-empiric approach (Noda, 1970) to estimate properties of the wave in a first approximation. Although other empirical and semi-empirical methods are available to assess this case, the specificity of the Capitólio event, described in Subsection 2.1, rule out these methods with exception of the Noda's method (please see Subsection 2.2). The application of the Noda's method allowed the estimation of the maximum wave amplitude generated near the rock impact onto the body of water.

METHODOLOGY

The methodology employed in this work is divided in two subsections. Subsection 2.1 describes the specificity of the Capitólio event and establishes hypotheses to assess the wave properties and Subsection 2.2 describes the Noda's method and details its application to the Capitólio event.

Hypotheses, considerations and idealization of the fall kinematics related to the accident in capitólio

Even though the focus of this manuscript is to estimate the maximum wave amplitude generated by the rock impact onto the body of water, some aspects of the accident are too specific for a first approximation. Nonetheless, the following characteristics could be observed from the falling of a porous rock, saturated with water after a rainy period:

- Falling dynamics – a solid rock detaches from a cliff (Figures 2a and 2b), progressively (from the base to the

Figure 2. Solid rock: (a) before (Source: Brisa, 2022) and (b) after detaching from the Cliff (Source: Correio do Povo, 2022)

"peak") hitting the lake 5 to 6 seconds after the detachment. The rock fell unbroken, with a 90 rotation in the vertical plane (normal to cliff), colliding with the water plane (of approximately $d = 4m$ depth). Immediately after the impact, the rock shattered to pieces, under a sort of effect of a "progressive detonation" along its length, generating a strong splash (Figure 3).

- Solid geometry – the block's geometry is irregular, tending to a pyramidal shape with triangular base and straight posterior face. Basically, the solid block could be circumscribed by a triangular-based prism, 30 m high, 4 m thick, with a base width of 8 m. Figure 4 illustrates the described geometry.
- Physical modelling of the rockfall: an analysis comprising the falling dynamics, the impact exerted by the block on the water, and its subsequent fragmentation, indicates the occurrence of a mixed rockfall (fragmented blocks of distinct sizes). Such model has already been reported in the literature as a possible mechanism that amplifies wave amplitudes (McFall & Fritz, 2016). At this stage of the study, though, semi-empiric approaches would still be able to estimate the wave amplitude (while considering a non-fragmented rockfall).

Definitely, the analysis of this specific impulse-wave event would require further two-dimensional and three-dimensional simulations in order to more accurately determine the velocity field and the wave amplitude in a chaotic zone. Nonetheless, based on the established hypotheses and on the data collected from those involved in the accident (rescuers and tourists), the wave amplitude was objectively estimated in this work. From an engineering perspective and considering the aforementioned analysis of the case, the method explored by Noda (1970), referred as Noda Method (1970) in this work, was chosen to estimate the impulse-wave event of Capitólio, admitting some technical-scientific reservations and simplified hypotheses (please see subsection 2.2).

Description of the Noda method (1970) and its application to the capitólio event

Noda (1970) modeled a landslide by considering a vertically falling box of λ width and height greater than the still water depth d being released onto a rectangular channel. Some assumptions were made to assess the resulting waves: 1) the volume of the box is small compared to the water volume within the channel; 2) the displacement over time of the box is known; 3) incompressible fluid and irrotational flow, allowing the usage of linearized equations of gravity waves; 4) the horizontal fluid velocity under the box is not a function of the vertical direction; and 5) impact phenomena can be ignored. Impulsive wave theory was used and expressions for wave amplitude both in the near-field (maximum

Figure 3. Videography of the event (Source: CNN BRASIL, 2022 - Public domain)

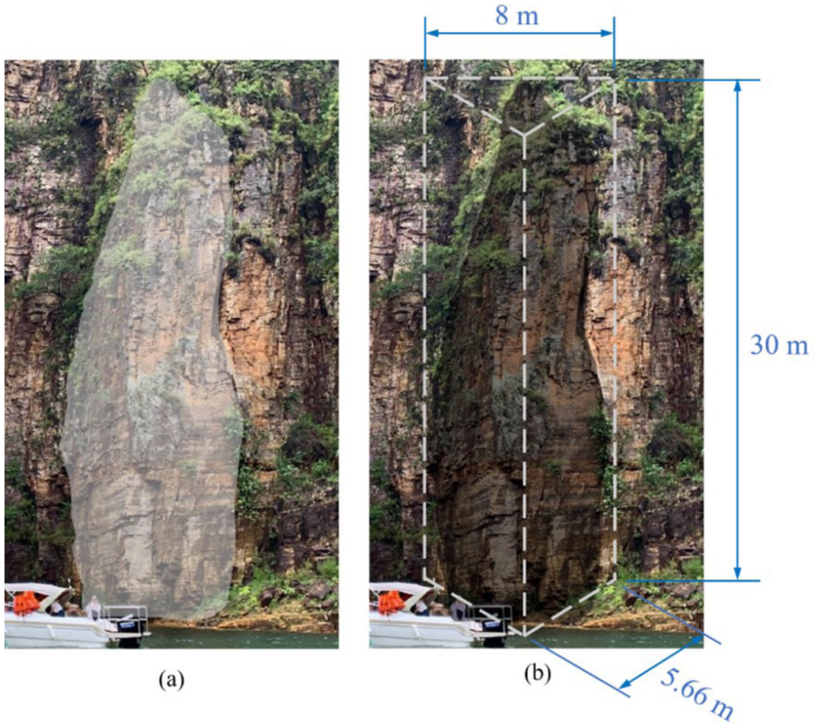


Figure 4. Block resemblance towards a triangular-based prism and its respective dimensions (Source: Brisa, 2022 - Public domain)

wave amplitude η_{max}) and in the far-field regions of the impact were obtained (Equation 1).

$$\eta(x,t)/\lambda = f\left(V/\sqrt{gd}, x/d\right) \quad (1)$$

where $\eta(x,t)/\lambda$ is the relative wave amplitude, $V/\sqrt{gd}$ is the impact Froude number Fr_{imp} with the slide impact velocity V and x/d is the relative horizontal distance from the box.

Experiments were also carried out with a series of boxes of λ width being released vertically onto a rectangular channel of d depth and the same width of the boxes. The free-fall velocity of the box, the impact velocity of the boxes in the water and the water depths in different distances from the disturbance were measured. These measurements allowed to establish wave patterns in function of the impact Froude number Fr_{imp} and the relative width of the box λ/d. Based on the model tests, Noda (1970) found four waves types as a function of Fr_{imp} and the relative slide thickness λ/d, namely the oscillatory, the non-linear transition, the solitary wave, and the bore regions.

In order to apply the Noda's method to the Capitólio event, the prism resulting from the block adaptation (Figure 4b) was assumed as a parallelepiped with the same volume, readjusting its geometry to that of the boxes used by Noda (1970). Figure 5 shows the approximation to apply Noda's method. By making this approximation, Noda's method hypotheses are considered to be valid, especially the vertically-falling block condition. Other empirical/semi-empirical methods, such as Kamphuis & Bowerin, 1970, Huber, 1980, Fritz et al., 2009, Heller & Spinneken, 2015, Hager & Evens, 2020, Han et al., 2022, consider the slide slope, whereas Noda's method is not associated with a slide slope, just as the approximation made in this work. Furthermore, Noda's method is capable of predicting the maximum wave amplitude near the fall; thus, the method is chosen to evaluate the Capitólio event.

Throughout the study, important parameters like the impact Froude number Fr_{imp}, the relative maximum wave amplitude $\left(\eta_{max}/\hat{\lambda}\right)$ and the maximum wave amplitude η_{max} were obtained for the assumed box width $\hat{\lambda}$, the mean water depth d, and the box/block impact velocity V. To that end, two situations concerning the impact velocity were taken into account: 1) a velocity V_{min} resulting from a free-fall time of $6s$; and 2) a velocity V_{max} resulting from a free-fall time of $5s$. Table 1 presents the acquired data, whereas Figures 6a and 6b exhibit the graphical representation of the results obtained along with the conclusions presented by Noda (1970).

Absolute and relative errors of the employed parameters were defined under some considerations. The only error explicitly obtained is referred to the falling velocity of the block, provided by the timeframe of the accident's footage. Other parameters, such as dimensions of the block and its density, were estimated by defining their characteristic values and their errors were estimated by fixing a deviation of $\pm 10\%$ from the correspondent characteristic value. Following the procedure of Heller et al. (2019), an absolute error of $0.034s$ for the free-fall time was obtained, resulting in relative error of 10% for impact velocity V, 11% for the impact Froude number Fr_{imp} and 14% for the relative width of the box λ/d.

RESULTS AND DISCUSSIONS

When it comes to describing the generated-wave profile, Figure 6a exhibits impact Froude numbers higher than 1, indicating non-linearity, even when considering their uncertainties. Moreover, as far as the geometrical characteristics of the block are concerned, its relative width $\hat{\lambda}/d$ was estimated as 1. Under these specific

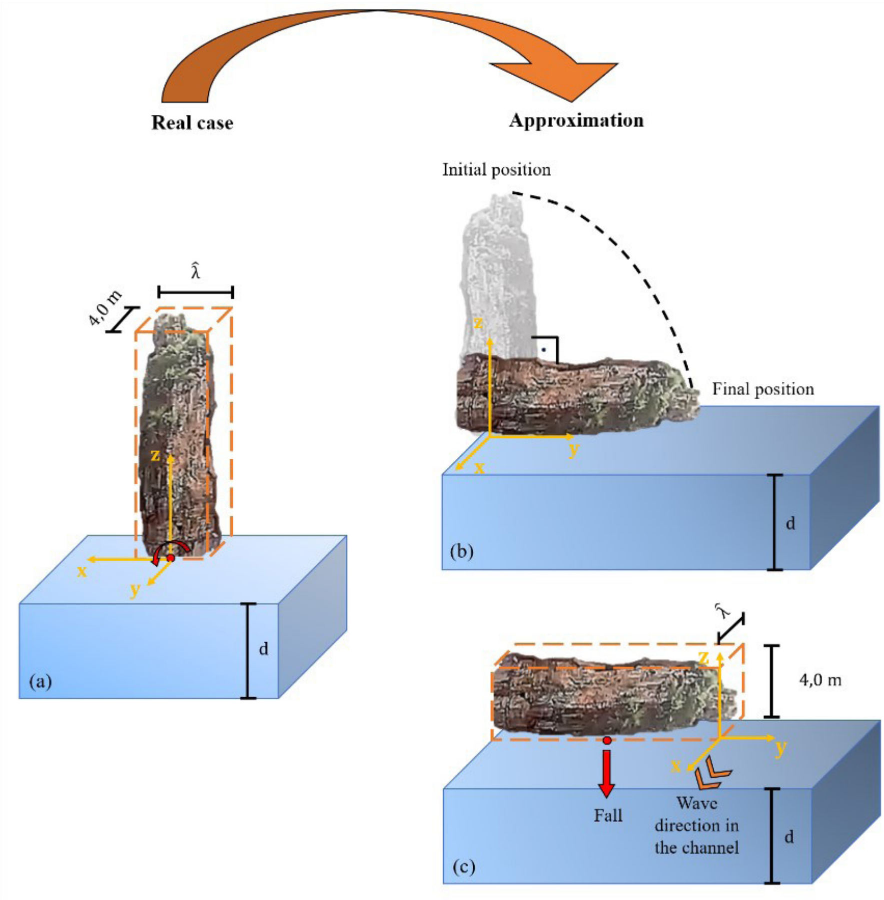


Figure 5. Approximation of the block fall in the Capitólio event: (a) real case – rotation of the block around its own base and consequent fall; (b) alteration of the block's position, from vertical to horizontal; and (c) parameterized block in an horizontal position impacts with known velocity, identical to experiments of Noda (1970).

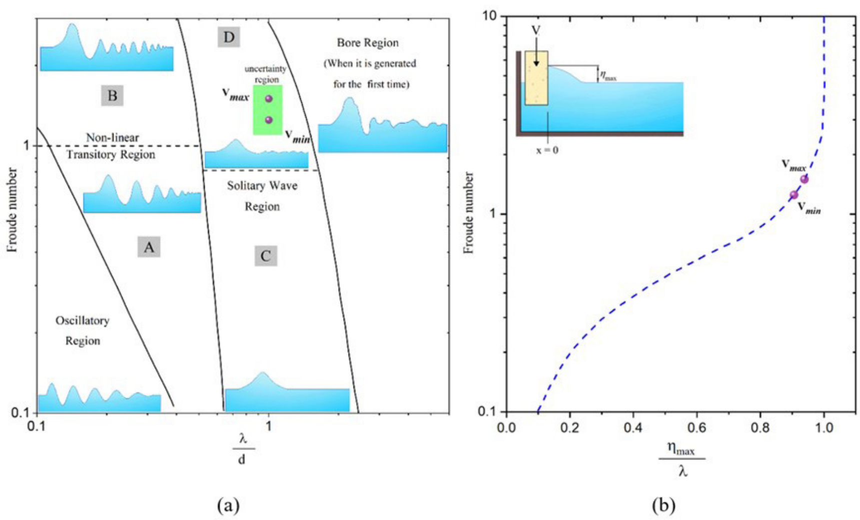


Figure 6. (a) Wave classification based on Noda's results (1970), in function of the relative width of the box λ / d and the impact Froude number. Four distinct regions for wave generation were identified in the domain: one oscillatory, one non-linear transitory, one appropriate for solitary waves and one suitable for bores. Estimate results obtained during the analyses pertaining this manuscript are highlighted by purple dots and the green region around the purple dots refers to the uncertainty region. (b) Noda's result (1970) for a wave generated near the impact ($x = 0$). The graph represents the ratio between the maximum wave amplitude and the box width (η_{max} / λ) in function of the impact Froude number. Estimate results obtained during the analyses pertaining this manuscript are highlighted by purple dots.

approximate conditions, the impulse wave produced in the disaster of Capitólio could be treated as a solitary wave. However, the parameter $\hat{\lambda}/d$ presents uncertainties concerning both the block geometry, and the lake local depth, which could alter the oscillatory profile and produce a non-linear wave or even a bore. Notwithstanding, through the analysis of the event's videography, it is possible to observe a turbulent-dissipating wave-front, typical of bore waves. Noda (1970) reported a similar effect in the experiments where the box was dropped from higher altitudes, where the ratio of height above the water to local depth was over 4.

In this scenario, the impulse wave of Capitólio would resemble a bore of high energy dissipation, with a maximum amplitude of 3.75 m. A lower amplitude could be predicted, if the local energy dissipation between the block and the water was taken into account. Ultimately, based on the data presented in Table 1, it was possible to estimate a transfer of mechanical energy from the block to the lake of 15%, which is in agreement with the results observed in the literature (Nascimento, 2001; Souza, 2007; Maciel & Nascimento, 2002a, 2002b; Souza & Maciel, 2005; Han et al, 2022).

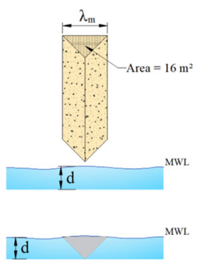
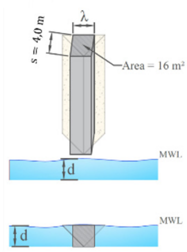
Considering the Capitólio event and using the wave amplitude obtained by Equation 1 as reference, Table 2 presents a comparison of two other empirical and semi-empirical models that also satisfy the condition of block falling vertically on the lake, i.e. Noda's 2D piston-type model (1970) and Heller's 2D granular slide model (2007). Deviations from the maximum wave amplitude reference ($\Delta\eta_{max}$) and energy transfer coefficients are also presented in Table 2.

Parameter P, known as impulse product and defined by Equation 2, is considered as the governing non-dimensional parameter, both to analyse sliding impact and to evaluate wave propagation zones (Heller, 2007).

$$P = Fr_{imp} S^{1/2} M^{1/4} \left\{ cos\left[\left(\frac{6}{7}\right)\alpha\right]\right\}^{1/2} \quad (2)$$

where Fr_{imp} is the impact Froude number, $S = \hat{\lambda}/d$ is the relative slide thickness, $M = m_s / \left(\rho_w b d^2\right)$ is the relative slide mass with the slide mass m_s, the water density ρ_w and the slide length b, and α is the hill slope angle.

Table 1. Geometric characteristics, falling dynamics and wave amplitudes for two velocity situations: 1) V_{min}, resulting from a free-fall time of $6\,s$; and 2) V_{max}, resulting from a free-fall time of $5\,s$. Absolut and relative uncertainty are defined from estimates of the employed parameters.

Base dimensions of the block λ (m)	Width of the parameterized box $\hat{\lambda}$ (m)	Local mean depth d (m)	Relative width of the box $\hat{\lambda}/d$	Impact velocity* V (m/s)	Impact Froude number Fr_{imp}	Wave pattern	Relative maximum amplitude $\frac{\eta(0,t)_{max}}{\hat{\lambda}}$	Maximum amplitude η_{max} (m)
8 ±0.8	4 ±0.4	4 ±0.4	1 ±0.14	7.85 ± 0.76 [*1]	1.25±0.14	- non-linear wave - solitary wave - bore wave	0.91	3.62±0.12
				9.42 ± 0.94 [*2]	1.50±0.17	- non-linear wave - solitary wave - bore wave	0.94	3.75±0.06

* Two velocity situations were taken into account: [*1] V_{min} for a free-fall time of 6 s and [*2] V_{max} for a free-fall time of 5 s. (1) The geometric information concerning the block was based on estimates. (2) The impact phenomenon and the fragmentation process caused by the block impact on water were ignored. Notes: Based on the observations made by Wiegel (1955), the Noda method (1970) for predicting waves generated near the impact region could be related to the results of Kranzer & Keller (1959). In fact, a wave amplitude of 2.85 m was obtained using their study concerning explosion-generated waves (i.e., a maximum percentage variation of 30%, when compared to Noda's η_{max}). The maximum energy-transfer coefficient $E_{wave} / E_{mechanical}$ during the impact was estimated in 15% based on the Boussinesq equations, while considering a soliton of maximum amplitude η_{max} = 3.75 m.

Table 2. Comparison between the three empirical/semi-empirical models considering wave amplitude and energy transfer coefficients for the maximum velocity.

Reference	Equation	η_{max} (m)	$\Delta\eta$ (%)	Energy variation (%)
Noda (1970) (2D block model)	$\eta(x,t)/\lambda = f\left(V/\sqrt{gd}, x/d\right)$	3.75±0.06	Basis	14.9
Noda (1970) (2D piston-type model)	$\eta_{max} = 1.32d(V/\sqrt{gd})$	7.94±1.19	+110	45.9
Heller (2007) (2D granular slide model)	$A_m = (4/9)P^{4/5}$ *	1.62±0.42	-57	4.2

* Parameter $A_m = \eta_{max}/d$ is the relative maximum wave amplitude.

The following values are computed using Equation 2 and Heller's method, considering the two scenarios of impact velocity (maximum and minimum) and erro from each parameter (Table 1): $1.11 \leq Fr_{imp} \leq 1.67$, $0.86 \leq S \leq 1.14$, $2.15 \leq M \leq 2.85$, $\alpha = 90°$ and $0.74 \leq P \leq 0.89$. The Noda's piston-like model overestimates the maximum wave amplitude in 110%, with $\eta_{max} = 7.94 \pm 1.19\,m$ when compared to the Noda's block model. On the other hand, Heller's method underestimates the maximum wave amplitude in 57%, with $\eta_{max} = 1.62 \pm 0.42$ m.

Input values of the model showed to be naturally very uncertain, such as the exact water depth, bathymetry, block characteristics (e.g. material, geometry and dimensions) and falling characteristics (e.g. time history). Even though Noda's method and other semi-empirical methods are conservative, the obtained estimations show that these models can provide useful information in an engineering point-of-view, due to the simplicity of their application.

The Noda's methods, i.e. vertical fall model and piston-like model, represent the extreme cases for the event and they result in maximum wave amplitude of 3.75 $\pm 0.06 \leq \eta_{max} \leq 7.94 \pm 1.19\,m$, providing a ratio of 1 to 2 in wave amplitude. It is worth noting that the horizontal displacement effect (piston-like effect) can be applied in this case, since the scale of λ is in the order of d. Regarding wave energy, considering a soliton of same amplitude with the same range of η_{max}, the energy dissipation rate would be in the range of $14\% \leq E_{wave} / E_{mechanical} \leq 46\%$ for the classical Boussinesq model.

LIMITATIONS OF THE THEORETICAL AND SEMI-EMPIRICAL APPROACHES / SUGGESTIONS FOR FUTURE RESEARCH

All analytical / semi-empirical techniques employed in the literature over the last 70 years for the prediction of impulse waves were grounded on mathematical models assuming a number of consolidated hypotheses (potential flows, impact of non-deformable or fragmented materials onto wave channels, among others). Additionally, many of these studies were based on two-dimensional analyses supported by validating physical experiments (carried out in laboratories or through fieldwork practices). In the theoretical approach, there are attempts to model impact waves by prescribing a bottom movement through a function and obtaining the response on the free surface. This attempt produces almost-analytical solutions using Fourier and Laplace transforms, quadrature integrations and asymptotic expansions. However, even though these attempts are frequently employed to study, e. g. tsunamis, almost all of the models described in the literature are based on potential flow and linear theories (Ursell, 1953; Press, 1965; Podyapolsky, 1968; Thomson, 1887, Dutykh & Dias, 2007).

Due to scarce available data, the analysis of the Capitólio's accident is still established over approximated parameters. In fact, there are many uncertainties related to the event and its parameters, since it not only involves a 90-degree impact, with high energy dissipation and momentum transfer between solid masses and a body of water, but also a specific fragmentation process under a globally 3-phase regime (water, air, solid). Moreover, the phenomenon also presents strong turbulence and a remarkable splash effect on impact produced by the sudden approximation of the solid (see Figure 1). Lastly, aggravating the situation, the characteristic time of the event is actually shorter than the characteristic time necessary for wave generation and propagation, which places it in the category of sudden approximation and, therefore, greater modeling difficulties.

Even with the help of state-of-the-art measuring transducers, usually employed to characterize velocity fields (ADVs, UDS, STIV, PIV) and free surfaces (ultrasonic/photonic techniques, ultrafast imaging), the specificity of Capitólio's accident brings about an unprecedented scenario with complex elements. When it comes to diagnosing the problem and producing technical solutions for it, under an engineering point of view, a more complete mathematical model should be considered and validated by numerical codes from Computational Fluid Dynamics, such as Mike21, Flow3D, ANSYS Fluent and DualSPHysics. In essence, the methodological path to describe the phenomenon must consist of a complete non-linear numerical model able to simulate impulse waves, taking in account also the viscosity of fluid coupled with turbulence modelling. This way, it would be possible to not only analyze in detail and more accurately the generation zone (near field), but also assess disturbances in the far-field regions of the impact.

FINAL CONSIDERATIONS

Although the impact wave may have potentiated the accident, it should be clear that all 10 deaths were due to the direct impact of the rock on boat. Additionally, the Capitólio's episode presented a very short characteristic time, typical of sudden-approximation phenomena. In these short-time phenomena, the impulse wave cannot even leave its own generation zone before the phenomenon breaks off, as opposed to the slower phenomenon (creeping approximation phenomena), which usually occurs in slopes significantly inferior to ninety degrees and the sliding material is already fragmented at the impact on the body of water. In order to precisely obtain the wave profile and energy dissipation during the impact, just numerical simulations based on complete mathematical models could provide reliable data (e.g. velocity fields, vorticities and momentum-transfer rate between solid and body of water). Lastly, despite the specificity level of the accident, the uncertainty pertaining the data input, the limitations of the employed semi-empirical approaches and the simplified hypotheses used in the analysis (Noda's Method), the wave-amplitude estimate near the impact was remarkably promising from an engineering point of view. Moreover, it serves as the basis for a comparative future study comprising its numerical simulation.

DATA AVAILABILITY STATEMENT

All data, models, and code generated or used during the study appear in the submitted article.

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Authors contributions

Geraldo de Freitas Maciel: Research coordinator, paper conception, writing, analysis and completion of results and discussion.

João Batista Pereira: Performed data collection, videography, analysis and discussion of results.

Yuri Taglieri Sáo: Discussion of results and proofreading the article.

Fabiana de Oliveira Ferreira: Literature review, discussion of results and formatting of the article.

Laine Ferreira Garcia: Literature review and article review.

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