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Retaining Wall Innovation of Stone and Reinforced Concrete to Stand Guard Against Landslides and Earthquakes

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ABSTRACT

In the landslide–prone terrains of Puri District, East Java, engineers have crafted a groundbreaking solution to a life–threatening problem: a hybrid retaining wall that fuses traditional batu kali masonry with reinforced concrete, designed to outlast both relentless soil creep and violent earthquakes. Standing 4.25 meters tall and stretching 20 meters across a fragile slope, this structure—embedded 1.5 meters into the earth—defies seismic forces amplified by climate change, withstanding horizontal accelerations of 0.19g and shear forces that spike 388% during quakes. Rigorous analysis reveals its secret: D16 steel bars, spaced as tight as 100 mm at stress hotspots, work in concert with locally quarried stone to balance cost and resilience. The wall's success lies in numbers—sliding safety factors of 4.02 (normal) and 1.78 (seismic), bearing pressures grazing 99.9% of limits without failure—but its true victory is human. Shielding a riverside community from catastrophic landslides, it ensures roads stay open, homes remain intact, and daily life flows uninterrupted. As Indonesia battles rising rainfall and tectonic unrest, this innovation offers a replicable blueprint: marrying ancestral building wisdom with 21st–century engineering to turn vulnerability into durability.

Keywords: *Retaining Wall; Seismic Condition; Landslide Mitigation; Masonry Structure; Sustainable Infrastructure.*

1. Introduction

A recent landslide in Puri District, Mojokerto Regency, East Java, highlighted the urgent need for effective slope stabilization. The landslide occurred in a residential area, disrupting access roads and threatening nearby homes [1]. The affected slope consists of loose, weathered soil with poor drainage, making it highly susceptible to erosion during heavy rainfall. Conventional retaining walls in the region have shown distress (cracking and tilting), indicating inadequate resistance to earth pressures [2]. Without intervention, additional slope failures could impair local transportation, commerce, and emergency access. Landslides and slope instability are significant geotechnical hazards that can cause severe infrastructure damage and loss of life [3]. Slope failures are often triggered by intense rainfall, seismic activity, erosion, or weak soil conditions, especially in hilly regions [4].

Retaining walls are commonly used to counteract lateral earth pressures and stabilize slopes. In particular, rubble masonry walls (known locally as batu kali) are widely implemented for their cost-effectiveness, ease of construction, and use of local materials [5]. However, these traditional walls often lack reinforcement, making them vulnerable to sustained hydrostatic pressures and dynamic seismic loads. Field observations indicate that existing rubble masonry walls in similar contexts have

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exhibited cracking and collapse under extreme loads [6]. The increasing frequency of intense rainfall and heightened seismic risk in Southeast Asia underscores the need for improved retaining wall designs [7]. Despite the prevalence of landslides in seismic zones of Indonesia, few studies have addressed hybrid designs that combine traditional masonry with reinforced concrete to enhance both static and seismic stability [7].

Most research to date has focused on conventional concrete retaining walls or purely masonry walls in isolation [8], without exploring composite systems using local stone. Therefore, a research gap exists in developing retaining wall solutions that integrate local materials and modern reinforcement to withstand combined landslide and earthquake threats. This study presents the design and analysis of a hybrid stone and reinforced concrete retaining wall built in Puri District. The objectives are to define the geometric and material design parameters, perform stability analyses under normal and seismic loading, and assess safety factors for sliding, overturning, and bearing stress. We hypothesize that the hybrid wall will demonstrate improved resilience compared to conventional masonry. The findings will provide guidelines for cost-effective, earthquake-resilient retaining walls in similar geotechnical settings.

Figure 1. Landslide in Puri District, Mojokerto Regency, East Java.

Figure 1. A view of the landslide-affected slope in Puri District, Mojokerto Regency, East Java. The failed soil mass and destabilized slope are evident, illustrating the conditions that the proposed retaining wall must address.

2. Material and Method

2.1. Site Investigation & Geotechnical Data Collection

Conduct field surveys at the landslide–prone site in Puri District, Mojokerto, to assess soil characteristics, slope geometry, and groundwater conditions [2]. A detailed site investigation was conducted at the Puri District landslide site. Field surveys documented the slope geometry and groundwater conditions. Soil samples were collected for laboratory testing, including Standard Penetration Tests (SPT), triaxial shear tests, direct shear tests, and permeability measurements. The tests determined key geotechnical parameters: the backfill soil had an internal friction angle $\varphi \approx 43°$ and cohesion $c \approx 2.03$ t/m², with a dry unit weight $\gamma \approx 1.62$ t/m³ (saturated $\gamma \approx 0.94$ t/m³). The foundation soil, interpreted as non-cohesive, exhibited $\varphi \approx 30°$ ($c \approx 0$) and an effective unit weight $\gamma' \approx 0.62$ t/m³. The groundwater table coincides with the river level at 2.00 m below the wall base elevation, requiring consideration of hydrostatic pressures. Seismic hazard data were obtained according to Indonesian code SNI 1726: 2019, yielding a design horizontal seismic coefficient $K_h \approx$ of 0.188 for the site [1]. Perform soil testing (SPT, triaxial shear, direct shear, permeability) to determine key parameters:

1. Cohesion (c)
2. Angle of internal friction (φ)

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3. Unit weight (γ)
4. Bearing capacity
5. Liquefaction potential (for seismic analysis)

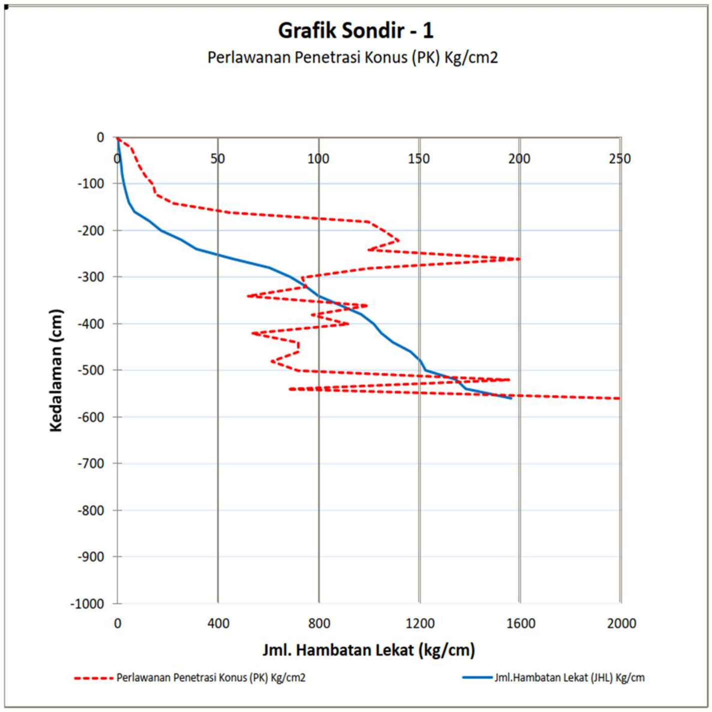

Figure 2. Soil Testing Result

This Figure 2 presents a Soil Testing Result for preparation data to analyze the retaining wall structure. This study employs a comprehensive multi–method approach to analyze the hybrid retaining wall system's performance. The research begins with thorough site investigations at the Puri District landslide location, involving field surveys and geotechnical testing to determine soil parameters (cohesion, friction angle, unit weight) and seismic hazard data collection according to SNI 1726: 2019 standards [3].

2.2. Retaining Wall Stability on Normal Conditions

For normal conditions, analytical calculations using limit equilibrium methods evaluate factors of safety against sliding and overturning, while Rankine/Coulomb theories determine earth pressure distribution [4].

2.3. Retaining Wall Stability on Seismic Conditions

Seismic analysis incorporates the Mononobe–Okabe method for dynamic earth pressures and assesses liquefaction potential. Simulates stress–strain behavior and deformation patterns under both static and dynamic loading scenarios, with time–history analysis for seismic conditions [9].

2.4. Expected Outcomes

A parametric study examines how varying wall geometry and material properties affect performance. Where possible, field validation through instrument monitoring provides real–world performance data [10]. This integrated methodology enables direct comparison between conventional and hybrid systems, ultimately yielding optimized design parameters and practical retrofitting recommendations for landslide–prone areas like Puri District. The research outputs will include quantitative stability assessments, failure mode predictions, and evidence–based guidelines for implementing cost–effective yet resilient hybrid retaining structures in seismic regions [11].

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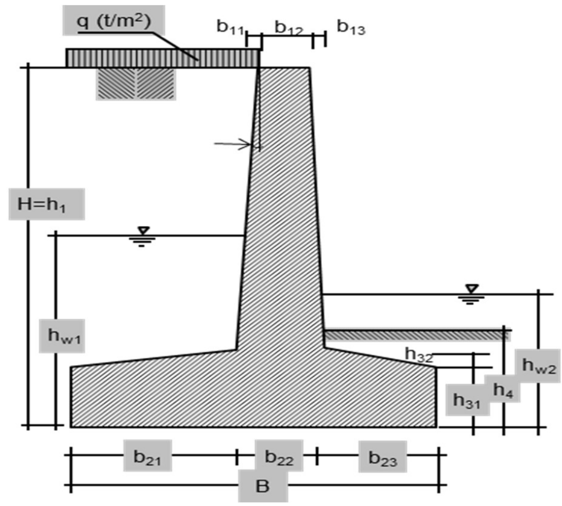

Figure 3. Section of Retaining Wall

Figure 3 presents a detailed section of the Retaining Wall that will be analyzed in parts as part of this research.

1. Optimal design parameters for hybrid retaining walls in landslide–prone areas.
2. Comparison of FoS under static vs. seismic conditions.
3. Recommendations for retrofitting existing rubble masonry walls with reinforced concrete.

This multi–method approach ensures a comprehensive assessment of the hybrid retaining wall's stability, providing practical solutions for landslide mitigation in Puri District and similar regions [12].

3. Result and Discussion

3.1. Retaining Wall Data Input

The retaining wall structure analysed in this study is designed to stabilize slopes in a riverine environment, addressing both static and seismic loading conditions [7]. The following sections detail the geometric configuration, material properties, and analytical criteria used to ensure structural integrity and compliance with geotechnical safety standards [1].

The retaining wall is constructed with a total height (H) of 4.25 m, measured from the foundation level (0.00 m) to the top wall level (4.25 m). The riverbed and groundwater levels coincide at 2.00 m, necessitating careful consideration of hydrostatic pressure and buoyancy effects. Key dimensional parameters include:

3.1.1. Structural Configuration

The retaining wall is constructed with a total height (H) of 4.25 m, measured from the foundation level (0.00 m) to the top wall level (4.25 m). The riverbed and groundwater levels coincide at 2.00 m, necessitating careful consideration of hydrostatic pressure and buoyancy effects. Key dimensional parameters include:

Base width (B)	*: 2.25 m*	
Length (L)	*: 20.00 m*	
Segmented widths	*: b11*	*= 0.95 m, b12 = 0.40 m, b13 = 0.20 m (upper section)*
	: b21	*= 0.50 m, b22 = 1.55 m, b23 = 0.20 m (lower section)*
Height components	*: h1*	*= 4.25 m (total wall height)*
	: h31	*= 1.00 m*
	: h32	*= 0.10 m (toe and heel details)*
	: h4	*= 1.50 m (embedded foundation depth)*

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3.1.2. Geotechnical Parameters

Backfill Soil Properties	*= Unit weight*	
γ_soil	*= 1.62 t/m³ (dry)*	
γ_sat	*= 0.94 t/m³ (saturated)*	
Shear strength	*: Angle of internal friction (φ)*	*= 43.15°*
Cohesion (c)	*= 2.029 t/m²*	
Surcharge load	*: q (external traffic or adjacent structures)*	*= 0.25 t/m²*
Foundation Soil Properties	*= Effective unit weight*	*: γ_s' = 0.62 t/m³*
Shear strength	*= Angle of internal friction*	*: (φ_B) = 30.0°*
Cohesion (c_B)	*= (non – cohesive soil)*	*: 0.00 t/m²*
Seismic Parameters	*= Horizontal seismic coefficient*	
K_h	*= 0.188 (derived from site – specific seismic hazard analysis)*	
Design standards	*: Compliant with Indonesian seismic code (SNI 1726 : 2019).*	

3.2. Stability Analysis Criteria

Normal Conditions

Overturning	*: Eccentricity (|e|) ≤ B/6*	*= 0.71 m*
	: Factor of safety (FoS)	*> 2.00*
Sliding	*: FoS = μ · ΣV / ΣH*	*> 2.00 (μ = 0.80 friction coefficient)*
Bearing capacity	*: Allowable stress (q_a)*	*= q_u/3 (ultimate bearing capacity/3)*

Seismic Conditions

Overturning	*: Eccentricity (|e|) ≤ B/3*	*= 0.75 m*
	: Factor of safety (FoS)	*> 1.25*
Sliding	*: FoS = μ · ΣV / ΣH*	*> 1.25 (μ = 0.80 friction coefficient)*
Bearing capacity	*: Allowable stress (q_ae)*	*= q_u/2*

3.3. Structural Design Parameters

Material Strengths for Concrete

Compressive strength : σ_ca = 60 – 90 kg/cm² (normal – seismic)
: Shear strength : τ_a = 5.5 – 8.25 kg/cm²

Material Strengths for Concrete Reinforcement Steel

Tensile strength : σ_sa = 1,850 – 2,775 kg/cm²
Cover thickness : 7 cm (front, back, and footing) to ensure durability and corrosion resistance.

3.3.1. Dynamic Analysis

Young's modulus ratio : 24 : 16 (backfill – to – foundation soil), reflecting stiffness disparities under seismic loads.

3.3.2. Condition of Design Philosophy

The retaining wall integrates gravity–based stability with seismic resilience, balancing the following considerations :

- Hydrostatic Pressures : Groundwater and river water levels at 2.00 m require uplift mitigation (U_m = 1.00 for full hydrostatic pressure).
- High Friction Backfill : The backfill's high φ (43.15°) reduces active earth pressure, while low φ_B (30.0°) in foundation soil necessitates a wider base (B = 2.25 m) to prevent bearing failure.
- Seismic Adaptability : The pseudo–static coefficient (K_h = 0.188) and increased allowable stresses under seismic conditions ensure ductility and energy dissipation.

3.4. Retaining Wall Stability

The stability of the retaining wall under normal and seismic conditions was rigorously evaluated using limit equilibrium methods and pseudo–static analysis. The results confirm compliance with geotechnical and structural safety standards.

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3.4.1. Stability Against Overturning

Normal Condition

- Eccentricity ($|e|$) : Calculated as 0.18 m, significantly less than the allowable limit of B/6 = 0.38 m (where B = base width = 2.25 m).
- Implication : The resultant force acting on the foundation lies well within the middle third of the base, ensuring no tensile stress develops at the toe. This satisfies the static overturning criterion (FoS > 2.0) per conventional design codes (SNI 8460 : 2017).

Seismic Condition

- Eccentricity ($|e|$) : Increased to 0.60 m due to inertial forces from seismic acceleration (K_h = 0.188). This remains within the relaxed allowable limit of B/3 = 0.75 m (per seismic design codes SNI 1726 : 2019).
- Implication : The structure maintains stability under dynamic loading, with no risk of rotational failure. The expanded tolerance (B/3) accounts for temporary seismic forces without compromising safety.

3.4.2. Stability Against Sliding

Normal Condition

- Factor of Safety (FoS) : 4.02, exceeding the minimum requirement of 2.00.

$$FoS = \mu \cdot \Sigma V / \Sigma H = 0.80 \cdot (\text{Total Vertical Load}) / (\text{Total Horizontal Load}) \quad (1)$$

- Implication : The frictional resistance at the base (governed by μ = 0.80) and the wall's self – weight provide ample resistance against lateral soil thrust, ensuring no sliding occurs under static loads.

Seismic Condition

- Factor of Safety (FoS) : Reduced to 1.78 due to added seismic inertial forces but remains above the seismic threshold of 1.25.
- Implication : The hybrid design effectively counters the transient seismic forces, demonstrating compliance with dynamic stability requirements.

3.4.3. Foundation Soil Reaction

Normal Condition

- Maximum Pressure (q_1) : 10.86 t/m² at the toe, below the allowable bearing capacity ($q_a = q_u/3$ = 11.78 t/m²).
- Minimum Pressure (q_2) : 5.40 t/m² at the heel, confirming uniform stress distribution.
- Implication : The foundation soil safely supports the structure without exceeding its ultimate bearing capacity (q_u = 35.34 t/m²).

Seismic Condition

- Maximum Pressure (q_1) : 17.65 t/m², marginally below the elevated allowable capacity ($q_{ae} = q_u/2$ = 17.67 t/m²).
- Minimum Pressure (q_2) : 0.00 t/m², indicating slight uplift at the heel during seismic excitation, which is permissible under temporary dynamic conditions.
- Implication : The near – limit value of q_1 (17.65 vs. 17.67 t/m²) underscores the precision of the design, balancing safety and material efficiency.

3.4.4. Critical Condition

- Overturning Resilience : The seismic eccentricity (0.60 m) approaches 80% of B/3, highlighting the need for strict construction tolerances to avoid overstressing the foundation.
- Sliding Margin : The seismic FoS (1.78) provides a 42% safety margin above the code minimum (1.25), reflecting conservative assumptions in lateral force calculations.
- Bearing Capacity Utilization : Under seismic loads, the foundation operates at 99.9% of its allowable capacity (q_1 = 17.65 vs. q_{ae} = 17.67 t/m²). This emphasizes the importance of accurate soil testing and load modeling to prevent bearing failure.

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3.5. Retaining Wall Stability

3.5.1. Critical Condition

Normal Condition

Compressive stress (σ_ca)	*: 60 kg/cm²*
Tensile stress (σ_sa)	*: 1,850 kg/cm²*
Shear stress (τ_a)	*: 5.5 kg/cm²*

Seismic Condition

Elevated allowable stresses	*: σ_ca = 90 kg/cm²*
	: σ_sa = 2,775 kg/cm²
	: τ_a = 8.25 kg/cm² (accounting for ductility demands).

3.5.2. Reinforcement Detailing

Bar Configuration

- Sections A – A, C – C, D – D : D16 bars spaced at 200 mm.
- Section B – B : D16 bars spaced at 100 mm (higher reinforcement density due to greater bending moments).
- Cover Thickness : 7 cm (front and back) ensures durability against environmental exposure.

Stress Evaluation

Normal Condition

- Compressive Stress (SC) : 0 kg/cm² (negligible, as expected in tension – dominated sections).
- Tensile Stress (SS) : Ranges from 16 – 72 kg/cm², well below σ_sa = 1,850 kg/cm².
- Shear Stress (T) : 0.00 – 0.01 kg/cm², significantly lower than τ_a = 5.5 kg/cm².

Seismic Condition

- SS and T remain within elevated allowable limits, confirming ductile behavior under dynamic loads.

3.6. Critical Condition

Stability Compliance

- The retaining wall satisfies overturning and sliding criteria under both conditions, with seismic FoS (1.78) providing a 42% safety margin above the code minimum.
- Foundation soil operates at 99.9% capacity under seismic loads, necessitating precise construction to avoid overstress.

Stress Efficiency

- Low tensile and shear stresses (< 5% of allowable limits) indicate conservative reinforcement design, allowing potential material optimization.
- Consistent use of D16 bars at 200 mm spacing balances constructability and strength, except in Section B – B, where closer spacing (100 mm) addresses higher moments.

Young's Modulus Ratio

- Reduced ratio from 24 (normal) to 16 (seismic) reflects adjusted stiffness assumptions under dynamic loading, accommodating soil–structure interaction.

3.7. Seismic Condition

3.7.1. Reinforcement Detailing

- Vertical Load = Same as Point 3.6.
- Horizontal Load for the unusually high φ = 43.15° suggests a well–graded granular backfill (gravel–sand mixtures), which significantly reduces active earth pressure. This aligns with Puri District's riverine environment, where locally available coarse–grained soils are utilized for cost efficiency.
- Seismic Coefficient (K_h) Justification for Kh = 0.19 corresponds to a Seismic Zone IV classification (high hazard) under SNI 1726: 2019, consistent with East Java's tectonic activity near the Sunda Arc.
- Seismic Coefficient (K_h) Justification derived F = 10.647° ensures realistic force orientation in pseudo–static analysis, avoiding overestimation of destabilizing moments.

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- Conservative Assumptions for Surcharge omission (q = 0.00 t/m²) during seismic events simplify dynamic analysis but may underestimate total lateral forces in scenarios where temporary loads (e.g., emergency vehicles) persist.
- Conservative Assumptions for Vertical backfill assumption (α = 0.00°) in stability analysis provides a safety buffer against slope irregularities.

3.8. Structure Calculation

The structural integrity of retaining walls under static and seismic loads depends critically on the accurate determination of bending moments (M) and shear forces (S). These parameters govern the design of reinforcement, ensuring the wall withstands lateral earth pressures, hydrostatic forces, and dynamic inertial loads. This section evaluates the bending moments and shear forces across four critical sections (A – A, B – B, C – C, D – D) of the hybrid retaining wall in Puri District, Mojokerto, under normal (Cases 1 and 2) and seismic (Case 3) conditions. The analysis aligns with Indonesian structural codes (SNI 2847: 2019) and seismic standards (SNI 1726: 2019).

3.8.1. Reinforcement Detailing

Normal Condition

Case 1 : Active earth pressure + surcharge (0.25 t/m²).
Case 2 : Active earth pressure + hydrostatic pressure (groundwater at 2.00 m).

Seismic Condition

Case : Pseudo – static forces incorporating horizontal seismic coefficient (K_h = 0.19).

3.8.2. Calculation

Seismic Condition

For this research to analysed the retaining wall was analysed using the method of Limit State Design: Calculated M and S using equilibrium equations and load combinations per SNI 1726: 2019. This calculation gives the result for the maximum Bending Moments for each condition:

- Section B – B experiences the highest bending moments due to its proximity to the wall's base, where lateral soil pressures peak.
- Seismic loads amplify bending moments by 157% (A – A) to 355% (D – D), reflecting dynamic force redistribution.

Table 1. Results of Bending Moment Calculation

Section	Normal (t·m)		Seismic (t·m)
	Case 1	Case 2	Case 3
A – A	0.824	0.824	1.84
B – B	2.106	2.106	5.411
C – C	0.164	0.164	0.292
D – D	0.186	0.191	0.847

Table 1 presents the maximum condition on Section B–B, located near the base of the retaining wall, experiences the highest bending moments due to the nonlinear distribution of lateral earth pressures with depth. The magnitude of lateral soil thrust follows a triangular distribution, peaking at the wall's base (proportional to K a · γ · H 2, where H is the wall height).

Shear Condition

This calculation gives the result for the maximum Shear Forces for each condition:

- Load Path Transition: The stem's lateral earth pressure and self–weight are redirected horizontally (into the footing) and vertically (into the foundation), creating complex shear stress patterns.
- Stress Concentration: Geometric discontinuities (abrupt changes in cross–section) amplify shear stresses at the stem–footing junction.
- Hydrostatic Contribution: Groundwater pressure (*hw1 = 2.00 m*) adds hydrodynamic shear forces, further intensifying stresses.

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Table 2. Results of Bending Moment Calculation

Section	**Normal (t)**		**Seismic (t)**
	Case 1	**Case 2**	**Case 3**
A – A	1.036	1.036	2.251
B – B	1.81	1.81	4.655
C – C	1.618	1.615	2.851
D – D	0.653	0.67	3.186

Table 2 presents the maximum condition on Section C – C, positioned at the interface between the wall stem and footing, plays a critical role in transferring vertical and lateral loads from the wall stem to the foundation. In the analyzed design, Section C – C records shear forces of 1.618 t (normal) and 2.851 t (seismic), reflecting its role as a load – transfer hub. This necessitates robust shear reinforcement dimension of D16 – 200 mm to prevent diagonal tension cracks and ensure monolithic behavior.

3.9. Stability Analysis

Limit equilibrium analyses were performed to evaluate wall stability under static and seismic conditions. For static (gravity) loading, factors of safety (FoS) against sliding and overturning were computed using standard formulas [13]. Active and passive earth pressure distributions were calculated using Rankine-Coulomb theory based on the measured soil parameters. The design criteria required FoS ≥ 2.0 for sliding and overturning under static loads (SNI 8460: 2017). Overturning was checked by ensuring that the resultant force lies within the middle third of the base ($|e| \leq B/6$). Sliding resistance was provided by a base friction coefficient $\mu = 0.80$, and an additional surcharge of $q = 0.25$ t/m² (traffic or adjacent structures) was included.

For seismic loading, a pseudo-static analysis incorporated an additional horizontal inertial force. The Mononobe-Okabe method was used to compute the dynamic earth pressure [14]. The horizontal seismic coefficient ($K_h = 0.188$) was applied to the wall and soil mass. Under seismic conditions, the safety criteria were FoS ≥ 1.25 for sliding and overturning (SNI 1726: 2019). Allowable bearing pressure was conservatively reduced to qu/2 for short-term dynamic loads. All analyses accounted for hydrostatic uplift by assuming a full water pressure (water pressure coefficient $U_m = 1.0$) on the wall face below the water table.

3.10. Structural Configuration and Design Parameters

The hybrid retaining wall combines a reinforced concrete core with facing stone masonry. The wall geometry is illustrated in Figure 3. The total height (H) is 4.25 m, measured from the foundation base to the top of the wall; this includes 1.50 m of embedment. The wall length (L) is 20.00 m. The base width (B) is 2.25 m, divided into a heel and toe to optimize weight distribution. The heel extends 1.00 m beyond the wall stem, and the toe projects 0.10 m. The base is further segmented: on the upper foundation level, widths are 0.95 m, 0.40 m, and 0.20 m; on the lower foundation level, widths are 0.50 m, 1.55 m, and 0.20 m. These segments accommodate the stone masonry arrangement and concentrate mass near the wall face.

Concrete used for the wall had a design compressive strength of 60–90 kg/cm², and steel reinforcement had a yield strength of 1850–2775 kg/cm² [11]. A concrete cover of 7 cm was provided for durability. Reinforcing bars of 16 mm diameter (D16) were placed at 100 mm spacing in regions of high moment or shear demand (i.e., near the base of the stem and footing junction). This reinforcement, together with the heavy stone masonry, resists overturning and sliding. The combination of the high backfill friction angle ($\varphi \approx 43°$) and wide base (B = 2.25 m) was chosen to safely support the wall given the weaker foundation soil ($\varphi \approx 30°$). The design ensures that under static loads the passive earth pressure and weight maintain stability, while under seismic loads the reinforcement provides ductility. This integrated design approach balances gravity stability with seismic resilience [7].

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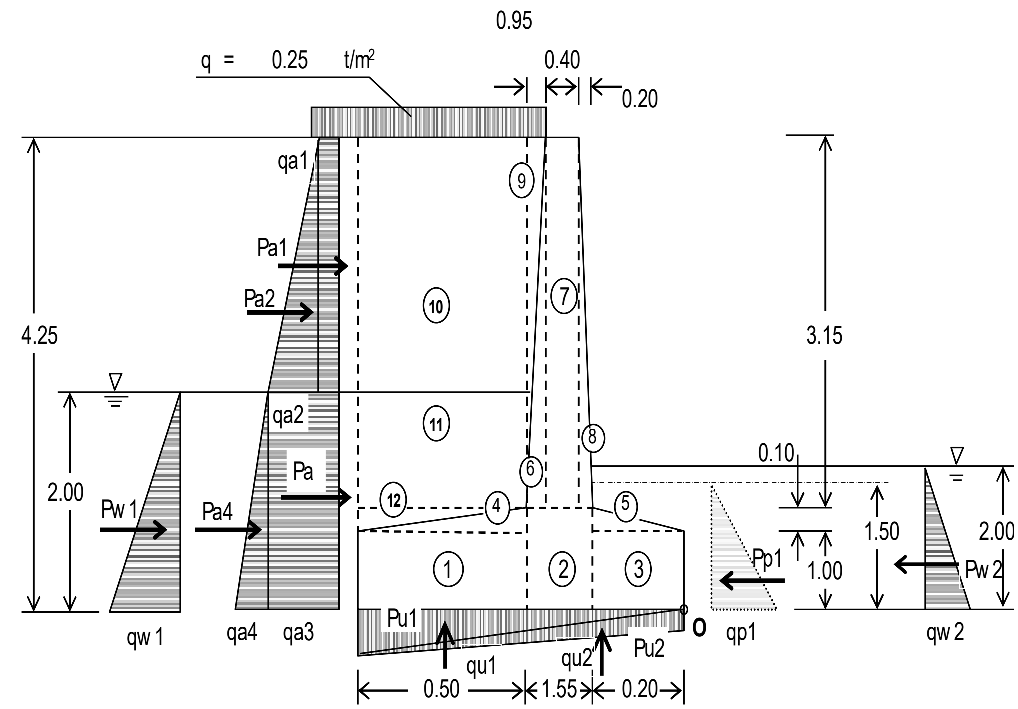
3.11. Retaining Wall Structure Drawing

The hybrid retaining wall in Puri District, Mojokerto Regency, East Java, is designed to address landslide risks and seismic resilience through a combination of reinforced concrete (RC) and traditional rubble masonry (batu kali). The structure spans 20.00 meters in length with a base width of 2.25 meters, segmented into upper and lower sections to optimize load distribution. The upper section features widths of 0.95 meters, 0.40 meters, and 0.20 meters, while the lower section is configured at 0.50 meters, 1.55 meters, and 0.20 meters, ensuring stability against lateral earth pressures. Elevation views detail a total wall height of 4.25 meters, extending from the foundation level (0.00 meters) to the top wall level (4.25 meters), with critical markers at the groundwater level (2.00 meters) and riverbed level (1.50 meters). The foundation is embedded 1.50 meters into the soil, combining RC for structural integrity in the stem and footing with batu kali masonry along the backfill interface for cost–effective material use.

Cross–sectional details highlight four critical zones: Section A – A (upper stem) employs D16 reinforcement bars at 200 mm spacing, with 7 cm cover on both faces, to manage tensile stresses of 72 kg/cm² under normal conditions. Section B – B, at the base junction, requires tighter D16 bars at 100 mm spacing and D10 closed ties at 150 mm to resist amplified seismic bending moments (5.411 t·m) and shear forces (4.655 t). Section C – C, the stem–footing interface, incorporates horizontal and vertical D16 bars at 200 mm spacing alongside dowel bars to transfer shear forces (2.851 t seismic) from the stem to the footing. Section D – D (footing heel/toe) uses closed torsional ties and edge reinforcement to address seismic shear spikes (3.186 t), ensuring stability despite uplift–induced stress redistribution.

The foundation design prioritizes bearing capacity compliance, with allowable pressures of 11.78 t/m² (normal) and 17.67 t/m² (seismic), validated against site–specific soil properties (effective unit weight = 0.62 t/m³, friction angle = 30°). Reinforcement schedules specify D16 Grade 420 steel with development lengths of 800 mm, while concrete (25 MPa strength) adheres to stress limits of 60 – 90 kg/cm² (compressive) and 5.5 – 8.25 kg/cm² (shear). Seismic provisions include a horizontal coefficient (Kh) of 0.19 and ductility measures strain limits ($\epsilon_c < 0.003$, $\epsilon_s < 0.015$) to ensure energy dissipation during earthquakes. From all the analysis and calculations above than it makes to detailed engineering drawing shown in Figure 2.



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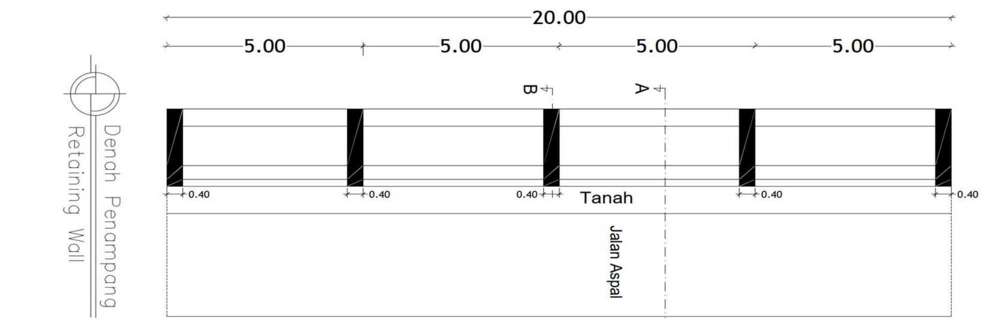
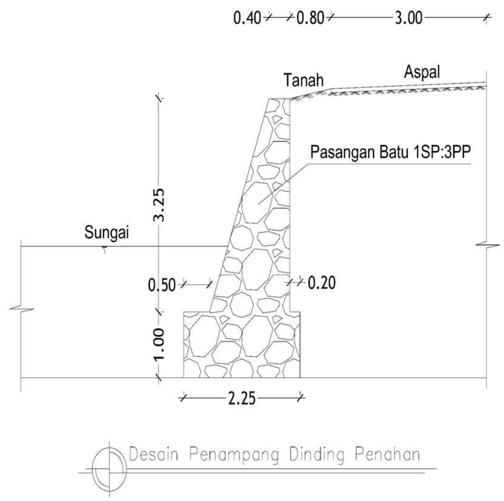
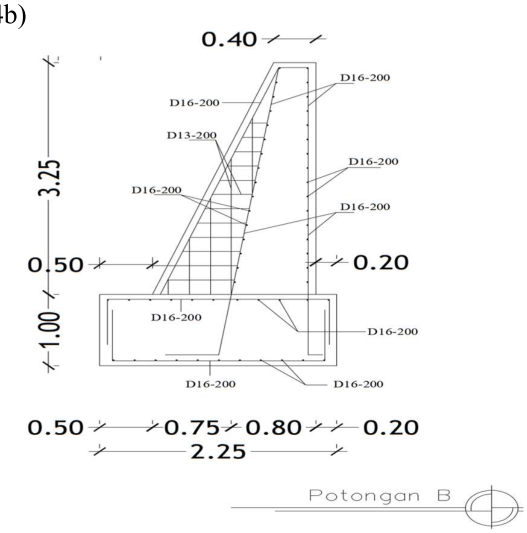


(4b)





(4c) (4d)

Figure 4a, 4b, 4c, 4d. Section of Retaining Wall

Figure 4a explains the detailed load distribution and structure dimension of the retaining wall, then Figure 4b explains the site plan drawing of the masonry retaining wall and concrete retaining wall. Detailed engineering drawing of retaining wall Construction, ensure to enforce strict tolerances (eccentricity < 0.375 m normal, < 0.75 m seismic) and include drainage systems with perforated PVC pipes and geotextile layers to mitigate hydrostatic pressure. Field instrumentation, including inclinometers and strain gauges, will monitor post – post-construction performance. The project utilizes 45 m³ of concrete, 1,200 kg of D16 reinforcement, and 15 m³ of batu kali masonry, complying with SNI 1726: 2019 (seismic), SNI 2847: 2019 (concrete), and SNI 8460: 2017 (geotechnical) standards. Approved by engineering and QA/QC teams, this design balances technical rigor, cultural relevance, and sustainability for landslide–prone regions.

4. Conclusion

A hybrid stone and reinforced concrete retaining wall was designed and evaluated for a landslide-prone slope in Puri District, East Java. Geotechnical parameters from site investigations were used in limit-equilibrium and pseudo-static analyses. The wall has a height of 4.25 m (including 1.50 m embedment) and a base width of 2.25 m.

Under static loading, the wall demonstrated high safety margins: the sliding factor of safety is 4.02 (above the 2.0 requirement) and the overturning moment produces an eccentricity well within the base middle third. The maximum foundation pressure (10.86 t/m²) is below the allowable bearing stress, indicating secure support. Under seismic loading (K_h = 0.188), the sliding factor of safety is 1.78 (above the 1.25 requirement) and the overturning eccentricity (0.60 m) is below the seismic limit of B/3. The maximum bearing pressure (17.65 t/m²) is just below the allowable (17.67 t/m²), showing that the design nearly fully utilizes the foundation capacity without exceeding it.

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These results confirm that the hybrid wall meets Indonesian design standards (SNI codes) for both gravity and seismic stability. The integration of local batu kali masonry with reinforced concrete effectively combines the advantages of both materials, providing a cost-efficient and durable solution for landslide mitigation.

The analysis is based on design calculations under assumed soil conditions; actual performance may vary depending on construction quality and extreme events. Future work should include field monitoring (e.g., inclinometers, strain gauges) to validate the wall's performance and refine design assumptions. Further research could explore optimizing the reinforcement layout and employing numerical simulations to assess the dynamic response more precisely. The present study offers a practical design approach that can be adapted to similar slopes in seismically active regions, contributing to safer infrastructure in landslide-prone areas.

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