Jurnal Serambi Engineering JSE

Volume XI, No.3, Juli 2026 Hal 20754 - 20759

p-ISSN : 2528-3561
e-ISSN : 2541-1934

Safety and Operational Efficiency Analysis of Rope Access Method on Non-Linear Geometrical Structure of Monumen Tugu Reog Ponorogo

Muhammad Fajar Mahmud Ananta, Firman Ardiansyah Ekoanindiyo

Industrial Engineering Department, Universitas Stikubank, Semarang
Corresponding author: muhammadfajar3003@mhs.unisbank.ac.id, firman@edu.unisbank.ac.id

Received: July 22, 2026 Approved: July 29, 2026

Abstract
The construction of the 60-meter high Monumen Tugu Reog Ponorogo by CV Gendhis Multi Karya faces extreme vertical accessibility challenges due to the non-linear curved geometry of the structure (dadak merak and barongan). The use of conventional scaffolding is considered slow, expensive, and poses a high risk of damaging the brass ornaments. This study aims to analyze the comparison of operational effectiveness (time, labor, cost) and occupational safety risk levels between scaffolding and rope access methods using the HIRARC matrix based on AS/NZS 4360:2004. Comparative analysis results show that rope access reduces equipment mobilization time by 87.5% (from 12 days to 1.5 days), saves active labor by 70.0% (from 10 people to 3 people), and cuts operational costs by 70.83% (from IDR 120,000,000 to IDR 35,000,000). The initial risk assessment indicates that all working at height activities fall into the High risk category (scores 10-15). After designing technical mitigation actions including dynamic anchor testing of at least 15kN in accordance with BS EN 795:2012 standards, thick canvas corner protectors, and a maximum wind speed limit of 20 knots (37 km/h), the risk level was successfully reduced to the Low category (residual risk scores 2-3). The implementation of rope access is proven to be the optimal solution that guarantees both safety and productivity aspects in the construction of cultural heritage buildings with complex geometries.
Keywords: *rope access, HIRARC, cost efficiency, AS/NZS 4360:2004, tugu reog monument*

Abstrak
Pembangunan Monumen Tugu Reog Ponorogo setinggi 60 meter oleh CV Gendhis Multi Karya menghadapi tantangan aksesibilitas vertikal yang ekstrem akibat geometri bangunan yang melengkung non-linear (dadak merak dan barongan). Penggunaan metode perancah (*scaffolding*) konvensional dinilai lambat, mahal, dan berisiko tinggi merusak permukaan ornamen kuningan. Penelitian ini bertujuan untuk menganalisis perbandingan efektivitas operasional (waktu, tenaga kerja, biaya) serta tingkat risiko keselamatan kerja antara metode perancah dengan metode akses tali (*rope access*) menggunakan matriks HIRARC standar AS/NZS 4360:2004. Hasil analisis komparasi menunjukkan metode akses tali mampu memangkas waktu mobilisasi alat sebesar 87,5% (dari 12 hari menjadi 1,5 hari), menghemat kebutuhan tenaga kerja aktif sebesar 70,0% (dari 10 orang menjadi 3 orang), dan menekan biaya operasional sebesar 70,83% (dari Rp 120.000.000,- menjadi Rp 35.000.000,-). Penilaian risiko awal (initial risk) menunjukkan seluruh aktivitas kerja di ketinggian masuk kategori risiko Tinggi (skor 10-15). Setelah dirancang tindakan mitigasi teknis berupa pengujian dinamis angkur minimal 15kN sesuai standar BS EN 795:2012, bantalan pelindung kanvas tebal, dan batas aman angin maksimal 20 knot, tingkat risiko berhasil ditekan ke kategori Rendah (residual risk skor 2-3). Penerapan akses tali terbukti menjadi solusi optimal yang menjamin aspek keselamatan sekaligus produktivitas pada konstruksi bangunan cagar budaya bergeometri kompleks.
Kata Kunci: *akses tali, HIRARC, efisiensi biaya, AS/NZS 4360:2004, monumen tugu reog*

1. Introduction

The construction of the 60-meter high Monumen Tugu Reog Ponorogo by CV Gendhis Multi Karya represents a high-complexity structural engineering project with an atypical architectural design. The main concrete core of the monument is clad in dynamic brass and copper ornamental reliefs forming non-linear curves that represent the feathers of a peacock (dadak merak) and a tiger facade (barongan). The realization of cultural heritage buildings with high aesthetic values demands strict spatial accuracy and flexible construction methods due to the asymmetric vertical access profiles of the structure [1][2].

Installing conventional steel scaffolding around the overhang of the monument's crown poses massive technical obstacles. Steel scaffolding pipes are rigid and fail to safely conform to curved geometric surfaces, require long erection and dismantling cycles, and present a high potential risk of scratching or denting the newly installed brass plates [3]. To circumvent these limitations, CV Gendhis Multi Karya selected industrial rope access as the primary vertical access mechanism. This method utilizes a double-rope system consisting of a working line and a safety line, adhering strictly to the safety guidelines of Ministerial Regulation Permenaker No. 9 Year 2016, specifically under Chapter V regarding safe rope access working methods [4]. However, executing construction tasks at extreme elevations exceeding 20 meters using temporary suspension systems still presents inherent safety hazards that can result in fatal falls if left unmanaged [5]. Hence, a scientific study is required to objectively evaluate and compare the operational efficiency of both scaffolding and rope access methods across performance parameters such as mobilization time, manpower configuration, and total financial expenditure. Furthermore, formulating a robust hazard identification, risk assessment, and risk control (HIRARC) framework based on the AS/NZS 4360:2004 standard is essential to guarantee the safety of the vertical technicians without sacrificing the project's physical progress [6], [7].

2. Material and Methods

Geography of Ponorogo Regency

The study was conducted at the construction site of the Monumen Tugu Reog Ponorogo, located in Sampung District, Ponorogo Regency, East Java, Indonesia. The site sits at geographic coordinates 7° 52' 0" S latitude and 111° 24' 0" E longitude, with an elevation of approximately 135 meters above sea level (ASL). Primary field observations and data collection were carried out over a three-month period from January to March 2024.

Operational Efficiency Analysis

Operational efficiency parameters comprising setup time, workforce requirements, and project costs were computed using the following relative efficiency (RE) formula:

$$RE = \frac{Xscaffolding \ \times Xrope\ acces}{Xscaffolfing} \times 100\%$$

Where $Xscaffolding$ represents the measured parameter under the steel scaffolding method and $Xrope\ acces$ represents the same parameter under the suspended double-rope access method.

Occupational Safety Risk Assessment (HIRARC)

Occupational hazards were identified across four key working-at-height phases. Risk scores were calculated semi-quantitatively by multiplying Likelihood (L) and Severity (S) values, using scales of 1 to 5 based on the AS/NZS 4360:2004 standard [8]. Risk evaluations were performed twice: first, prior to introducing safety countermeasures (Initial Risk Assessment) and subsequently, after implementing engineered control mechanisms (Residual Risk Assessment) [9].

3. Results and Discussion

Field Safety Incident Logbook (Near-Miss Data)

During the three-month observational window, the field safety officer logged 14 instances of near-miss incidents and unsafe conditions at the monument's elevated zones, primarily concentrated during ornament cladding work (**Table 1**).

Table 1. Logbook of Safety Incidents and Unsafe Conditions at Heights

No	Structural Location	Elevated Activity	Incident Details	Frequency
1	Peacock Crown (42 m)	Anchor Installation	Rigid concrete anchor slipped under dynamic pre-loading	3 Times
2	Tiger Head (28 m)	Ascent/Descent Maneuver	Work line rubbed against sharp brass ornament edges	4 Times
3	Peacock Crown (45 m)	Ornament Carving	Hand tools dropped from height to the drop-zone below	4 Times
4	Tiger Head (30 m)	Rope Rigging Transition	Unexpected high-velocity wind gusts of up to 25 knots	3 Times

Comparative Analysis of Operational Parameters

The performance metrics of both access methods were compared across parameters of setup duration, active elevated personnel, facade accessibility, and operational expenditures (**Table 2**).

Table 2. Comparative Operational Parameters of Access Methods

Performance Indicators	Steel Scaffolding Method	Suspended Rope Access Method	Percentage Change / Efficiency
Setup and Mobilization Time	12 Days	1.5 Days	87.5% (Faster)
Active Workforce Size	10 Scaffolding Riggers	3 Rope Access Technicians	70.0% (Lighter)
Facade Angular Coverage	60% (Obstructed by pipes)	95% (Unobstructed movement)	35.0% (More Flexible)
Total Operational Cost	IDR 120,000,000	IDR 35,000,000	70.83% (Cost-Saving)

To justify the financial figures in **Table 2** and address academic audit requirements, the cost components of both methods were detailed and compared (**Table 3**).

Table 3. Detailed Operational Cost Breakdown for Both Methods

Access Method	Cost Allocation Components	Technical Cost Calculation Details	Total Component Cost
Scaffolding	Steel Pipe Frame Rental	200 frame sets × IDR 50,000 per set × 3 months	IDR 30,000,000
	Material Transport (Mobilization)	Flat-bed truck logistics to the remote monument site	IDR 10,000,000
	Assembly & Dismantling Wages	10 riggers × IDR 150,000 per day × 18 working days	IDR 27,000,000
	Safety Perimeter Netting	Industrial catch netting, base plates, tieback pipes	IDR 23,000,000
	Disnaker Equipment Certification	Mandatory local government safety testing (Silo)	IDR 30,000,000
	Total Scaffolding Cost	Sum of all scaffolding expenses	IDR 120,000,000
Rope Access	Personal Protective Equipment	3 sets of harnesses, descenders, backups, and ropes	IDR 18,000,000
	Portable Anchors & Padding	Dynamic concrete anchors and heavy-duty canvas pads	IDR 2,000,000
	Certified Technician Wages	3 rope technicians × IDR 400,000 per day × 10 days	IDR 12,000,000
	Administrative Izin Kerja (JSA)	Administrative safety clearances and briefings	IDR 3,000,000
	Total Rope Access Cost	Sum of all rope access expenses	IDR 35,000,000

The breakdown in **Table 3** shows that steel scaffolding is highly capital-intensive due to long-term pipe rental fees, high logistical mobilization costs, and mandatory government safety certification fees (Silo). Conversely, rope access relies on individual personal protective equipment, which represents a reusable capital investment for future projects [10], [11].

Operational Efficiency Calculations

Using the values from **Table 2** and **Table 3**, the relative time efficiency is calculated as follows:

$$RE_{time} = \frac{12 - 1{,}5}{12} \times 100\% = \frac{10}{12} \times 100\% = 87{,}5\%$$

The relative workforce efficiency in terms of personnel reduction is calculated as follows:

$$RE_{personel} = \frac{10 - 3}{10} \times 100\% = \frac{7}{10} \times 100\% = 70\%$$

The project's financial efficiency achieved by selecting the suspended rope access method is calculated as:

$$RE_{cost} = \frac{120{,}000{,}000 - 35{,}000{,}000}{120{,}000{,}000} \times 100\% = \frac{85{,}000{,}000}{120{,}000{,}000} \times 100\% = 70{,}83\%$$

Applying the suspended rope access system saved CV Gendhis Multi Karya a net sum of IDR 85,000,000 on the vertical cladding phase.

Initial Hazard Risk Assessment (HIRARC)

The initial risk level of rope access work on the monument's exterior before implementing custom safety measures was determined using the likelihood and severity parameters of the AS/NZS 4360:2004 standard (**Table 4**) [12].

Table 4. Initial Risk Assessment Matrix for Elevated Rope Access Work

No	Elevated Work Phases	Identified Hazards	Potential Impact	L	S	Score	Risk Class
1	Anchor & Line Rigging	Concrete structural cracks	Anchor pull-out, fatal falls	2	5	10	High Risk
2	Vertical Rope Maneuver	Friction on sharp plate edges	Working line cuts, fatal falls	3	5	15	High Risk
3	Relief Ornament Carving	Unsecured hand-held tools	Tool drops, injuries below	4	3	12	High Risk
4	Emergency Rescue Event	Suspension trauma delay	Severe orthostatic shock	2	5	10	High Risk

Residual Risk Assessment and Controls

To mitigate these hazards and protect technicians, a set of engineering controls and procedural safety protocols were introduced. The residual risk levels were evaluated after incorporating these safety measures (**Table 5**) [13].

Table 5. Residual Risk Assessment and Safety Controls

No	Elevated Work Phases	Recommended Safety Countermeasures	L	S	Score	Risk Class
1	Anchor Installation	Non-destructive dynamic testing of anchor to ≥ 15kN (Class A Type BS EN 795:2012)	1	3	3	Low Risk
2	Rope Maneuvers	Heavy canvas corner padding on all brass plate edges	1	3	3	Low Risk
3	Ornament Carving	Wrist-worn tool lanyards on all hand carving tools	2	1	2	Low Risk
4	Emergency Rescue	Routine mock-rescue drills for emergency response	1	3	3	Low Risk

The required concrete anchor load threshold of 15 kN is based on structural testing of dynamic fall-arrest systems [14]. These tests show that using dynamic safety ropes and knots reduces impact forces below 6 kN during fall occurrences, protecting the integrity of both the anchor and the concrete [15]. To address wind hazards on the open-air monument, a weather-adaptive Job Safety Analysis (JSA) protocol was established [16]. A maximum wind speed limit of 20 knots was set for active rope work. If local anemometer readings at the monument's crown exceed this threshold, work must be suspended immediately, and technicians must be evacuated to ground level.

4. Conclusion

Integrating the suspended rope access method at the Monumen Tugu Reog Ponorogo project achieved significant improvements in both safety and productivity:

1. Primary elevated hazards, including rope failures from sharp edges, anchor slippage, and wind gusts, were identified. Implementing a 15 kN dynamic anchor load test compliant with BS EN 795:2012, canvas corner padding, and wrist-worn tool lanyards successfully reduced the initial high-risk scores (10 to 15) down to low-risk residual scores (2 to 3).
2. The suspended rope access system provided significant operational advantages over scaffolding. It reduced setup times by 87.5% (from 12 days to 1.5 days), lowered elevated workforce requirements by 70.0% (from 10 riggers to 3 technicians), and reduced project costs by 70.83% (saving IDR 85,000,000).

5. Acknowledgment

The authors express their gratitude to Department of Industrial Engineering, Faculty of Information Technology and Industry, Universitas Stikubank (UNISBANK) for providing the technical facilities and field data and to the site management of CV Gendhis Multi Karya for providing administrative support and access required to complete this research.

6. Abbreviations

HIRARC	Hazard Identification, Risk Assessment, and Risk Control
JSA	Job Safety Analysis
K3	Keselamatan dan Kesehatan Kerja (Occupational Health and Safety)
APD	Alat Pelindung Diri (Personal Protective Equipment)
kN	Kilonewton
S	Severity
L	Likelihood

7. References

[1] A. Bramantyo And A. Wibowo, “Analisis Risiko Keselamatan Kerja Pada Pekerjaan Konstruksi Ketinggian Menggunakan Metode Bowtie,” *J. Matriks Tek. Sipil*, Vol. 10, No. 2, Pp. 185–192, 2022.

[2] I. K. Gede, K. Adi, P. I. Wahyuni, And I. W. Runa, “Model Pengelolaan Proyek Bangunan Pura Lempuyang Madya,” *J. Ris. Teknol. dan Manaj.*, Vol. 5, No. 1, Pp. 146–154, 2025.

[3] Aziz, Napoleon Naufal, et al. "Analisa Potensi Bahaya Pada Pekerjaan Pemasangan Scaffolding Overhaul Boiler Pltu Pelabuhanratu." *Jurnal Rekayasa Teknologi Nusa Putra* 8.1 (2022): 16-24.

[4] B. Rachmatulloh, “Pana Rope Access Dalam Optimalisasi Keselamatan dan Kesehatan Kerja (K3),” *J. Pendidik. Dan Teknol. Indones.*, Vol. 12, No. 2, 2023.

[5] E. W. Asih And H. Kurniawan, “Pengukuran Beban Kerja Fisik dan Beban Kerja Mental Berbasis Ergonomi Terhadap Karyawan PT. Woneel Midas Leathers,” *J. Teknol. Ist Akprind*, No. 0274, 2022.

[6] Tjahjono, Budi, Dermawan Zebua, and Vira Mita. "Analisis kajian literatur risiko keselamatan dan kesehatan kerja (K3) dalam pembangunan gedung bertingkat di Indonesia." *Jurnal Penelitian Jalan Dan Jembatan* 3.2 (2023): 11-16.

[7] M. A. Akmal, K. Rusba, I. Siboro, And U. Balikpapan, “Analisis Penilaian Contractor Management System (CSMS) Pada Kontraktor PT . XYZ,” *J. Keselam. Transp. dan Ind.*, Vol. 12, No. 1, Pp. 305–312, 2026.

[8] Ferlania, Dianda Aryntya Firia, Rana Atikah Ardlianti, and Adelina Zian Andriani. "Analisa Penerapan SMK3 (Sistem Manajemen Kesehatan Dan Keselamatan Kerja) Pada Proyek Konstruksi Di Kota Lamongan." *Industri Inovatif: Jurnal Teknik Industri* 14.2 (2024): 244-248.

[9] B. Bramantio, "Analisis Risiko Kecelakaan Kerja Menggunakan Metode Bowtie Pada Proyek The Grandstand Surabaya," *J. Teknik ITS.*, Vol. 10, No. 2, 2021.

[10] M. Ilham And F. Rachmawati, "Analisa Kelayakan Finansial Proyek Apartemen (Studi Kasus : Tower Aubrey Grand Shamaya Surabaya)," *J. Teknik ITS*, Vol. 10, No. 2, 2021.

[11] J. V. Mandagi, S. Nisumanti, And N. Puspita, "Evaluasi Kinerja Biaya Dan Waktu Pada Pelaksanaan Pekerjaan Bracing Perkuatan Tiang Pancang Proyek Tol Kapal Betung Paket I Seksi Ia," *J. Ilmiah Tekno GlobaL*, Vol. 11, No. 02, Pp. 67–71, 2022.

[12] T. Dahniar And F. D. Ibnu, "Penerapan Metode Hirarc Untuk Pengelolaan Risiko Kesehatan Dan Keselamatan Kerja Di Industri Besi," *Industri Inovatif : Jurnal Teknik Industri ITN Malang*, Pp. 34–39, 2025.

[13] M. Riyan, P. Sukapto, And T. Yogasara, "Perbaikan Sistem Kerja Untuk Meningkatkan Keselamatan Dan Kesehatan Kerja (K3) Serta Produktivitas Melalui Pendekatan Ergonomi Partisipatif (Studi Kasus Di PT . Eka Karya Sinergi Bandung)," *Jurnal Rekayasa Sistem Industri*, Vol. 12, No. 2, Pp. 237–250, 2023.

[14] Sáez, Pedro Ignacio, et al. "Determining the Safest Anchoring Knot in a Fall Arrest System by Means of Static Tests." *Symmetry* 16.2 (2024): 167.

[15] Devi, Mauren Helvia. *Sistem Pendukung Keputusan Rekrutmen Pegawai Menggunakan Metode Preference Selection Index (PSI)*. Diss. Universitas Islam Negeri Maulana Malik Ibrahim, 2022.

[16] G. Smarandana, A. Momon, And J. Arifin, "Penilaian Risiko K3 Pada Proses Pabrikasi Menggunakan Metode Hazard Identification , Risk Assessment And Risk Control (Hirarc)," *J. Intech Tek. Ind. Univ. Serang Raya*, Vol. 7, No. 1, Pp. 56–62, 2021.