Welding Quality Control Analysis on Steel Structure of Pedestrian Bridge (JPO) at PMJ Land Tower Building from a Project Management Perspective

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ABSTRACT

Welding of steel structure components in pedestrian bridge (JPO) elements of high-rise buildings is a critical operation that determines structural integrity and user safety. Weld joint failures may reduce load-bearing capacity by 25–40%, making a comprehensive quality control system essential. Empirical studies specifically examining welding quality control for high-rise building JPO structures based on AWS D1.1:2025 and project management perspectives remain scarce in Indonesia; no published study has yet integrated technical, managerial, and human resource factors in a single quantitative model. This study aims to: (1) identify the actual implementation of welding quality control based on AWS D1.1:2025; (2) analyze factors affecting welding output quality; (3) identify dominant variables; and (4) formulate improvement recommendations. A descriptive-associative quantitative method was applied with 35 respondents — welders, Quality Control Inspectors, Welding Inspectors, Site Engineers, Field Supervisors, and Supervision Consultants — at the PMJ Land Tower Building project, East Jakarta (2024–2025). Data were collected via a 5-point Likert scale questionnaire covering 23 independent variables (X1–X23) across four dimensions: technical aspects, human resources, management & supervision, and work environment. Analysis used SPSS 26, including validity testing (Pearson, r-table = 0.334), reliability (Cronbach's $\alpha = 0.892$), normality (Kolmogorov–Smirnov), descriptive statistics, rank score analysis, and Pearson correlation. Variable mean scores ranged from 3.89 to 4.26 (Good to Very Good). The three dominant variables were Technical Training (X12, mean = 4.26), Welder Certification (X3, mean = 4.17), and WPS & PQR (X2, mean = 4.14). Work Environment (X5) and VT Effectiveness (X16) scored lowest (mean = 3.89). Correlation testing yielded $r = 0.086$ ($p = 0.622 > 0.05$), interpreted through a *compliance gap* — a discrepancy between positive respondent perceptions and actual field implementation. The study recommends enhancing RKS specifications, improving NDT consistency through an Inspection and Test Plan (ITP), strengthening welder qualification systems, and implementing digital documentation for improved traceability.

Key words: quality control, steel structure welding, AWS D1.1:2025, pedestrian bridge, project management, NDT.

INTRODUCTION

Pedestrian bridges (JPO-*Jembatan Penyeberangan Orang*) connecting adjacent buildings in high-rise complexes continuously bear dynamic loads from pedestrian traffic. Unlike roadside overpasses, JPO structures within tall buildings operate under restricted conditions — confined access, elevated positions, and building vibrations-making weld joint integrity a non-negotiable safety requirement. Failure at welded connections may reduce structural load-bearing capacity by 25–40% and potentially trigger progressive collapse [1, 2].

The PMJ Land Tower Building project in East Jakarta employs structural steel for inter-building JPO connections, with an estimated 300–450 weld joints. Preliminary assessments during site mobilization identified several risk factors: variability in active welder qualifications, inconsistent Non-Destructive Testing (NDT) execution, and contract documents (RKS) that reference AWS D1.1

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without operationally explicit defect acceptance criteria. Field conditions — overhead welding, confined spaces, and fluctuating ambient temperatures — further complicate consistent weld parameter control.

Welding quality control is not purely technical. From a project management perspective, quality is a function of integrated planning, assurance, and control systems [3, 4]. Previous research has addressed welding quality control on road bridges [5, 6], yet specific studies on JPO elements in high-rise buildings using a project management approach remain limited [2]. No published work has: (a) compared AWS D1.1 requirements against project RKS specifications operationally; (b) integrated technical, managerial, and HR factors in a single quantitative model; or (c) identified dominant variables influencing welding quality in Indonesian high-rise construction.

Based on these research gaps, this study pursues three objectives: (1) to identify actual welding quality control conditions at the PMJ Land Tower JPO based on AWS D1.1:2025; (2) to analyze factors affecting welding quality and identify dominant variables; and (3) to formulate quality system recommendations from a project management perspective. The *novelty* of this research is threefold: (i) the first study to evaluate welding quality control for high-rise building JPO elements based on AWS D1.1:2025 in Indonesia; (ii) integration of 23 quality variables from four dimensions in a single multi-stakeholder quantitative model; and (iii) examination of the gap between RKS specifications and AWS D1.1 as the basis for management-oriented recommendations.

Quality Management in Construction Projects

Quality management in construction encompasses three pillars: quality planning, quality assurance, and quality control, ensuring project outputs conform to pre-established standards [3]. ISO 9001:2015 defines seven fundamental principles: customer focus, leadership, people engagement, process approach, continuous improvement, evidence-based decision-making, and relationship management [7].

Total Quality Management (TQM) emphasises participation of all organizational elements in achieving quality excellence [8]. Applied to steel welding projects, TQM operates through: (1) top-management commitment to quality procedures; (2) continuous training for welders and inspectors; (3) real-time process parameter monitoring; and (4) Non-Conformance Report (NCR) feedback mechanisms. Stenberg et al. [2] showed consistent TQM implementation can reduce defect rates in fatigue-loaded connections by up to 35%.

In the welding cycle, quality management covers three phases: pre-welding (WPS verification, equipment calibration, joint preparation), in-process (current, voltage, travel speed, preheat/interpass temperature control), and post-welding (visual inspection, NDT, traceability documentation). Kerzner [4] emphasises that quality control effectiveness depends on a clear Work Breakdown Structure (WBS) and a fully traceable documentation system.

AWS D1.1:2025 and SNI 1729:2020 Standards

AWS D1.1:2025 Structural Welding Code – Steel is the comprehensive standard governing all aspects of structural steel welding: WPS/PQR qualification, welder qualification, material requirements, inspection procedures, and defect acceptance criteria [1]. The 2025 edition introduces updated NDT requirements, criticality-based joint classification, and digital documentation integration [9].

Nationally, SNI 1729:2020 on Specifications for Structural Steel Buildings adopts ANSI/AISC 360-16 and requires all structural welding to comply with AWS D1.1 or an equivalent standard [10]. When RKS documents merely cite these standards without operationally defining acceptance criteria, interpretive conflicts between contractors and supervisors become inevitable — as confirmed by Wardani and Priyanto [5] in the Progo Bridge replacement project.

Technical and Managerial Dimensions of Welding Quality Control

The technical dimension covers process parameter verification (current, voltage, travel speed, heat input), material selection (electrodes, filler metals, shielding gases), preheat/interpass temperature control, and visual/NDT inspection [2, 11]. Hamzah and Donoriyanto [6] demonstrated that applying

Statistical Quality Control (SQC) using seven tools reduced weld defect rates by 30% through systematic process monitoring.

The managerial dimension encompasses structured documentation, effective cross-functional communication, NCR mechanisms, and leadership that cultivates a quality culture [12]. Human resource factors — welder certification, Welding Inspector competence, and personnel motivation — are critical for output consistency [13]. Singh [14] identified that 67% of defect rate variation in structural steel welding projects stems from managerial and human resource factors rather than technical parameters alone.

Non-Destructive Testing (NDT) in Weld Inspection

NDT enables defect detection without compromising material integrity [15]. Standard methods for structural steel weld inspection include Visual Testing (VT), Liquid Penetrant Testing (PT), Magnetic Particle Testing (MT), Ultrasonic Testing (UT), and Radiographic Testing (RT) [16, 17]. Method selection follows joint type, geometric access, and criticality category per AWS D1.1:2025 Table 6.1.

RESEARCH METHODS

Research Design and Location

A descriptive-associative quantitative approach was used: descriptive to characterize actual quality control conditions, and associative to analyze the relationship between quality control variables and welding output quality [18, 19]. Research was conducted at the PMJ Land Tower Building project, East Jakarta, on the JPO steel structure works, from August 2024 to January 2025.

Population and Sample

The population comprised 42 personnel directly involved in welding and quality control activities. Applying the Slovin formula at a 5% margin of error yielded a minimum sample of 38; 35 respondents participated, which is acceptable for exploratory research with a limited population. Purposive sampling criteria were: (a) minimum 3 years of steel construction experience; and (b) direct involvement in the PMJ Land Tower project. Sample composition: welders (15), QC Inspectors (8), Welding Inspectors (6), Site Engineers (3), Field Supervisors (2), and Supervision Consultants (1).

Research Variables

Twenty-three independent variables (X1–X23) were grouped into four categories: (1) *Technical Aspects* — AWS D1.1 compliance (X1), WPS & PQR (X2), welder certification (X3), welding equipment (X4), NDT execution (X7), weld parameter control (X17), and related technical variables; (2) *Human Resources* — technical training (X12) and HR motivation (X19); (3) *Management & Supervision* — QC supervision (X6), QC documentation (X8), RKS clarity (X9), project management (X10), team communication (X11), quality leadership (X13), NCR & corrective action (X14), and RKS compliance (X15); and (4) *Work Environment* — work environment conditions (X5), VT effectiveness (X16), and field documentation (X18). The dependent variable (Y) is welding output quality measured by conformance with AWS D1.1:2025 acceptance criteria.

Data Collection

A 5-point Likert scale questionnaire (1 = Strongly Disagree to 5 = Strongly Agree) comprising 30 items covering all research variables was used. Additionally, field observations and semi-structured interviews with 8 key project personnel were conducted to enrich the qualitative analysis.

Data Analysis

Analysis stages: (1) editing, coding, and tabulation; (2) validity testing — Pearson Product Moment correlation (r-calculated > r-table = 0.334, n = 35, $\alpha = 0.05$); (3) reliability testing — Cronbach's Alpha (threshold $\alpha > 0.70$); (4) normality testing — Kolmogorov–Smirnov; (5) descriptive statistics — mean, standard deviation, and score categorization (1.00–1.79 = Very Poor; 1.80–2.59 = Poor;

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2.60–3.39 = Fair; 3.40–4.19 = Good; 4.20–5.00 = Very Good); (6) rank score analysis to identify dominant variables; and (7) Pearson correlation to analyze the X–Y relationship.

RESULT AND DISCUSSION

Respondent Characteristics

The diverse respondent composition — field executors (welders, 43%), quality inspectors (QC Inspector & Welding Inspector, 40%), and project managers (Site Engineer, Supervisor, Consultant, 17%) — provided a comprehensive multi-perspective view of quality control conditions on the project. The majority (71%) had over 5 years of experience in steel construction, confirming the reliability of their field perceptions. However, interviews revealed that only 58% of active welders held valid qualification certificates compliant with AWS D1.1:2025 requirements; the remaining 42% operated on experience without formally renewed certification.

Validity and Reliability

Pearson Product Moment validity testing showed all 30 questionnaire items had r-calculated values of 0.645–0.756, all exceeding r-table = 0.334 ($n = 35$, $\alpha = 0.05$), confirming all items are valid. Reliability testing yielded Cronbach's $\alpha = 0.892$ (Very Good category, $0.80 \leq \alpha < 0.90$), indicating high internal consistency and instrument dependability.

The Kolmogorov–Smirnov normality test yielded Asymp. Sig. values of 0.200 (Quality Control, X) and 0.195 (Welding Output Quality, Y), both exceeding 0.05. H_0 is accepted: data are normally distributed, satisfying parametric statistical assumptions.

Descriptive Statistics and Dominant Variables

Table 1 presents the complete descriptive statistics. Overall, mean scores of independent variables ranged from 3.89 to 4.26, indicating respondents perceived quality control implementation as Good to Very Good.

Table 1. Descriptive Statistics of Research Variables

Code	Variable	Mean	Std Dev	Min	Max	Category
X1	AWS D1.1 Compliance	4.03	0.71	3	5	Good
X2	WPS & PQR	4.14	0.65	3	5	Good
X3	Welder Certification	4.17	0.71	3	5	Good
X4	Welding Equipment	4.09	0.85	2	5	Good
X5	Work Environment	3.89	0.80	2	5	Good
X6	QC Supervision	3.97	0.71	3	5	Good
X7	NDT Execution	4.11	0.76	3	5	Good
X8	QC Documentation	4.09	0.74	3	5	Good
X9	RKS Clarity	4.00	0.87	3	5	Good
X10	Project Management	3.97	0.79	3	5	Good
X11	Team Communication	4.06	0.71	3	5	Good
X12	Technical Training	4.26	0.70	3	5	Very Good
X13	Quality Leadership	4.11	0.74	3	5	Good
X14	NCR & Corrective Action	3.94	0.78	3	5	Good
X15	RKS Compliance	4.14	0.65	3	5	Good
X16	VT Effectiveness	3.89	0.82	3	5	Good
X17	Weld Parameter Control	4.03	0.79	3	5	Good
X18	Field Documentation	3.94	0.81	3	5	Good

Code	Variable	Mean	Std Dev	Min	Max	Category
X19	HR Motivation	3.97	0.76	3	5	Good
Y	Welding Output Quality	4.14	0.67	3	5	Good

Rank score analysis identified the three highest-scoring variables as X12 (Technical Training, mean = 4.26), X3 (Welder Certification, mean = 4.17), and X2 (WPS & PQR, mean = 4.14) — all reflecting aspects that received strong project attention. Conversely, X5 (Work Environment, mean = 3.89) and X16 (VT Effectiveness, mean = 3.89) scored lowest, marking the areas most requiring improvement. Dependent variable Y (Welding Output Quality, mean = 4.14) indicates respondents generally perceived welding results as meeting established standards.

Pearson Correlation Test

Table 2. Pearson Correlation Test Results

Variable	r	p-value
Quality Control (X) vs Welding Output Quality (Y)	0.086	0.622

Pearson correlation yielded r = 0.086 with p-value = 0.622 ($p > 0.05$). Based on Sugiyono [18] criteria, r = 0.086 falls in the Very Weak category (0.00–0.199). Since p-value > 0.05, H_0 is accepted: no statistically significant relationship exists between quality control variables and welding output quality.

This does not imply quality control has no influence on welding quality. Four complementary explanations apply. First, *low variability effect*: uniformly high mean scores (3.89–4.26) compress data dispersion, making linear correlation statistically difficult to detect. Second, *threshold effect*: once a quality control system reaches the "Good" level, incremental perceptual improvements may not produce proportional output gains. Third, *compliance gap*: positive respondent perceptions do not fully reflect consistent field implementation [2]. Fourth, *unmeasured external factors* — extreme weather, schedule pressure, and subcontractor coordination — also affect welding outcomes.

Qualitative Findings and Compliance Gap Analysis

Although quantitative analysis did not reveal a significant statistical relationship, field observations and interviews identified four critical findings explaining the compliance gap.

RKS Specification Clarity. Contract documents cited AWS D1.1 as a reference without specifying quantitative defect acceptance criteria, required NDT methods per joint type, or rejection/rework mechanisms. This caused interpretive conflicts between contractor and supervisory parties — consistent with Wardani and Priyanto [5].

NDT Execution Inconsistency. Penetrant Testing (PT) was performed selectively based on schedule availability and certified personnel availability rather than joint criticality per AWS D1.1 Table 6.1. Among respondents, 68% stated NDT decisions were more influenced by project schedule than technical protocols.

Welding Inspector Qualifications. Not all inspection personnel held valid AWS QC1 certification. In several cases, inspections were conducted by QC Engineers with general welding knowledge but without formal Welding Inspector qualifications, potentially reducing supervision consistency and objectivity.

Documentation Traceability. The QC documentation system — inspection forms, NDT reports, and Material Test Reports (MTR) — functioned adequately. However, the ability to rapidly retrieve the complete history of a specific weld joint (WPS, PQR, welder qualification record, inspection results) remained limited, indicating a sub-optimal archiving system.

The integration of quantitative and qualitative findings confirms the compliance gap: despite positive quality system perceptions (mean 3.89–4.26), consistent implementation at every weld joint still faces practical constraints of time, resources, and inter-party coordination. Ramadayanti and

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Suryadi [20] affirm that welding quality control effectiveness strongly depends on management commitment and execution consistency, not merely procedure availability.

CONCLUSION

Four principal conclusions are drawn. (1) Welding quality control implementation at the PMJ Land Tower Building project is generally in the Good category (mean 3.89–4.26), with Technical Training (mean = 4.26) as the highest-performing variable and Work Environment (mean = 3.89) as the most critical area for improvement. (2) Pearson correlation revealed no statistically significant relationship between quality control variables and welding output quality ($r = 0.086$; $p = 0.622 > 0.05$), explained by low variability effect, threshold effect, compliance gap, and unmeasured external factors. (3) Rank score analysis identified Technical Training (X12), Welder Certification (X3), and WPS & PQR (X2) as the three dominant positive contributors to welding quality. (4) Qualitative analysis revealed four critical implementation gaps: insufficient RKS specification detail, inconsistent NDT execution, heterogeneous Welding Inspector qualifications, and sub-optimal documentation traceability. Four recommendations are proposed: (1) Enhance RKS documents with quantitative defect acceptance criteria per AWS D1.1:2025 Table 6.1, required NDT methods by joint type and criticality, and standardized rework procedures; (2) Establish an Inspection and Test Plan (ITP) identifying all critical joints, NDT methods, testing frequency, and hold/witness points, integrated with the project schedule; (3) Strengthen personnel qualification systems by requiring valid AWS QC1 certification for all Welding Inspectors prior to mobilization and implementing structured training programs for welders; (4) Implement cloud-based digital documentation with unique identification numbers per weld joint linking all related records (WPS, PQR, qualification, inspection reports, NCR) for rapid, systematic traceability. Future research should: (a) conduct multi-project comparative studies to identify best practices; (b) apply multiple linear regression ($Y = \beta_0 + \beta_1 X_1 + \cdots + \beta n Xn$) for precise variable contribution modelling; and (c) integrate Industry 4.0 technologies — IoT sensors and machine learning — in real-time welding quality monitoring.

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