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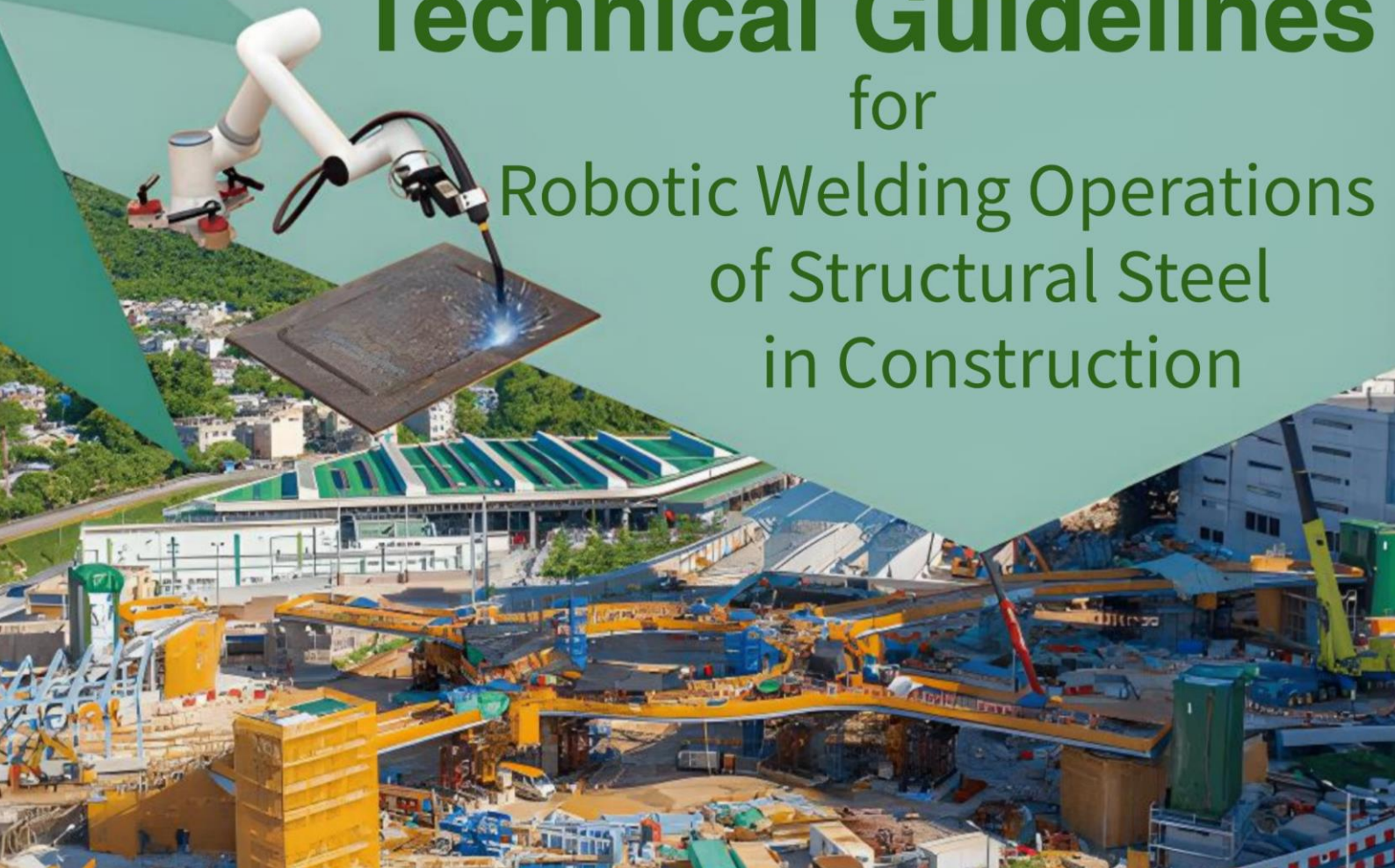
Chinese National Engineering Research Centre For Steel Construction (Hong Kong Branch)

Technical Guidelines

for Robotic Welding Operations of Structural Steel in Construction



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FOREWORD

This “Technical Guidelines for Robotic Welding Operations of Structural Steel in Construction”(TG), commissioned by the Civil Engineering and Development Department (CEDD), marks a major step toward standardising robotic welding of structural steel in Hong Kong and demonstrates CEDD’s determination to realise our mission of pursuing innovation and technology to enhance the efficiency, productivity, quality and safety of our works. Developed through a collaborative effort among the Building Technology Research Institute (BTRi), the Chinese National Engineering Research Centre for Steel Construction (Hong Kong Branch) at the Hong Kong Polytechnic University, and key industry stakeholders, the TG addresses the need for high-quality welding across a range of materials, from conventional to ultra-high-strength steels (Grade S275 to S960). It sets out strict requirements to ensure safety, reliability, and structural performance in both workshops and on-site environments.

Leveraging the Chinese Mainland’s leading edge in the fabrication of high-quality steel, the TG provides a robust framework for the local industry to adopt these high-quality materials with confidence. The TG also strengthens the industry's technical capacity. Robotic welding complements manual processes by handling repetitive tasks with high precision and consistency. Integrating automation with traditional skills improves productivity and safety, particularly for high-strength steel, where precise heat-input control is essential to maintain weld quality. These advantages enable broader use of high-strength steel, supporting more efficient and sustainable project delivery.

The TG promotes a continuous assurance system to address rapid technological change. As Hong Kong adopts modern construction methods and broadens the use of high-strength steel, this document provides a rigorous, practical, and adaptable baseline to support future innovation.

Ir FONG Hok-shing, Michael, JP

Director of Civil Engineering and Development

PREFACE

We are pleased to present this TG for Robotic Welding Processes and Personnel. It provides a comprehensive framework for robotic welding operations under diverse environmental and on-site conditions. It addresses a growing demand for standardized, high-quality welding operations in steel construction using S275 to S960 steel. Its primary purpose is to ensure that robotic welding operations, whether conducted in controlled shop environments or challenging site conditions, consistently meet rigorous technical standards, thereby enhancing safety, reliability, and performance in modern construction projects.

This TG is written in accordance with the current welding qualification practice originally developed for manual and automatic welding. In many ways, robotic welding may be considered as a specialized operation of automatic welding, and a robotic arm is employed to hold a welding torch to perform single as well as multi-pass welding. Depending on the levels of automation and control of the robotic arm, the welding torch is then able to perform welding according to various geometric parameters through *mechanical systems*, such as positions, orientations, and travel speed (i.e. welding speeds), and also welding parameters through *electrical systems*, such as voltages, currents, welding speeds, and wire feeding speeds. It should be noted that while geometric parameters are dependent on both hardware and software of the robotic arms, the welding parameters are primarily defined as in conventional welding procedure specifications.

In order to facilitate an industrial-wide adoption of this TG, its main context follows closely to the principles of BS EN ISO 14732:2025, which is directly relevant to mechanized and automatic welding personnel. Moreover, various sets of knowledge requirements for effective robotic welding are presented in Annexes A to C of this TG, including those on welding units, welding technology, and robotic welding operators. These sets of knowledge requirements provide key references to facilitate practitioners in performing robotic welding according to their welding experiences and equipment, and while fully complying with prevailing international regulations and practice. In addition, essential requirements of robotic systems for structural welding are listed in Annex D.

The drafting of this TG is the outcome of a collaborative effort. Contributions from the following organizations and representatives are gratefully acknowledged.

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Their valuable feedbacks have been instrumental in shaping both the standards and the procedures outlined in this TG.

K.F. Chung & H.C. Ho

CONTENTS

ANNEX

ABBREVIATIONS

BTRi	Building Technology Research Institute
CEDD	Civil Engineering and Development Department
EMC	Electromagnetic Compatibility
FCAW	Flux Cored Arc Welding
GMAW	Gas Metal Arc Welding
HAZ	heat-affected zone
HOKLAS	Hong Kong Laboratory Accreditation Scheme
MIG	Metal Inert Gas Welding
MMAW	Manual Metal Arc Welding
NDT	non-destructive testing
PPE	Personal Protective Equipment
pWPS	Preliminary Welding Procedure Specification
R-GMAW	Robotic Gas Metal Arc Welding
R-LBW	Robotic Laser Beam Welding
R-PAW	Robotic Plasma Arc Welding
SAW	Submerged Arc Welding
TIG	Tungsten Inert Gas Welding
TG	Technical Guidelines for Robotic Welding Operations of Structural Steel in Construction
WPS	Welding Procedure Specification

1 INTRODUCTION

(1) Grades S275 to S960 structural steel are widely used in modern construction due to their superior strength-to-weight ratios, enabling efficient structural design. However, welding such materials, particularly S690 to S960 steel, demands good control and precision as well as skilled welders to ensure welding quality and efficiency. Robotic welding, encompassing automated and mechanized processes, offers consistency and productivity, and requires full compliance with stringent requirements in order to maintain high levels of quality under varying site conditions.

(2) **Scope:** This "Technical Guidelines for Robotic Welding Operations of Structural Steel in Construction"(TG) outlines various qualification tests for robotic welding operators and welding setters performing fusion welding on all steels up to S960 grade. It specifies technical standards for systematically assessing operators and setters, ensuring that qualifications are uniformly recognised regardless of product type, location, or examining body. It prescribes the abilities of operators and setters to control the robotic system, select appropriate welding parameters, and produce high-quality structural welds. It covers fusion welding processes classified as robotic, automated, or mechanized welding.

(3) By adhering to these standards, this TG promotes consistent and reliable welding practice across the industry, ensuring competence and enhancing quality of welded products in diverse environments.

(4) **Differences from ISO 9606-1:** While ISO 9606-1 focuses on qualification testing for manual welders performing fusion welding on steel, emphasizing individual skill assessment through standardized test pieces and acceptance criteria for imperfections, this TG adapts and extends these principles specifically for robotic welding operators and welding setters. It incorporates automation-specific elements, such as essential variables for sensor configurations, robotic control systems, and programming, which are not addressed in ISO 9606-1. Additionally, this TG aligns with BS EN ISO 14732: 2025 for mechanized and automatic welding personnel, providing a more tailored framework for robotic welding in structural steel, including essential knowledge tests and revalidation mechanisms beyond the focus of manual welding in ISO 9606-1.

(5) **Mechanism for Ensuring Qualification:** The qualification of robotic welding operators or welding setters is ensured through a multi-tiered mechanism, including initial testing methods like welding procedure tests (EN ISO 15614), pre-production tests (EN ISO 15613), test pieces (EN ISO 9606), or production samples, combined with essential knowledge assessments (Annex A) and periodic validity confirmations every six months by supervisors. Revalidation occurs every three to six years through retesting, weld testing, or continuous qualification under employer oversight, with revocation for non-compliance. This rationale promotes sustained competence, adaptability to technological changes, and consistent weld quality, reducing risks of defects in high-strength steel structures by verifying both procedural adherence and practical skills.

(6) In general, qualification tests should be applied to both welding procedures and welders, provided that all pertinent requirements, such as test piece dimensions and testing standards, are met (refer to EN ISO 15614-1). This dual applicability ensures that both the methods and the operators maintain high standards of quality and consistency.

(7) Upon expiration of the qualification's validity period, existing qualifications may be revalidated. Alternatively, the qualification scope may be updated to comply with the latest edition. It is mandatory that all new qualifications and re-qualifications adhere strictly to the provisions of the latest edition of this TG. This approach ensures ongoing compliance and fosters continuous improvement in robotic welding within the construction sector.

2 NORMATIVE REFERENCES

(1) The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited shall apply. For undated references, the latest edition of the referenced document, including any amendments, shall apply.

(2) ISO 3834-2, *Quality requirements for fusion welding of metallic materials – Part 2: Comprehensive quality requirements.*

(3) ISO 3834-3, *Quality requirements for fusion welding of metallic materials – Part 3: Standard quality requirements.*

(4) ISO 4063, *Welding and allied processes – Nomenclature of processes and reference numbers*

(5) ISO 9606-1, *Qualification testing of welders – Fusion welding – Part 1: Steels*

(6) ISO 9606-2, *Qualification testing of welders – Fusion welding – Part 2: Aluminium and Aluminium alloys*

(7) ISO 14555, *Welding – Arc stud welding of metallic materials*

(8) ISO 15609-1, *Specification and qualification of welding procedures for metallic materials – Welding procedure specification – Part 1: Arc welding*

(9) ISO 15609-3, *Specification and qualification of welding procedures for metallic materials – Welding procedure specification – Part 3: Electron beam welding*

(10) ISO 15609-4, *Specification and qualification of welding procedures for metallic materials – Welding procedure specification – Part 4: Laser beam welding*

(11) ISO 15613, *Specification and qualification of welding procedures for metallic materials – Qualification based on pre-production welding test*

(12) ISO 15614-1, *Specification and qualification of welding procedures for metallic materials – Welding procedure test – Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys*

(13) ISO 15614-2, *Specification and qualification of welding procedures for metallic materials – Welding procedure test – Part 2: Arc and gas welding of aluminium and its alloys*

(14) ISO 15614-7, *Specification and qualification of welding procedures for metallic materials – Welding procedure test – Part 7: Overlay welding*

(15) ISO 15614-8, *Specification and qualification of welding procedures for metallic materials – Welding procedure test – Part 8: Welding of tubes to tube-plate joints*

(16) ISO 15614-11, *Specification and qualification of welding procedures for metallic materials – Welding procedure test – Part 11: Electron and laser beam welding*

(17) BS EN ISO 14732: 2025, *Welding personnel – Qualification testing of welding operators and welding setters for mechanized and automatic welding of metallic materials*

3 TERMS AND DEFINITIONS

For the purposes of this document, the following terms and definitions apply.

3.1 Automatic welding

Automatic welding is a fusion welding process in which all operations are performed by equipment without operator intervention. It utilizes programmed procedures and robotic systems to ensure consistent, high-quality structural welds.

3.2 Pre-production welding test

A pre-production welding test is a welding examination similar to procedure tests but uses non-standard test pieces that simulate production conditions, ensuring welding methods are effective before full-scale manufacturing begins.

3.3 Production test

A production test is a welding examination conducted in the production environment on real or simplified joints with welding units, carried out before or during production interruptions to ensure quality.

3.4 Programming

Programming involves incorporating approved welding procedure specifications and specified welding unit movements into a program to automate the welding process.

3.5 Robotic welding

(1) Robotic welding is defined as the use of mechanized programmable tools (robotic arms) that automate welding by executing welds and handling parts along pre-defined paths with preset parameters, requiring minimal or no operator intervention. Equipped with torches, sensors, and control systems, these industrial robots ensure precision, repeatability, and high-quality fusion welds for structural applications using structural steel from S275 to S960. It is classified into fully automated systems (independent operation) or semi-automated systems (with operator oversight for loading/unloading).

(2) Key Differences Between Robotic Welding and Automatic welding

(a) Scope and Flexibility: Robotic welding is a specific subset of automatic welding that relies on programmable industrial robots (e.g., multi-axis arms) for versatile, adaptable operations across various joint types and environments. In contrast, automatic welding is a more general term encompassing any mechanized or programmed system, including non-robotic fixed automation (e.g., dedicated welding machines for repetitive tasks without the programmability of robots). For the technical requirements of robotic systems for structural welding, please refer to Annex D.

(b) Operator Involvement: Both minimize operator intervention, but robotic welding often allows for semi-automated modes where operators program or monitor the robot, while fully automatic welding (broadly) may involve no human input at all

post setup.

(c) Applications: Robotic welding excels in high-precision, variable production settings (e.g., structural steel erection), offering greater efficiency in complex scenarios, whereas automatic welding includes simpler, high-volume fixed processes.

3.6 Setting up

Setting up involves the correct adjustment of the welding unit before welding, which may require adjustments to the robot program to ensure proper configuration and operation.

3.7 Welding operator

A technical person who operates welding equipment, adjusts settings, monitors processes, and ensures weld quality to meet specified standards.

3.8 Welding setter

A person who arranges materials, positions components, and prepares welding setups to ensure accurate and efficient operations.

3.9 Welding unit

Devices that supply and control energy for welding processes and enable movement of the welding torch or workpiece, including jigs and fixtures, robot manipulators, rotating devices, and welding machines.

3.10 Welding unit operation

Managing and controlling welding equipment, adjusting settings, and executing welding tasks to ensure consistent processes and high-quality welds in production environments.

3.11 Examining body

An authorized organization under Hong Kong Laboratory Accreditation Scheme (HOKLAS) that has been appointed to verify compliance with relevant industry standards.

3.12 Welding equipment

Individual apparatus used for structural welding, such as a power source or a wire feeder.

3.13 Revalidation

The formal renewal of an operator's or setter's qualification for a longer period when it expires or is about to expire. It is done using one of the methods in Clause 5.3 and proves the person is still competent.

4 QUALIFICATION

4.1 Methods of qualification

(1) **Objective:** Section 4.1 is intended to define standardized methods for qualifying robotic welding operators and setters, ensuring competence in producing high-quality welds for structural steel.

(2) **Methods:** The qualification process shall be based on either a Preliminary Welding Procedure Specification (pWPS) or a Welding Procedure Specification (WPS), both developed in accordance with EN ISO 15609. There are four primary methods for qualifying welding operators or welding setters:

(a) **Welding Procedure Test (EN ISO 15614):** This method involves performing a welding procedure test that complies with EN ISO 15614. It assesses the welder's ability to follow the specified welding procedures accurately.

(b) **Pre-Production Welding Test (EN ISO 15609 or EN ISO 15613):** This approach is based on pre-production welding test as detailed in EN ISO 15609 or EN ISO 15613, ensuring that welding operators or welding setters can prepare and execute welding according to pre-defined procedures before actual welding.

(c) **Test Piece Method (EN ISO 9606):** Qualification through test pieces involves welding specific samples as per EN ISO 9606. This method evaluates the welding operator or welding setter's practical skills, and the quality of the welds produced.

(d) **Production Test or Production Sample Test:** This method relies on tests conducted during actual production or using production samples to assess the welding operator or the welding setter's performance.

(3) For arc welding processes using method c) and method d), both the testing methods and the acceptance criteria shall comply with EN ISO 9606 for butt or fillet welds or EN ISO 15614-8 unless an application standard specifies otherwise. Additionally, for overlay welding under methods a), c), and d), and for method b) when referencing EN ISO 15614, qualification tests require visual inspection, surface testing (magnetic particle or liquid penetrant), and bend testing, provided a qualified WPS is utilized.

(4) For other welding processes using methods c) and d), qualifications shall adhere to the relevant standards. If these standards do not specify testing and acceptance criteria, the minimum requirements include visual inspections and either macro-section analysis or volumetric testing for butt welds. The acceptance criteria should align with the relevant international Welding Procedure Specification (WPS).

4.2 Requirements for welding operators and setters

(1) All qualification methods shall include an essential knowledge test tailored to the specific welding unit, as detailed in Annex A. Supplementary to these qualification methods, welding operators or setters are strongly recommended to possess essential knowledge related to welding technology, as recommended in Annex B. In addition, every welding operator shall hold a valid Certificate for Gas Welding Safety Training Course issued by an authorized organization in Hong Kong, or an equivalent qualification recognized by

the relevant authority.

4.3 Changes requiring re-qualification

(1) Welding operators and setters shall follow a qualified Welding Procedure Specification (WPS) and shall be re-qualified if any of the following essential changes occur:

(a) Welding Process Changes: Any alteration in the welding process, except for variants within welding process 13 as defined in ISO 4063.

(b) Sensor Configuration: Transitioning between welding with and without an arc sensor and/or a joint sensor.

(c) Technique Modification: Shifting from a single-run-per-side technique to a multi-run-per-side technique.

(d) Welding Unit Changes: Changing the type of welding unit, including modifications to the robotic control system.

(e) Sensor Removal: Moving from welding with sensors to welding without sensors.

(2) Adhering to these criteria ensures the continued competence and quality of automatic welding operations.

5 PERIOD OF VALIDITY

5.1 Initial qualification

(1) The qualification of a welding operator or setter commences on the date the test piece(s) are welded, provided that all required tests have been completed and the results are acceptable. Each qualification shall be re-affirmed every six months to maintain its validity.

(2) This sub-clause applies to all Revalidation options specified in Section 5.3.

5.2 Confirmation of validity

The qualification of a welding operator or a welding setter for a specific process shall be confirmed every six months by a responsible welding supervisor or an authorized examining body. This confirmation verifies that the individual has operated within their qualified range, thereby extending the qualification's validity for an additional six-month period. This sub-clause applies to all Revalidation methods detailed in Section 5.3.

5.3 Revalidation of qualification

(1) Revalidation of a welding operator's or a welding setter's qualification shall be conducted by an authorized examining body. The competence of the welding operator or the welding setter shall be periodically verified using one of the following methods:

(a) **Re-testing:** The welding operator or the welding setter shall undergo re-testing every six years to confirm their qualification.

(b) **Periodic Weld Testing:** Every three years, two welded specimens produced within the last six months of the qualification's validity period shall be subjected to radiographic, ultrasonic, or destructive testing. The results shall be recorded, and the acceptance criteria for imperfections shall adhere to the applicable standards. These tests shall replicate the original test conditions. Successful testing re-validates the qualification for an additional three-year period.

(c) **Continuous Qualification:** A qualification shall remain valid provided that it is confirmed in accordance with Section 5.2 and all of the following conditions are met:

i. The welding operator or the welding setter is employed by the same manufacturer or steel erector for whom they were originally qualified and who is responsible for the manufacture of the product;

ii. The manufacturer or the steel erector has been registered on the list of approved Specialist Contractors for Public Works under the category of structural steelwork under the Development Bureau of the Government of Hong Kong SAR;

iii. The manufacturer or the steel erector has documented that the welding operator or the welding setter has consistently produced welds of acceptable quality in accordance with application standards.

(2) These Revalidation methods ensure that welding personnel maintain their competence and continue to meet the quality standards required for their roles.

5.4 Revocation of qualification

(1) A welding operator's or a welding setter's qualification shall be revoked if there is specific evidence questioning their ability to produce welds that meet the product standard quality requirements (e.g., ISO 5817 for imperfection levels). Examples of such evidence include:

(a) Repeated weld defects identified through inspection or non-destructive testing (NDT), such as excessive porosity, cracks, or undercuts exceeding acceptance criteria.

(b) Failure in periodic weld testing, Revalidation assessments, or production sample tests, where the mechanical properties of welds (e.g., tensile strength or toughness) do not meet requirements as per EN ISO 15614.

(c) Documented non-compliance with Welding Procedure Specifications (WPS) during audits, such as improper parameter adjustments or sensor configurations leading to inconsistent weld quality.

(d) Incidents of safety violations related to welding operations, including failure to adhere to robotic system maintenance protocols resulting in equipment malfunctions and substandard welds.

(e) Evidence from project rework or structural failure attributable to the operator's or the setter's welds, confirmed by a root cause analysis.

(2) Upon revocation, only the qualifications directly related to the questioned welding activities are affected. All other qualifications that remain unchallenged shall continue to be valid.

6 CERTIFICATES AND DOCUMENTATION

(1) Upon satisfactory test results, the examining body shall issue a certificate confirming that the welding operator or the welding setter has successfully passed the qualification test. All pertinent test conditions shall be documented on the certificate. If the welding operator or the welding setter does not meet any of the prescribed test criteria, no certificate shall be issued.

(2) The issuance of the certificate is the sole responsibility of the examining body. A suggested certificate format is provided in Annex E.

(3) The manufacturer's preliminary Welding Procedure Specification (pWPS) or Welding Procedure Specification (WPS) shall comply with the relevant sections of EN ISO 15609, as well as EN ISO 15614-11 or EN ISO 14555.

(4) Any change to the essential variables for qualification testing that exceeds the permitted range requires a new qualification test and the issuance of a new certificate.

(5) It should be noted that all certificates and test reports/records of welding tests and revalidation shall be kept on file.

ANNEX A:

ESSENTIAL KNOWLEDGE ON WELDING UNITS

A.1 General

This annex outlines essential knowledge on welding units that a welding operator or welding setter shall have in order to ensure that procedures are followed, and common practices are complied with.

A.2 Welding sequences/procedures in the relevant process

(1) **Understanding Welding Procedure Requirements:**
Comprehensive knowledge of the specific welding procedures applicable to the relevant process, including sequence steps and operational guidelines.

(2) **Influence of Welding Parameters:**
Insight into how various welding parameters, such as voltage, current, and speed, affect the quality and integrity of the weld.

A.3 Joint preparation and weld representation in the relevant process

(1) **Conformance to Welding Procedure Specification (WPS):**
Ensuring that joint preparation strictly adheres to the guidelines and requirements outlined in the WPS.

(2) **Cleanliness of Fusion Faces:**
Maintaining the cleanliness of fusion faces to prevent contamination and thereby ensure optimal weld quality.

A.4 Weld imperfections in the relevant process

(1) **Identification of Weld Imperfections:**
Ability to recognize and categorize common weld defects, such as porosity, cracks, and undercuts.

(2) **Understanding Causes of Imperfections:**
Knowledge of the factors that contribute to weld imperfections, including improper technique, unsuitable materials, and environmental conditions.

(3) **Prevention and Remedial Actions:**
Implementing strategies to prevent weld imperfections and executing corrective measures when defects are identified.

A.5 Welding operator’s or welding setter’s qualification range

Awareness of Qualification Range:
Understanding the specific range and limitations of their qualifications to ensure they operate within their certified abilities.

A.6 Process operation

(1) **Programming Knowledge (if Applicable):**
Proficiency in programming welding equipment, where relevant, to automate and control welding processes.

(2) **Control System Comprehension:**
Familiarity with the welding unit's control systems and the ability to interpret and respond to system signals effectively.

(3) **Operation of Moving Systems:**
Skills to manage and operate any moving components of the welding system safely and efficiently.

(4) **Utilization of Auxiliary Equipment:**
Competence in using additional equipment that supports the welding process, such as clamps, feeders, and cooling systems.

(5) **Handling of Jigs, Fixtures, and Setup Procedures:**
Expertise in setting up and adjusting jigs and fixtures to ensure accurate and consistent welds.

(6) **Management of Parameters and Adjustments:**
Ability to adjust welding parameters in accordance with established procedures to maintain weld quality.

(7) **Adherence to Safety Regulations and Precautions:**
Commitment to following all safety protocols and regulations to create a safe working environment and to prevent accidents.

(8) **Execution of Start-Stop Procedures:**
Proper techniques for initiating and terminating welding operations to ensure equipment longevity and process consistency.

ANNEX B:

ESSENTIAL KNOWLEDGE ON WELDING TECHNOLOGY

B.1 General

While an assessment of job knowledge is recommended, it is not universally mandatory. This annex delineates the essential knowledge and requirements for robotic welding operators or welding setters. It ensures that welding operators and welding setters possess the necessary competency to uphold industry standards, adhere to safety protocols, and perform their duties proficiently within the local construction environment.

The knowledge outlined herein represents the foundational level necessary for competent performance in these welding roles and for compliance with established procedures and industry best practices.

B.2 Requirements

B.2.1 Basic Skills in Welding

Proficiency in Common Welding Methods:

(1) Manual Metal Arc Welding (MMAW): Ability to perform MMAW with competence, ensuring strong and quality welds.

(2) Tungsten Inert Gas Welding (TIG): Skilled in TIG welding, maintaining precision and control for high-quality finishes.

(3) Metal Inert Gas Welding (MIG): Capability to execute MIG welding efficiently, optimizing speed without compromising weld integrity.

Welding on structural steel:

Competence in welding steel, understanding its unique properties and welding requirements.

B.2.2 Health and Safety

(1) **Workplace Safety Practices:**
Comprehensive understanding of safety protocols to mitigate risks associated with welding operations.

(2) **Proper Use of Personal Protective Equipment (PPE):**
Correct utilization of PPE, including welding helmets, gloves, and safety boots, to protect against hazards.

(3) **Safe Handling of Welding Equipment:**
Knowledge of safe practices for operating and managing welding machinery and tools to avoid injuries and equipment damage.

B.2.3 Work Readiness

(1) **Physical Fitness and Hand-Eye Coordination:**
Maintaining the necessary physical condition and dexterity required for effective welding tasks.

(2) **Understanding of Construction Site Operations:**
Basic comprehension of construction workflows and site dynamics to integrate welding activities seamlessly into broader project objectives.

B.2.4 Welding Techniques and Procedures

(1) **Welding Symbols, Drawings, and Specifications:**
Proficiency in interpreting welding symbols and technical drawings to accurately execute welding tasks as per specifications.

(2) **Welding Joints:**
Understanding different types of welding joints, including butt joints, fillet welds, and lap joints, and their appropriate applications.

B.2.5 Material Properties

(1) **Properties of Metals and Alloys:**
Basic knowledge of the characteristics of commonly used construction metals and alloys, enabling informed welding decisions.

(2) **Heat Effects on Materials During Welding:**
Awareness of how heat treatment impacts material properties, preventing issues such as warping or weakening of the weld.

B.2.6 Visual Testing of Welds

Inspect welds visually to identify surface defects, ensure quality standards are met, and determine necessary corrective actions.

ANNEX C:

ESSENTIAL KNOWLEDGE FOR ROBOTIC WELDING OPERATORS

C.1 General

This annex provides an overview of the essential knowledge for robotic welding operators and setters to effectively operate, program, and maintain robotic welding systems for S275 to S960 steel members. While not mandatory, this knowledge is recommended to ensure safe, efficient, and high-quality welding outcomes. It builds on the fundamental knowledge of welding technology outlined in Annex B, and it is developed to cover robotic systems, emphasizing automation, precision, and integration with construction practice. This annex supports standardized training and certification compliant with BS EN ISO 14732:2025 for mechanized and automatic welding personnel.

The knowledge areas represent the minimum competency needed to comply with industry best practice, reduce weld imperfections, and adapt to complex joint geometries, and site-specific challenges.

C.2 Requirements for effective robotic welding operation

This section lists out a number of basic requirements which are considered to be essential for safe and effective robotic welding operations.

C.2.1 Basic Skills in Robotic Welding

(1) **Proficiency in Robotic Welding Methods**
Competence in key processes such as Robotic Gas Metal Arc Welding (R-GMAW/MIG), Robotic Laser Beam Welding (R-LBW), and Robotic Plasma Arc Welding (R-PAW), including setup, parameter setting and adjustment.

(2) **Understanding Robotic Systems**
Working knowledge of robot components, including manipulators, end-effectors (e.g., welding torches), power sources, and wire feeders, with an ability to perform basic assembly and calibration.

(3) **Welding Structural Steel**
Awareness of material-specific requirements for welding S275 to S960 steel, such as the use of low heat input energy to prevent HAZ softening and the use of low-hydrogen consumables to avoid hydrogen cracking.

C.2.2 Health and Safety

(1) **Robotic-Specific Safety Practice**
Understanding hazards like pinch points, arc flash, and electromagnetic interference, with protocols for safe human-robot interaction, including emergency stops and safety zones.

(2) **Proper Use of PPE and Equipment**
Effective use of specialized personal protective equipment (PPE), e.g., anti-static gloves for robotic handling, and safe operation of automated systems to minimize risks from fumes, radiation, or mechanical failure.

(3) **Regulatory Compliance**
Familiarity with Hong Kong safety standards (e.g., CIC guidelines) and international norms (ISO 10218 for industrial robots), including risk assessments for on-site robotic welding.

C.2.3 Work Readiness

(1) **Physical and Technical Fitness:**
Maintaining dexterity for programming interfaces and visual acuity for monitoring welds, alongside an understanding integration with site operations.

(2) **Adaptability to Environments**
Knowledge of handling variable site conditions, such as temperature fluctuations or dust, to ensure long-term reliability.

C.2.4 Programming and Control

(1) **Robot Programming**
Proficiency in using software of the welding robots, to define weld paths, speeds, and parameters according to a welding procedure specification.

(2) **Sensor and Control Systems**
Understanding arc sensors, joint sensors, and adaptive controls for real-time adjustments, ensuring precision in single or multi passes.

(3) **Parameter Optimization**
Ability to set and monitor variables such as voltage (20 ~ 30 V), current (150 ~ 300 A), and travel speed (0.3 ~ 0.6 m/min) to achieve acceptable overall performance.

C.2.5 Troubleshooting and Maintenance

(1) **Identification of Issues**
Recognizing common robotic welding defects, e.g., misalignment, sensor failure, and their causes, with strategies for remedial actions.

(2) **System Maintenance**
Basic skills in performing routine checks, such as calibrating manipulators, replacing consumables, and updating software to prevent downtime.

(3) **Integration with Quality Systems**
Knowledge of linking robotic data logs to quality assurance processes per ISO 3834.

C.2.6 Visual Testing and Quality Evaluation

(1) **Weld Inspection**
Ability to visually assess weld quality against surface defects, e.g., porosity, undercuts, and select non-destructive testing (NDT) methods like ultrasonic or radiographic inspection.

(2) **Documentation**
Recording welding parameters and outcomes to support traceability and compliance with EN ISO 15614.

In general, completion of accredited programs provided by recognised training organizations on robotic welding is a demonstration to have acquired robotic welding skills.

ANNEX D:

REQUIREMENTS OF ROBOTIC SYSTEMS FOR STRUCTURAL WELDING

D.1 General

This Annex specifies the minimum mechanical and electrical requirements for robotic welding systems used in structural steel welding (grades S275 to S960). These requirements ensure system reliability, precision, and safety, directly supporting weld quality, operator qualification, and quality assurance processes (as per Clause 4). Compliance with this annex is mandatory for systems employed under this TG to minimize risks such as weld imperfections, equipment failures, or safety hazards. Requirements are performance-based to allow flexibility across manufacturers while aligning with international standards, including ISO 10218-1 (Safety Requirements for Industrial Robots – Part 1: Robots) and IEC 60204-1 (Safety of Machinery – Electrical Equipment of Machines – Part 1: General Requirements).

Moreover, robotic systems shall satisfy the baseline technical requirements for welding robotic under the Technical Circular (Works) No. 9/2025 as issued by the Development Bureau, and shall comply with the Occupational Safety and Health Ordinance (Cap. 509), requiring risk assessments, safe systems of work, and employer duties to maintain equipment, as well as the Construction Sites (Safety) Regulations (Cap. 59I), which cover machinery inspection, maintenance, and operator safety on construction sites. Electrical installations shall comply with the Electricity Ordinance (Cap. 406) and its subsidiary regulations, including the Electricity (Wiring) Regulations (Cap. 406E) for safe electrical supply and the Electrical Products (Safety) Regulation (Cap. 406G) for product safety.

Robotic systems include components such as manipulators, welding torches, sensors, control units, power sources, and auxiliary equipment (e.g., jigs and fixtures). Systems shall be capable of handling fusion welding processes (e.g., GMAW, FCAW, and SAW) under varying site conditions, with emphasis on adaptability for high-strength steel applications (S690 to S960) and shall incorporate provisions for environmental controls as per Section 18 of the General Specification for Civil Engineering Works 2020, CEDD.

D.2 Mechanical Requirements

Mechanical components shall ensure positional accuracy, durability, and stability to achieve consistent welds within the essential variables defined in Clause 4.2 of this document.

(1) **Positional and Repeatability Accuracy**
Robotic manipulators shall achieve a positional accuracy of ±0.2 mm and a repeatability of ±0.1 mm for weld path tracking, tested in accordance with ISO 9283 (Manipulating Industrial Robots – Performance Criteria and Related Test Methods). This ensures precise seam tracking for complex joint geometries, aligning with BS EN 1090-2 tolerances for assembly.

(2) **Load Capacity and Payload**
The system shall support a minimum payload for welding torches, sensors, and fixtures, with overload protection to prevent mechanical failure during operation, at a typical range from 5 kg to 12 kg. For a system with a lower payload, it is necessary to provide justifications together with project-specific, qualified WPS to demonstrate that the system maintains positional accuracy, repeatability, and overall stability.

(3) **Durability and Fatigue Resistance**
Mechanical joints, gears, and structures shall withstand continuous operation for at least 10,000 hours without degradation exceeding 0.05 mm in alignment, verified through fatigue testing per manufacturer specifications or equivalent standards.

(4) **Flexibility and Range of Motion**
Multi-axis robots (minimum 6 axes) shall provide a working envelope of a typical operation radius of 0.5 to 1.5 m, with rotation capabilities of ±180° on primary axes to accommodate on-site structural welding. For specialized applications in confined spaces where a compact system is required, a reduced operation radius may be proposed. In such cases, it is necessary to provide justifications together with project-specific, qualified WPS to demonstrate that the system maintains positional accuracy, repeatability, and overall stability.

(5) **Maintenance Provisions**
Systems shall include accessible components for routine maintenance, such as quick-release fixtures and diagnostic ports, with recommended intervals (e.g., monthly lubrication of joints) in line with Cap. 509 duties for safe maintenance and Cap. 59I inspection requirements.

(6) **Adequate Working Space for 3D Movement**
Provide adequate working space for the 3D movement of the robotic welding arm.

(7) **Collision Stop Sensors**
Equip the robot with sensors to stop the robot upon collision.

(8) **Pre-set Welding Path and Speed Uniformity**
Follow a pre-set welding path with consistent welding speed to produce welds with uniformity.

D.3 Electrical Requirements

Electrical systems for both fully automated and manually controlled robotic welding provide stable power delivery, reliable sensor integration (where applicable), and robust safety features to maintain welding parameters and prevent disruptions.

(1) **Power Source Stability**
Welding power supplies deliver voltage and current within ±5% of Welding Procedure Specification (WPS) values (e.g., 20–30 V, 150–300 A) to ensure consistent heat input and minimize heat-affected zone (HAZ) effects in high-strength steels. For manually controlled systems, power sources shall allow operator adjustments via intuitive interfaces (e.g., dials or touchscreens) while maintaining stability, with ripple voltage not exceeding 3% to accommodate manual variations.

(2) **Sensor and Control Performance**
For fully automated systems, arc and joint sensors shall detect deviations with an accuracy of ±0.2 mm to support real-time adaptive control. Manually controlled systems may use simplified sensors (e.g., basic seam tracking) or rely on operator monitoring, with control systems processing data at a minimum rate of 50 Hz to ensure responsiveness. Both systems shall support WPS compliance, as required by BS EN ISO 15614-1.

(3) **Electromagnetic Compatibility (EMC)**
Systems shall comply with IEC 61000-6-2 (EMC – Immunity for Industrial Environments) and IEC 61000-6-4 (EMC – Emission Standard for Industrial Environments) to avoid interference with other site equipment, in line with Cap. 406 requirements for safe electrical installations in construction environments.

(4) **Electrical Safety**
Wiring, grounding, and insulation shall meet the requirement of IEC 60204-1 and Cap. 406E, including overcurrent protection, fault detection, and isolation switches. Power consumption should not exceed 10 kW for standard setups, with energy-efficient modes for prolonged operation.

(5) **Integration and Communication**
Systems shall support standard protocols (e.g., EtherCAT, PROFINET) for interfacing with external monitoring tools, ensuring data logging of parameters like voltage, current, and speed.

D.4 Certification and Verification

(1) **Manufacturer Certification:** Robotic systems shall be certified by the manufacturer for compliance with ISO 10218-1 (robot safety) and IEC 60204-1 (electrical safety), or equivalent regional standards (e.g., CE marking in Europe or UL certification in the USA). Proof of certification, including test reports, shall be provided.

(2) **Initial Verification:** Before deployment, systems shall undergo pre-production testing (per EN ISO 15613) to verify mechanical and electrical performance under simulated site conditions, including load tests and parameter stability checks.

(3) **Periodic Verification and Calibration:** Annual calibration by qualified technicians is required, with verification of accuracy, stability, and safety features. Results shall meet acceptance criteria (e.g., no deviation > ±0.2 mm in positioning).

(4) **Audit Integration:** Compliance shall be audited during quality assurance reviews (Part 4), with non-conforming systems being subject to revocation of usage approval. Examining bodies under HOKLAS shall oversee verification.

D.5 Documentation

(1) **Technical Manuals:** Manufacturers shall supply detailed manuals covering mechanical specifications, electrical schematics, maintenance schedules, and troubleshooting guides.

(2) **Records Retention:** Users (e.g., contractors) shall maintain records of certification, verification tests, calibration results, and maintenance activities for at least six years, aligned with Clause 6 (Certificates and Documentation). Records shall include system performance data logs for traceability in case of weld failures.

ANNEX E:

CERTIFICATE FOR ROBOTIC WELDING OPERATORS / SETTERS

Manufacturer's welding procedure specification Reference No.:		Examining body Reference No.:	
Name of robotic welding operator or welding setter:		Photograph	
Certificate number of general welding training:			
Training organization:			
Date of birth:			
Employer:			
Testing standard:			

Copy of Certificate of General Welding Training

Welding process(es):		
Welding equipment:		
Details for automatic welding		
Joint sensor	Yes / No	
Arc sensor control	Yes / No	
Single run / Multi run technique	Single / Multi Run	
Joint type		

Additional information available of the welding procedure specification No.: _____

<table>
<tr><td colspan="3">The qualification is based on:

☐ Welding procedure test (4.1 a) of TG[1]
☐ Pre-production welding test (4.1 b) of TG
☐ Standard test piece (4.1 c) of TG
☐ Production test or production sample testing (see 4.1 d)

Result of the qualification test see document No.:
_____
(Welding Procedure Qualification Record)</td><td colspan="3">Name of examining body:

_____

Date of examination: _____-

Location: _____

Validity of qualification until: _____</td></tr>
<tr><td colspan="3"></td><td colspan="3">Revalidation for qualification by employer/welding coordinator for the following 6 months</td></tr>
<tr><td colspan="3">Revalidation for qualification by examining body for the following 6 years</td><td>Date</td><td>Signature</td><td>Position/ Title</td></tr>
<tr><td></td><td></td><td></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Confirmation of the validity by examining body for the following 3 years (refer to 5.3 b)

Date	Signature	Position/ Title

Confirmation of the validity by examining body for the following 3 years (refer to 5.3 c)

Date	Signature	Position/ Title

[1]TG refers to Technical Guidelines for Robotic Welding Operations of Structural Steel in Construction

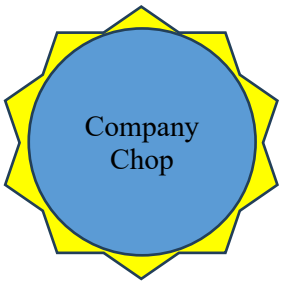
Logo of the authorized training organization

This is to certify that

XXXX

has fulfilled all the requirements prescribed of the Robotic Welding Operator Program on Automated and Robotic Welding Technology for Structural Steel, who has passed all the evaluations and assessments in compliance with:

- EN ISO 15614
- EN ISO 9606-1:2017 or BS EN 287-1:2011



Signature of
the representative of
the authorized training organization

Date of issue

Date of expiry

Figure E1 Sample certificate for robotic welding operators/setters

ANNEX F:
ADDITIONAL REFERENCES

[1] ISO 9283:1998, *Manipulating industrial robots — Performance criteria and related test methods*

[2] ISO 10218-1:2025 - Robotics — Safety requirements. Part 1: Industrial robots

[3] ISO 12100:2010, Safety of machinery — General principles for design — Risk assessment and risk reduction

[4] ISO 13849-1:2023, Safety of machinery — Safety-related parts of control systems — Part 1: General principles for design

[5] ISO 13850:2015, Safety of machinery — Emergency stop function — Principles for design

[6] ISO 14118:2017, Safety of machinery — Prevention of unexpected start-up

[7] ISO 14119:2024, Safety of machinery — Interlocking devices associated with guards — Principles for design and selection

[8] IEC 60204-1: Electrical equipment of machines — Part 1: General requirements

[9] IEC 60896-21:2004 - Stationary lead-acid batteries - Part 21: Valve regulated types - Methods of test

[10] IEC 62619:2017 - Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries, for use in industrial applications

[11] Technical Requirements for Construction Robots for Painting, Plastering and Welding, Construction Industry Council

Notes

- Compliance: All procedures shall comply with this TG and referenced standards. Non-compliance may result in certificate revocation.
- Updates: This TG will be reviewed from time to time to incorporate technological advancements and industry feedback.
- Accessibility: Digital copies are available via the BTRI website (https://btri.hk/).