



PIPING

Control Construction Through Design: Count Your Welds

Strategic Weld Planning and Control in 3D Piping Layout Design to Ensure Constructability and Efficient Field Execution.

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ABSTRACT

Welding is one of the most critical activities in piping construction and fabrication for process plants such as refineries, petrochemical complexes, fertilizer plants, and power facilities. While welding is traditionally viewed as a construction activity, many welding challenges originate during the engineering and 3D layout stage when constructibility aspects are overlooked. Improper weld location, inaccessible weld joints, excessive field welds, or poorly defined spool breaks can significantly impact safety, cost, quality, and project schedule.

This paper discusses the key weld and spooling considerations that must be addressed during 3D piping layout design. The paper highlights the unique challenges. It also examines the limitations faced by construction contractors when weld requirements are not considered in the design phase. Furthermore, the paper emphasizes the critical role of the piping layout engineer in ensuring constructibility, optimizing pipe spooling, minimizing field welds, and improving overall project efficiency.

1. INTRODUCTION

In modern industrial projects, piping systems consist of thousands of welded joints connecting pipes, fittings, valves, and equipment. Each weld represents potential point of inspection, cost, delay, and risk if not properly planned.

Traditionally, piping layout engineers focus primarily on:

- Layout
- Routing
- Structural integrity and Pipe Stress requirements
- Equipment connectivity
- Pipe support locations
- Maintenance accessibility

However, constructability of welds and spooling strategy are often overlooked during layout design, which later creates major construction difficulties.

A poorly planned weld location may lead to:

- Excessive cost
- Material Wastage
- Inaccessible welding positions
- Requirement of special welding procedures
- Excessive scaffolding
- Safety hazards
- Increased NDT cost
- Delays in hydro testing
- Contractor disputes

2. CHALLENGES FACED BY CONTRACTORS WHEN WELD CONSIDERATIONS ARE IGNORED

Failure to address weld constructability during design phase creates major difficulties for contractors during execution, directly affecting the efficiency and quality of the construction process.

Key impacts:

- a. **Higher construction costs:** Extra scaffolding, manual welding, and complex setups increase labor expenses.
- b. **Schedule delays:** Poorly located welds slow down welding, inspection, and overall progress.
- c. **Safety risks:** Confined space welding raises hazards for workers.
- d. **Inspection difficulties:** NDT methods like radiography may be impossible due to obstructions.
- e. **Rework:** Design changes during construction lead to costly rework and project delays

Summary: Proactive weld planning during design minimizes cost, improves safety, and ensures smoother construction. Ignoring these considerations shifts risks and inefficiencies onto field contractors, ultimately affecting project delivery.

3. TYPE OF PIPE WELDS:

Pipe welds are categorized based on where they are performed and how the piping is assembled during a project. Understanding these weld types helps in planning fabrication, improving quality, and optimizing construction schedules.

- a. **Field Welds:** Welds done at the construction site, mainly for final connections, tie-ins, and adjustments. Conditions are variable, so they require careful control.
- b. **Shop Welds:** Welds completed in a controlled fabrication shop, offering higher quality, better productivity, and easier inspection. Common for pipe spools and prefabricated assemblies.
- c. **Module Welds:** Welds performed during module or skid assembly in a module yard. Most welding is completed before shipment, reducing on site work and improving safety.
- d. **Other Weld Types:**
 - **Fit Field Weld (FFW):** FFW is a pre-planned field weld where a short trim allowance typically 100 – 150 mm is intentionally left. This extra length allows the contractor to verify dimensions on site, then trim, bevel, and weld the piece to accommodate any field-related variations such as nozzle misalignment, brownfield offsets, or rack tolerance issues.
 - **Tack welds:** These welds are small temporary welds used to hold parts in place before final welding. Designers should recommend their use in areas with tight access, difficult alignment, or

space constraints were maintaining accurate fit-up is challenging and a standard field weld may not be practical.

- **Spool Welds:** Within prefabricated pipe spools.
- **Tie-In Welds:** Connecting new piping to existing systems.
- **Temporary Welds:** Support or lifting attachments used during construction.
- **Dissimilar weld:** Welding two different metals, such as carbon steel and stainless steel, using specially selected filler alloys that can handle the differences in thermal expansion, melting behavior, and metallurgical compatibility is called dissimilar weld. Because the materials behave differently during welding and in service, welders must carefully manage stress, corrosion risks, and microstructural changes to ensure a reliable and long-lasting joint.

4. IMPORTANCE OF WELD PLANNING IN 3D LAYOUT DESIGN

Proper weld planning during design has many benefits:

- a. **Improved Constructability:** Welds positioned with proper clearance allow welders to work safely and efficiently.
- b. **Reduced Construction Time:** Efficient spooling and minimized field welds significantly accelerate erection.
- c. **Cost Optimization:** Field welding is typically 1.5 to 3 times more expensive than shop welding. While specific ratios can vary by region, this cost disparity is primarily driven by labor and environmental factors.
- d. **Improved Safety:** Avoiding welding in confined spaces or hazardous zones reduces risk.
- e. **Improved Quality:** Shop welds generally provide better weld quality due to controlled conditions.

5. DESIGN CONSIDERATION

Modern 3D design platforms such as SmartPlant 3D, PDMS/E3D, and AutoCAD Plant 3D enable engineers to evaluate weld constructability early in the design phase, thereby extending the piping designer's responsibility beyond layout development to include construction-driven decisions. Unlike natural flange breaks, field weld (FW) locations require deliberate selection based on sound engineering judgment rather than being dictated solely by shipping dimensions or

modularization limits. Appropriate weld placement therefore demands a clear understanding of installation constraints and prevailing site conditions. In carbon steel piping, the heat-affected zone (HAZ) typically extends approximately 3 – 5 mm beyond the visible fusion line of the weld. While major piping codes such as ASME B31.3, EN 13480, and similar standards do not specify a mandatory minimum spacing between circumferential welds, weld-to-weld spacing is generally governed by project specifications (refer Example Fig. 1) and established industry practice to safeguard weld quality, manage residual stresses, and ensure long-term service performance.

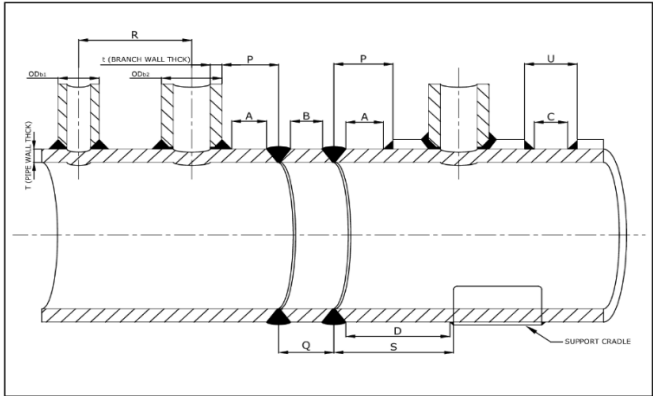


Fig. 1. Example from Fluor Executed Project

Key considerations for designers include:

5.1. Weld Orientation Considerations

Orientation of welds significantly impacts welding quality and productivity.

Preferred Weld Orientation

Weld Orientation	Recommendation
Horizontal Weld	Preferred
Flat Position	Highly preferred
Vertical Weld	Avoid where possible
Overhead Weld	Avoid

Notably, BS 2633 provides explicit guidance on minimum weld separation distances to prevent overlapping HAZs and excessive residual stresses. Specifically, for attachment welds (see Fig. 2), the minimum distance S —measured from weld toe to weld toe between an attachment weld and a circumferential weld shall be at least $2t$ or 40 mm, whichever is smaller. This requirement offers a prescriptive benchmark that can be adopted where project specifications or other applicable codes are silent on minimum spacing criteria.

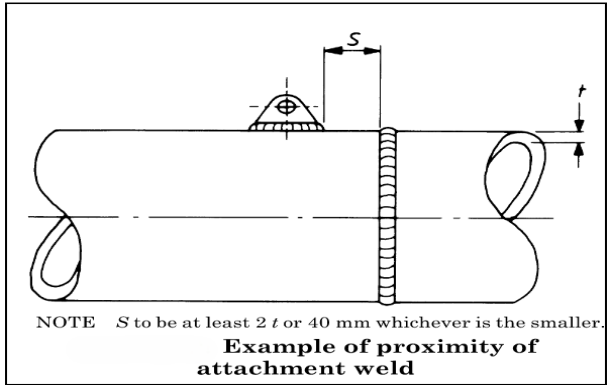


Fig. 2. Example of proximity of attachment weld. BS 2633

Key Guidelines for Weld Placement

- a. Horizontal welds are preferred as they are generally easier to execute and inspect.
- b. Vertical welds should be minimized and only incorporated when no practical alternative exists.
- c. Vertical welds often demand 6G welding positions (Fig. 3), which are significantly more challenging and require highly skilled welders to perform effectively.

This image illustrates the four primary pipe welding positions used in fabrication to determine how a pipe is fixed or rotated during the welding process.

- **1G Horizontal Rolled Position:** The pipe is placed horizontally and rotates while the welding remains stationary.
- **2G Vertical Position:** The pipe stands vertically, and the welding axis is horizontal.
- **5G Horizontal Fixed Position:** The pipe is fixed horizontally and does not rotate; the welder moves around the pipe.
- **6G Inclined Position:** The pipe is fixed at a 45° angle, requiring the welder to work around it. This is the most challenging position and demands a high level of welding skills.

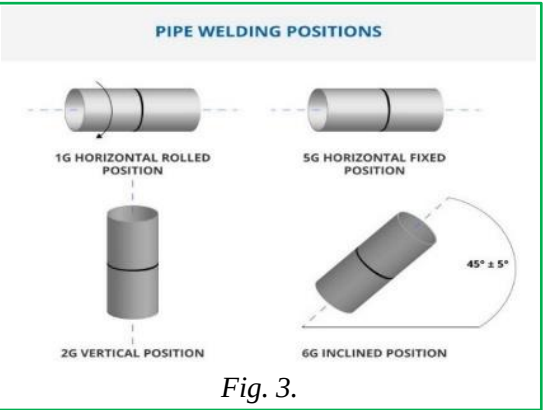


Fig. 3.

5.2. Accessibility and Clearance Requirements

Ensuring proper accessibility around weld joints is critical for safe, efficient, and high-quality construction. Poorly planned weld locations often lead to delays, rework, or poor weld quality. Designers must anticipate these challenges during the design phase and incorporate clearance requirements into the piping layout.

Common Access Challenges

- Proximity to structures:** Welds placed too close to walls, beams, or other obstructions limit welder maneuverability and machine accessibility. (Fig. 4)
- Crowded piping systems:** Welds positioned between adjacent pipes can restrict torch angles and inspection access.
- Hidden locations:** Welds behind equipment or machinery are difficult to reach and may require costly disassembly.
- Supports and clamps:** Welds near pipe supports or clamps can obstruct torch access and complicate post-weld treatments.

Recommended Clearance Guidelines

- Minimum clearance:** Maintain at least 150 – 200 mm around weld joints. Or follow the client and industry specification (Fig. 1).
- Additional clearance required for:**
 - Large diameter pipes (to accommodate larger torches and inspection tools).
 - Alloy steel welding (due to more complex PWHT (Post-Weld Heat Treatment) requirements).
 - Automated welding equipment (which requires more operational space).

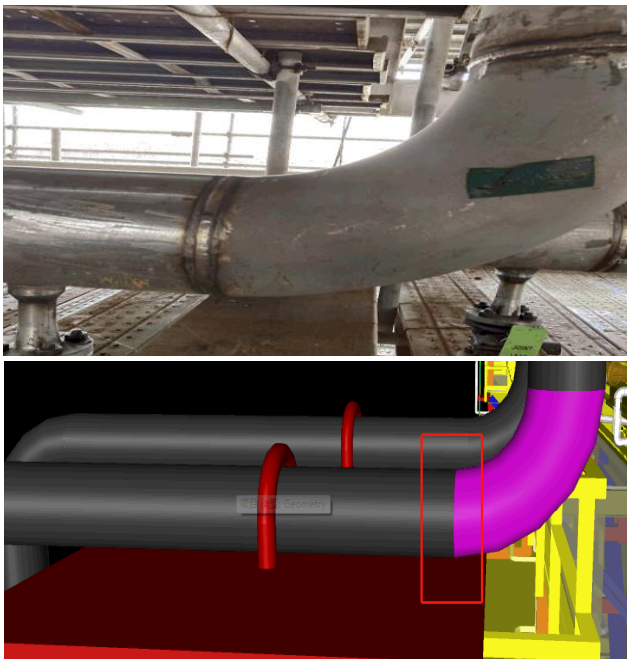


Fig. 4. Fitting the weld joints on the steel beam creates challenges for welding and NDE

5.3. Avoid Welding in Confined Spaces

Welding in confined spaces poses serious safety, quality, and productivity risks. Restricted areas such as existing pipe racks, behind vessels, near structural members, underground trenches, or inside pits often limit ventilation and increase hazards.

Key problems include:

- Poor air circulation and risk of gas buildup.
- Restricted welder movement and posture.
- Difficulty in performing NDT inspections.
- Higher risk of accidents and reduced efficiency.

Best practice: Designers should relocate spool breaks to open, accessible areas whenever possible. This ensures safer working conditions, smoother welding operations, and easier inspection and maintenance.

5.4. Welds in ATEX/Hazardous Zones

Welding in ATEX (ATmosphères EXplosibles) classified areas is a high-risk activity that demands strict controls. Hot work in such zones requires a permit-to-work system, thorough risk assessment, and often production shutdowns. Safety measures typically include continuous gas detection, use of non-sparking tools, and flame-retardant welding habitats to isolate ignition sources from flammable gases or dust.

Key considerations for designers:

- Use flange connections near hazardous equipment to reduce hot work.
- Avoid welds in hazardous zones wherever possible.
- Relocate welds outside classified areas to minimize risk.

Best practice: In revamp projects, designers should clearly mark hazardous zone requirements in drawings and work package and discuss them upfront with both the client and contractor. This proactive approach ensures safer construction planning and avoids costly delays.

5.5. Welding of Unequal Pipe Thickness

Welding pipes of unequal thickness is a common challenge, especially when connecting different piping classes, valves with thicker bodies, or tie-ins during revamp projects. If not addressed during design, and if not agreed with client, construction teams face added work such as machining, transition pieces, or weld buildup.

Best practice:

- Provide proper transition welds to ensure smooth thickness changes.
- Add detailed instructions to the tie-in package.

Summary: Anticipating thickness mismatches during design prevents costly rework, improves weld quality, and ensures compliance with industry standards.

5.6. Branch Connection Considerations

Branch connections significantly affect welding complexity and construction effort. Common options include weldolets, sockolets, threadolets, and stub-in connections.

In some projects, DIN class piping may not align with standard weldolet specifications. If mismatched fittings are selected, construction teams may face:

- Excess weld thickness and reinforcement requirements
- Special machining or transition pieces
- Delays in fabrication and inspection

Best practice: Designers with Material Engineer must verify branch connection compatibility during the design stage, ensuring proper fit up, code compliance, and constructability. Selecting the right branch type early prevents costly rework, material waste and improves overall project efficiency.

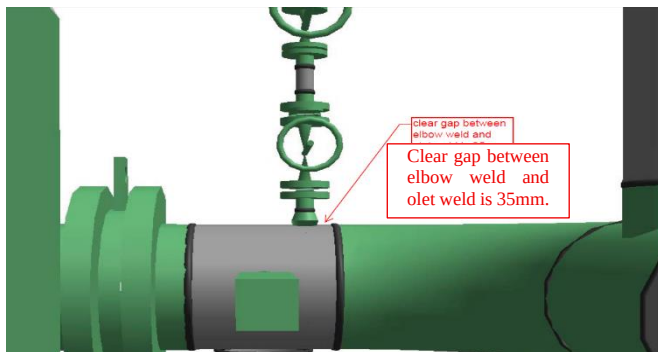


Fig. 5. The actual gap between the elbow weld and the outlet weld is 35 mm, whereas the required weld to weld clearance should be 75 mm or three times the wall thickness (whichever is greater).

5.7. Requirement of Special Welding Machines

Certain welding operations demand specialized equipment such as orbital welding machines, automatic welding systems, and PWHT units. These machines improve weld quality, consistency, and productivity but require careful planning during design.

Challenges:

- Poorly located welds may block access to equipment.
- Inadequate planning leads to delays and costly adjustments during construction.

Best practice: Verify machine clearance around weld joints and plan lifting paths for equipment movement and installation.

5.8. Battery Limit Philosophy

Battery limits define the interface between contractors or process units, making the choice of connection type a critical design decision.

Best practice:

- Use flanged connections or flanged valves at battery limits.
- Avoid welded connections, as they often lead to:
 - Unclear responsibility for hydrotesting
 - Contractor disputes over scope and accountability
 - Greater complexity for tie-ins and future modifications

Summary: Designers should clearly specify battery limit requirements in the scope of work and discuss them in front with both client and contractor. Standardized connections reduce risk, simplify construction, and improve coordination. In revamp projects, battery limits must be explicitly marked in drawings and specifications to prevent disputes and delays.

5.9. Pipe Spooling Strategy

Pipe spooling is the process of dividing piping systems into shop fabricated segments, which can greatly reduce construction effort when planned effectively.

Benefits of proper spooling:

- Less field welding and higher weld quality
- Faster erection and reduced site congestion
- Lower labor costs and improved productivity

Key principles for designers:

- Maximize shop fabrication.
- Minimize field welds to reduce site risks and delays.
- Keep spool sizes transportable and avoid excessively heavy segments and ease of handling at site.
- Ensure crane accessibility for lifting and installation.

Summary: Effective spooling improves constructability, reduces costs, and streamlines site operations. Designers must balance shop fabrication with transport and erection constraints to achieve optimal results.

5.10. Weld Saving Opportunities

Careful piping routing and detailing can minimize welds, improving constructability and lowering costs.

Example:

Instead of: Pipe → Elbow → Short Spool Pipe → Elbow

Consider: Elbow → Elbow connection where feasible.

Benefits:

- Fewer weld joints to fabricate and inspect.
- Reduced labor and material costs.
- Improved overall welding quality and efficiency.

Summary: Designers should always evaluate routing options to eliminate redundant welds. Smart detailing reduces site work, simplifies inspection, and enhances project productivity.

6. SPECIAL CHALLENGES IN REVAMP PROJECTS

Revamp projects are far more complex than greenfield developments due to existing site constraints and limited flexibility.

Typical challenges include:

- Highly congested piping areas with little room for new welds.
- Existing structures blocking weld access
- Restricted shutdown windows, requiring precise planning.
- Limited crane access for heavy spools or equipment.
- Strict hot work restrictions in operating plants.
- Special material welding like Aluminum.

Best practice: Tie-in welds must be carefully planned to minimize plant downtime. Advanced 3D modeling plays a critical role in identifying congestion, access limitations, and safety risks before construction begins, enabling proactive solutions.

7. ESSENTIAL WELD DESIGN CHECKLIST FOR PIPING DESIGNERS.

Before finalizing a piping layout, designers must confirm key weld constructability aspects to ensure safety, quality, and efficiency.

Five critical checks:

- Accessibility:** Is there sufficient space for the welder, tools, and inspection equipment?
- Orientation:** Are welds positioned horizontally wherever possible to improve quality and ease of execution?
- Safety of Location:** Are welds kept outside confined spaces and hazardous zones to reduce risks?
- Spooling Efficiency:** Does the layout maximize shop fabrication and minimize field welds?
- Constructability:**
 - Can welding machines, scaffolding, and NDT equipment reach the weld safely and effectively?
 - In situations where information is incomplete or uncertain, apply FFW. When full details are available, opt for a standard field weld with the final shop cut length.
 - Figures 6, 7, and 8 illustrate design examples that lead to constructability issues.



Fig. 6. R-pads are too close to adjacent welds, raising local stresses, restricting welding/NDE access, and risking nonconformance/rework

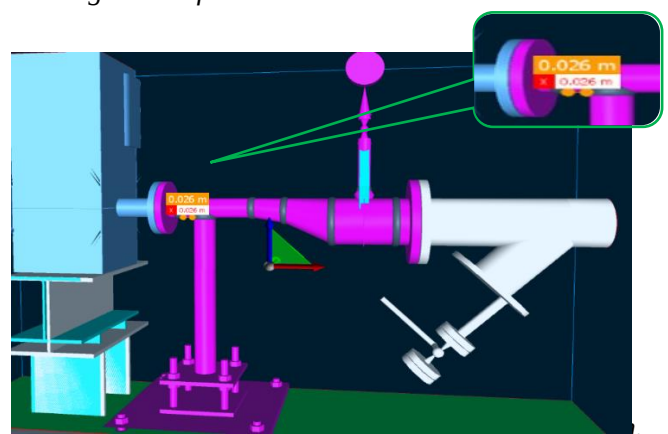


Fig. 7. Weld to Weld Gap 26 mm only against 50 mm.

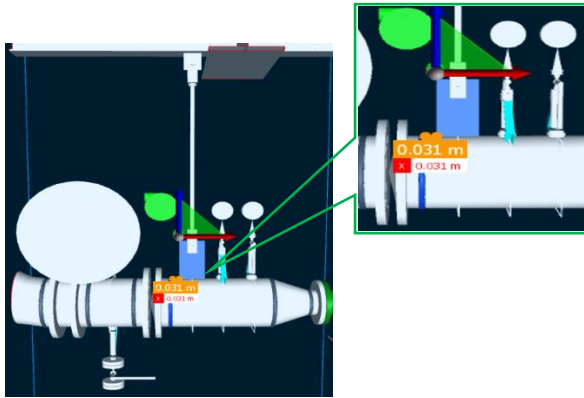


Fig. 8. Weld to Weld Gap 31 mm only against 50 mm.

8. CONCLUSION

Weld planning is a critical yet often overlooked aspect of piping layout design. Many construction challenges arise not from fabrication limits but from inadequate weld planning during engineering.

By integrating weld accessibility, orientation, spooling strategy, and construction constraints into the 3D modeling process, designers can greatly enhance constructability and project efficiency.

Benefits of proper weld design:

- Reduced field welding and rework
- Improved safety and easier inspection
- Faster construction and smoother execution
- Lower overall project cost.
- Higher weld quality and reliability

Successful projects require close collaboration between design engineers, fabrication teams, and contractors. The 3D piping layout engineer plays a central role in bridging design with intent with field execution, ensuring that weld planning supports safe, efficient, and cost-effective construction.

Good to Know

1. Welders' Approach When Minimum Weld Gap Is Not Achieved

When the specified weld-to-weld spacing cannot be met; such as a specification requirement of 50 mm but only 35 mm shown on the isometric, the welder does not continue without authorization. The issue is reported to QC, who then raises an RFI or deviation request for engineering review. Inspection and construction engineers evaluate the situation, considering factors such as alternate WPS options (Welding Procedure Specification is a formal document that describes how a weld must be made to meet code, project, and quality requirements.), access limitations, potential heat-affected zone overlap, and NDE (Non-Destructive Examination refers to a set of inspection methods used to evaluate the integrity, quality, and soundness of a weld or material without damaging it) accessibility.

Based on this assessment, they issue a formal disposition (formal disposition is an official, written decision issued by engineering, QA/QC, or the client that states how a non-conforming or unclear field condition must be handled.). Welding may proceed only after written approval, often with controlled parameters or enhanced inspection to ensure weld quality within the reduced spacing.

2. The Future with AI in Pipe Welding (Overview)

AI-driven welding technologies are increasingly being adopted to improve the efficiency, quality, and safety of pipe welding operations. By combining real-time sensing with adaptive control algorithms, these systems support more stable weld processes and early defect detection. Robotic welding platforms incorporating AI can adjust to complex pipe geometries and variances in fit-up, improving consistency across multi-pass welds and reducing rework. While still an emerging field, early deployments suggest measurable gains in productivity and quality. Additionally, digital twins and AI-powered simulations enable pre-weld evaluation of stresses and process parameters, enhancing decision-making and weld reliability in critical piping and pressure applications.

REFERENCES:

- (1) Fluor Executed Projects experiences.
- (2) ASME 31.3
- (3) EN 13480
- (4) API 650
- (5) BS 263

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