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What Mechanical Contracting Managers need to know about Piping Codes and Customer Specifications

The purpose of this paper is to make management of mechanical contractors aware of requirements associated with doing work to the ASME B31 Piping Code and the importance of recognizing customer specification requirements.

Executive Summary

The ASME B31 Code for Pressure Piping is standard industry practice. Compliance is important, and can be crucial if there is a dispute. The B31 Code specifies fabrication and installation practices and examination, inspection and testing practices. Customer specifications add requirements that exceed those required by Code, and contractors should look carefully for "death clauses" that allow the owner to randomly examine welds that were not required to be examined by the contract.

Background

The American Society of Mechanical Engineers published the ASME Boiler Code in 1914 in response to property damage and deaths caused by boilers exploding. The Power Piping Society published a 9-page *Standard Specification for Power Piping* in 1922, and ASME published the 136 page long ASA *B31 Code for Pressure Piping* in 1935. The purpose of these Codes was to ensure that what is being built was safe. They specified design rules, listed the materials that were permitted, specified fabrication practices, inspection, examination and leak testing requirements.

While the ASME Boiler and Pressure Vessel Code is widely adopted by local jurisdictions, the B31 *Code for Pressure Piping* is not widely so adopted. Rather, the B31 *Code* requires that the owner of the facility in which piping will be installed specify the B31 Code Section that applies to the work being performed. Those Sections are:

ASME B31.1	Power Piping
ASME B31.3,	Process Piping
ASME B31.4,	Pipeline Transportation Systems for Liquids and Slurries
ASME B31.5	Refrigeration Piping
ASME B31.8	Gas Transmission and Distribution Piping Systems
ASME B31.9	Building Services Piping
ASME B31.12	Hydrogen Piping

See: https://cstools.asme.org/csconnect/FileUpload.cfm?View=yes&ID=22855. for detailed descriptions of the scopes of each section.

Identification of the Applicable Code Section

When a contractor receives specifications for piping from the owner's engineer, **the first thing the contractor should do is identify the B31 Code section that applies to the work**. That may be in the specification itself, in the piping line list or on the drawings. Different code sections may apply to different piping systems, e.g., steam piping in a refinery may be to B31.1, the process piping may be to B31.3 and the hydronic piping in an office building on the site may be to B31.9. Being sure that the code section applicable to any piping system is important because the extent of examination and the acceptance criteria for welds is different in each code section. That is, if you think the applicable code section for a hydronic piping system is B31.9 but the owner's inspectors think it is B31.3, there will be a problem since B31.3 requires 5% random radiography of each welder's welds, and every time a weld is rejected, you have to radiograph two more welds made by that welder. When welders are not advised that their welds will be radiographed, many will not pay sufficient attention to the details, and that will result in rejected welds.

If the engineering specification lists all the B31 Code Sections and says: "fabricate and install in accordance with the applicable code section," specify the code section that you will work to in your bidding documents.

If no code is specified, you should specify the code section that you will follow when you bid the job. While this may seem counterintuitive (i.e., why build to a code when you don't have to?), the codes are standard industry practice. In the event that the piping develops leaks after two years in service and the owner decides it was your fault and sues, if you followed standard industry practice (i.e., one of the B31 Code Sections) when you installed the piping, you will have a much better leg to stand on in the witness stand that just saying: "Well, we installed it like it showed on the drawings. . . "

Each section of the B31 Code covers the following:

- materials that are permitted,
- pressure design,
- sets limits on stresses, including stresses resulting from thermal expansion
- specifies fabrication, installation methods and techniques, including welding, brazing and postweld heat treatment requirements.
- specifies the extent and acceptance criteria for examinations, inspections, and tests.
- Specifies maintenance and repair activities (in some sections)

Design Considerations

The engineering organization that is responsible for the project should provide the details of the design, including consideration of:

- pressure
- upper and lower operating temperatures
- dead weight loads
- thermal expansion effects and the need for flexibility.

- hydraulic transients, and
- earthquake (seismic) loads

If you do not have a sufficiently detailed design that includes not only the material, pipe size and schedule, but also details for supports, anchors and restraints, slope, drainage, etc., either exclude any and all design considerations from your quote or include enough money in the quote to design the piping system to cover the above.

Welding and Fabrication Considerations

Contractors need to be aware of the following which are specified in the B31 code section:

- Requires that you have and follow Welding Procedure Specifications (WPSs) and Brazing Procedure Specifications (BPSs)
    - They refer you to ASME Section IX for the qualification of WPSs and BPSs and qualification of personnel. Section IX requires that contractors qualify their own procedures and welders; however, the B31 code takes exception to that:
        - They allow the use of WPSs and BPSs qualified by a technical competent group or agency such as NCPWB.
        - They allow contractors to interchange welders and brazers once they are qualified. Welders and brazers have to be qualified by a contractor, but once qualified, their records can be transferred to other contractors,
            - NCPWB together with UA coordinate that activity.
        - If a welder or brazer does not use a process for 6 months, his qualifications for that process expire. Contractors have to maintain records showing when welders and brazers last used each process.
            - NCPWB and UA coordinate with contractors to keep welder qualifications from expiring.
    - If you qualify your WPSs or your welders, Section IX requires that personnel who supervise the welding of the test coupons have to be qualified[1].
- Specifies default welding electrode and filler metal requirements.
- Welding procedures must be where the work is being done, not back in the office.
- Foremen should always verify three things
    - that welders are using the electrodes and filler metals that are specified in the WPS,
    - that the preheat specified in the WPS or on the drawings is being used, and
    - each joint has been properly cut, beveled, aligned and tack welded before the root pass is welded.
- Specifies weld end preparation details, fit-up and alignment requirements on mating pipe and fitting ends and the use of backing rings. Due to the tolerances on pipe and fitting dimensions, it can be difficult to achieve the required internal alignment when joining standard weight pipe over NPS 12 without doing weld buildup and/or grinding on the pipe ends internal surfaces, so be sure include time for that when you price the work.

[1] See: https://cstools.asme.org › csconnect › FileUpload.cfm?View=yes&ID=62700

- You will always get a fully penetrated weld if your welders use backing rings. While backing rings are not suitable for some service conditions (corrosive fluid, high purity service, risk of crevice corrosion, etc.), backing rings have been used successfully in steam, hot water and compressed air service for decades. They are a good fit when B31.9, *Building Services Piping* or B31.1 *Power Piping* is imposed.
- Butt welded and branch connection joints (including couplings) must be beveled, aligned and fit up so that full penetration joints can be made. Whether or not the welder has to achieve 100% penetration for the full length of a joint depends on what in required under the examination requirements which we will cover later. After each groove weld joint has been tack welded together, it should be examined by someone other than the welder before the welder is allowed to make the root pass. This can be documented directly on the pipe near the joint using a paint marker using the words: "Fitup OK" followed by the foreman/supervisor/QC inspector's initials and date. I have been involved as an expert witness in a number of lawsuits that would never have arisen had this practice been followed.
- Socket welds are required to have a gap between the end of the pipe and the base of the socket *before* welding. *There is no requirement to have that gap after welding.* If you get pushed into examining socket welds for gap either with a manual device that one inserts into the socket or by radiography, ask your customer to show you where the Code says that gap has to be present *after* welding. The do not -- but that requirement may be in the engineer's specification.
- Integrally reinforced outlet connections (e.g. weld-o-lets) are permitted. See sketches in the Code for the extent of welding that is required. Fabricated branch connections using two pieces of pipe (aka: stub-ins) are also permitted. When using these, you will have to perform calculations to determine if a reinforcing pad is or is not required (See PFI ES-36[2].)
- Repair welding is permitted. Repair welds are required to be reexamined by the same method that was used to detect the flaw.
- Minimum preheat temperatures are specified in each B31 Section. The minimum preheat in all B31 Sections is 50°F.
- Postweld heat treatment requirements, including maximum heating rate, holding temperature, minimum holding time and maximum cooling rates are specified. Postweld heat treatment temperatures and holding times are specified in one table based on the base metal P-number, and exceptions based on the base metal P-number and the thickness of the materials being joined are found it a subsequent table. For quick discovery of the P-number to which a material is assigned, see www.pnumbers.com.
- Pipe is allowed to be bent hot or cold. There are out-of-roundness limits. Low alloy steel that is bend usually requires postbend heat treatment in a manner similar to welds.
- Flanged joint, threaded joints and joints made with engineered fittings (e.g., Victaulic couplings) are permitted.

Examinations, Inspections and Tests

Contractors are required to have a program that specifies the extent of training of those who perform visual examination. Typical programs require a minimum number of both classroom training hours and

[2] The Pipe Fabrication institute is at https://pfi-institute.org

on-the-job training hours. AWS Certified Welding Inspectors are commonly accepted under such programs. Annual near-vision acuity testing is required.

All welds must be visually inspected on all accessible surfaces. That includes all external surfaces and internal surfaces that are withing about 1-3/4 of the diameter of the pipe. Welds attaching couplings and outlet fittings should be inspected for root penetration using a small mirror and a flashlight. There is no requirement to document the inspections performed individual welds, provided inspectors keep contemporaneous log books or other records identifying what they examined and the results. There are requirements to have documentation of examinations such as radiography, ultrasonic examination, magnetic particle, etc.

Inspection includes not only visual inspection of welds, but also inspection of the entire installation. This includes verifying that the correct materials have been installed, that the dimensions of the piping and locations of supports, restraints and anchors are as required by the design, and that threaded, bolted, and other types of joints have been properly assembled. Most issues that arise are about welds, but you should have someone who is qualified to look at all aspects of the installation, not just welding.

There are qualification requirements for customer inspectors. While it is probably not smart to question your customer's inspector's qualifications, management should be aware that the B31 code has such requirements.

When welding stainless steel or nickel alloy piping, it is normal to fill the pipe with argon (purge) to prevent discoloration of the internal weld surfaces. If a specification requires you to "purge" the pipe, the level of discoloration that is acceptable should be agreed on. See Pipe Fabrication Institute (PFI) ES-50, *Internal Oxidation for Piping Welds* for guidance and a basis for agreement.

The extent of nondestructive examination is dictated by each Code Section, and each Section is different.

B31.1, *Power Piping*, requires 100% radiographic for all welds in piping which is designed to operate above 750ºF or is designed to operate between 350 and 750ºF and over 1025 psi and is over NPS 2 and over 3/4 inches thick. Welds operating outside below these conditions require visual examination of those surfaces that are readily accessible for visual examination.

B31.5, Refrigeration Piping, requires no nondestructive examination except when the refrigerant is Groups A3 and B3 (flammable), then 5% random examination by radiography is required, and, if a weld is rejected, two more welds made by that welder have to be radiographed, similar to what is required under B31.3. Visual examination of accessible surfaces is required for all other piping

B31.9, *Building Services Piping*, requires no nondestructive examination. Visual examination of accessible surfaces is required.

B31.3, *Process Piping*, is different. It has Fluid Service Categories that specify the extent of nondestructive examination that is required. Those Categories are:

- **Normal** - 5% random radiography of butt welds.
- **Category M** – (Toxic Fluids) 20% random radiography of butt welds.
- **High Pressure** – (over Class 2500 Flange rating) 100% radiography of butt and branch connections.
- **Category D** – (low pressure and temperature, noncombustible fluids) Visual examination only.
- **High Purity – (**Pharmaceutical, Food and Beverage, Chip manufacturing). Visual only, but examination with a borescope is common.
- **Severe Cyclic Condition** – (Stress changes exceed 80% of the allowable stress and the system will see over 7000 thermal cycles) 100% radiography of all butt welds and branch connections.

Normal Fluid service is the default Fluid Service Category. The owner or the engineer must specify where any other Fluid Service Category is applicable before the special rules for those Categories apply.

B31.3 Normal Fluid Service is the riskiest for contractors to work with because it requires 5% random radiographic or ultrasonic examination of the welds made by each welder on a lot basis. The risky part is that if a weld is rejected, you have to examine 2 more welds made by that welder in that lot. If one of those is bad, you have to examine 2 more welds made by that welder in that lot. If one of those is bad, you have to examine all of the welds made by that welder in that lot. While 5% random examination does not look that risky, the skill and ability of your welders to make acceptable welds will dictate how many welds you will have to examine in the long run. It is crucial that you have your system for identifying lots, tracking the number of welds in each lot, ensuring that welds made by each welder who welded in each lot got examined and that two more welds for each failed examination are examined. This system has to be up and running at the very beginning of the work and tracked faithfully until the project is complete since it is easy for the owner's inspectors to find discrepancies, and once the owner's inspectors think you are not following the code, it's a downhill slide. PFI[3] Standard ES-48, *Random Examinations*, provides good guidance on selection of lots and provides other sage advice on staying ahead of the owner on random examinations. Both B31.3 and PFI ES-48 note that defining a "lot" is the contractor's responsibility unless such is specified in the engineering specification. Smart contractors will present their random examination program to the owner and the Engineer before the first weld is made.

Nondestructive Examination Acceptance Criteria

Each B31 Code Section has its own acceptance criteria for welds. B31.9, *Building Services Piping*, allows more reinforcement and undercut than B31.1 does. In fact, for B31.1 service over 750°F, welds have to be ground nearly flush. Smart contractors ensure that welds do not exceed the maximum reinforcement and undercut limits and that there is no lack of fusion, slag, porosity or cracks on accessible surfaces. Fillet welds, including reinforcing fillets on outlet connections, should be

measured for size. When a customer inspector finds weld flaws that are obvious, that only prompts him to look more closely, initiating a downhill slide.

Radiographic and Ultrasonic Examinations

Acceptance criteria for radiographs are also different in different B31 Sections.

[3] See https://www.pfi-institute.org/

B31.1 does not allow any cracks, incomplete fusion or incomplete penetration. Slag, porosity and porosity are more limited than other B31 Sections permit. This was written when backing rings were industry practice. A properly installed backing ring always results in full penetration.

B31.5 refers to B31.3 Normal Fluid Service acceptance criteria when 5% random examination is imposed for Groups A3 and B3 (flammable) refrigerants. Interestingly, if radiographic or ultrasonic examination is imposed by contract, the only acceptance criteria are no lack of fusion and the length of incomplete penetration may not exceed 1-1/2 inches around the circumference.

B31.3 acceptance criteria depend on the Fluid Service Category:

- Normal Fluid Service: No cracks and no incomplete fusion are permitted. Incomplete penetration up to 1-1/2 inches long in any 6 inches of weld length, some slag and some porosity are permitted
- Category M Fluid Service: Same as Normal Fluid Service
- High Pressure Fluid Service: Tight limits on reinforcement both OD and ID, no undercut permitted (either OD or ID), and there is a surface roughness limitation of 500 micro-inches. No incomplete penetration is permitted.
- Severe Cyclic Fluid Service: Same as High Pressure Fluid Service.
- High-purity Service: No incomplete penetration is permitted. The level of discoloration of the root will usually be limited. Examination by borescope is required.

Customer Imposed Examinations

Customer specifications frequently impose nondestructive examinations that exceed Code requirements. When they do, Contractors need to read that part of the specifications carefully. All the B31 Code Sections[4] have paragraphs that specify the following:

> "The degree of examination and the acceptance standards beyond the requirements of this Code shall be a matter of prior agreement between the manufacturer, fabricator or erector and the Owner."

The reasons for these words:

- It costs more to make welds that are radiographic quality than it does for welds that will not be radiographed. Welders will pay more attention to the details when they know the weld will be examined more closely, and this takes more time which costs more.
- It is unfair to the welder, his supervisor and the contractor to be expected to make welds that satisfy certain acceptance criteria using examinations to which the production welds were not subjected.
- The only way to make welds that satisfy radiographic or ultrasonic acceptance criteria is to radiograph or ultrasonically examine those welds, find the flaws, make the appropriate repairs and reexamine the welds.

When examinations that exceed code requirements are imposed by the contract, three things have to be specified by the Owner:

- The method of examination (RT, UT, etc.)

[4] Paragraph 341.3 in B31.3, Paragraph 536.2 in B31.5 and paragraph 936.5 in B31.9. Similar paragraphs are found in the ASME Boiler Code Sections and in AWS D1.1 through D1.8.

- The extent (100% of all welds, 5% random, one spot radiograph on one of every 5 welds, etc.)
- The acceptance criteria (e.g., incomplete penetration is rejectable, etc.)

While the owner has the right to repeat any examinations and to inspect the piping using examination methods specified in the engineering design or the applicable B31 Code Section, the owner is not entitled to perform examinations or inspections that were not part of that Code Section or the contract. Clauses in contracts that allow the owner to examine welds using any method he chooses at any time[5], and that the contractor will be responsible for making repairs at his cost is known as a "death clause." Contractors should always take exception to death clauses. Alternatively, contractors should clarify in their bids that the cost of repairing welds that are examined using the methods or acceptance criteria not specified in the Code or contract shall be in accordance with the extra work terms and conditions of the contract.

This also extends to visual examination. The codes specify direct visual examination, so if the owner uses a borescope or video camera to examine the internal surfaces of welds that are not accessible for direct visual examination, that is outside the scope of the Code. ASME Section V makes a distinction between direct visual examination and remote visual examination, and remote visual has to be imposed by code or by contract to be applicable.

If a customer shows up in your trailer with radiographs of some welds that were not required by Code or by contract to be radiographed and has rejected them and demands that they be repaired, do not allow the project manager to make the repairs because doing so establishes a precedent. Once that precedent is established, that opens the door for the customer to repeat the process and the demand more repairs over and over. The decision about what to do if this happens is a senior management decision, not a project manager decision.

If you subcontract nondestructive examination services, the Contractor is still responsible for being sure that radiographs are acceptable. This applies even if radiographer works for the Owner and it extends to film quality (i.e., the radiograph has to be made in such a manner that very small indications can be seen)

- The film needs to be adequately exposed (if you hold it up to fluorescent lights in the office, you should not be able to see anything except identification marks)
- It needs to be adequately sensitive (the 4t hole should be visible on the penetrameter image.)

If a contractor subcontracts fabrication services to another organization, any contractual requirements that you are subject to should flow down to your subcontractors, and that should be in writing.

Pressure Testing

All the B31 code sections require that completed piping be tested for leaks. The standard test is hydrostatic testing at 1-1/2 times the system design pressure for a minimum of 10 minutes. Once that is completed, the pressure may be reduced to not less than the system design pressure so that the system

[5] From a large school district specification for hydronic piping: "Welding performed under these specifications shall be subject to special tests and inspections by the Owner or his agent, including rigid Ultra Sonic Testing (UT) and radiographic inspection at random. . . ." This is a potential death clause.

can be safely walked down and checked for leaks. Testing can be done on portions of completed systems when convenient.

Leak testing may also be done using pneumatic testing with air or other gases. The test pressure is 1.1 times the design pressure. Pneumatic testing is dangerous when compared to hydrostatic testing since gasses are compressible, so when they are pressurized, they store energy. If failure occurs, it can be catastrophic. ASME *Postconstruction Code* PCC-2, Part 5 has a section that allows you to calculate energy stored in a system and express that energy in pounds of TNT. It also specifies how to determine the safe standoff distance based on that calculation. The American Society of Safety Professionals publishes ASSP A10.35, *Safety Requirements for Pressure Testing of Steel and Copper Piping Systems* which specifies good practices when doing pressure testing.

When testing piping systems made from carbon or low alloy steel, the possibility of brittle failure needs to be considered since steel gets brittle when it gets cold. Piping with a wall thickness less than 1 inch is unlikely to fail during hydrostatic testing since the lowest temperature that water would ever be at is 32°F. The risk of brittle failure should be evaluated in more detail for thicker materials or when pneumatic testing.

While hydrostatic testing is usually the end of the installation process for piping, leaving residual water in a piping system for more than a week has the potential of initiating corrosion that may not stop even after the piping system is put in service. This can happen when the pipe was made using electric resistance welding (ERW) and when the water is bioactive (e.g., well water). Both can lead to localized corrosion which leads to pitting attack which leads to leaks. Water used for hydrostatic testing should be chemically treated to kill any bacteria to avoid microbiologically induced corrosion. If the system will not be put in service within a week of performing hydrostatic testing and it cannot be completely drained and dried, the contractor should use water to which corrosion inhibitors have been added. Alternatively, vapor phase corrosion inhibitors[6] can be placed in the piping and all open ends sealed off until the system can be put in service.

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[6] See Coretc at https://www.cortecvci.com/