OREGON'S FIRST ASTM A1010 BRIDGE AND RISK MANAGEMENT

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BIOGRAPHY

Hormoz Seradj is a Steel Bridge Standards Engineer with the Oregon Department of Transportation in the Oregon Department of Transportation Bridge Engineering Section. He has twenty years with the bridge engineering section and more than eleven years overseas experience in structural design and construction. He has an MS in civil engineering from the University of Oklahoma and BS in civil engineering from the University of Science and Technology in Tehran, Iran. Hormoz holds professional engineering licenses in Oregon, Oklahoma and Idaho. He designed the first high performance steel box girder bridge in the Nation.

Hormoz is a member of two AASHTO Technical Subcommittees for Structural Steel Design (T-14) and Bearings and Expansion Devices (T-2) of the AASHTO Subcommittee on Bridges and Structures. He also is a panel member of many NCHRP projects.

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SUMMARY

The composition of ASTM A 1010 includes over 11 percent chromium making this steel more resistant to corrosion than conventional weathering steel and all grades of high performance steel. The Oregon Department of Transportation decided to go ahead with a trial project including design and fabrication of the first public steel plate girder bridge utilizing ASTM A 1010.

Steel production and plate girders fabrication did not meet the project schedule. This paper presents project development process and steps that were taken to minimize impact to traveling public.

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BACKGROUND

Corrosion of steel bridges has been an ongoing problem that requires significant cost for maintenance and replacement. This problem is more pronounced in areas with coastal weather conditions such as in the State of Oregon.

The composition of ASTM A1010 Steel includes over 11 percent chromium, making this steel more resistant to corrosion than conventional weathering steels and all Grades of high performance steel. The Oregon Department of Transportation became interested in ASTM A1010 for its possible use in the construction of steel bridges. Furthermore, the State of Washington expressed an interest in cooperating in an investigation and trial use of this steel when constructing bridges that are known to have a high risk for corrosion.

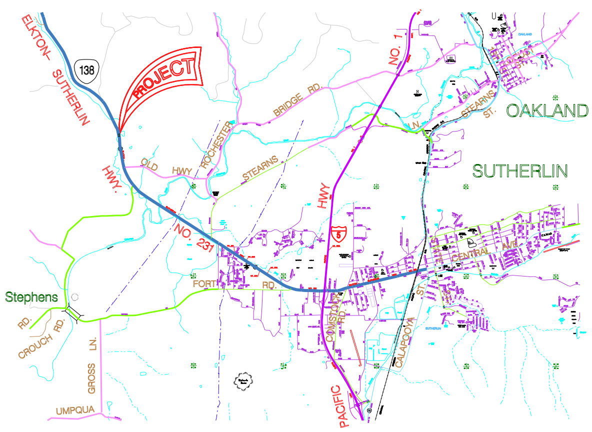

Figure 1. Location of Dodge Creek Bridge at MP 21.15 of Elkton-Sutherlin HWY

Figure 2. Section losses of Ross Island Bridge in Portland, Oregon

Steel is a very efficient construction material. However, its tendency to corrode potentially resulting in a high life cycle cost therefore has lost opportunities for consideration by some engineers and owners. One factor that increases maintenance cost is the need to recoat steel members during the designed life of the bridge. Steel bridges on the Oregon coast require a significant portion of the State's bridge Preservation budget because they must frequently painted. In addition some of the older inland bridges in Oregon sustain corrosion loss before preservation work can be scheduled, due to lack of funding. The Ross Island Bridge in Portland, Oregon, (Fig. 2) is a good example of section loss in a steel bridge due to corrosion.

Therefore, changing the chemical composition of the steel to create a more corrosion resistant material that does not require painting is desirable. Weathering steel has been helpful in reducing the corrosion rate; however, it cannot be used in many harsh corrosive environments.

In the 1990's, ArcelorMittal USA made Duracorr® steel, ASTM A1010, available in the United States. However, it is mainly used in industrial applications as thin plates and occasionally used in plates with higher thickness. The first bridge application of Duracorr® Steel was in a multi-cell box system bridge construction with a plate thickness of 0.16-inch in the Fair View Road of Colusa County in the state of California. This is a two span multi-cell box system bridge using uncoated ASTM A1010 steel.

The Federal Highway Administration recommends that weathering steel be used with caution for low water crossing with ten feet or less over stagnant sheltered water and eight feet or less over moving water (FHWA 1989). While the Fair View Road Bridge has about one foot of clearance between the soffit of the multi-cell box system and the channel stream.

The Oregon Department of Transportation conducted research on the corrosion performance, weldability and applicability of A1010 steel for highway applications. The State of Oregon's studies concluded that a one hundred foot span is the upper limit for thin plates and multi-cell box systems. The State of Oregon's fabricators were not interested in purchasing a sufficiently long press break because of its high price, limited use and competition with other alternate options used in very short span bridges. Another concern was the inability to directly inspect inside of the relatively small box girders used to make efficient use of small gage sheet steel.

The Oregon Department of Transportation investigated a broader use of Duracorr for bridges spanning more than 100 feet. ASTM recognizes the maximum thickness of A1010 steel to be one inch. A key need from the steel mills is an ASTM A1010 plate that is thicker than one-inch that meets ASTM A709 Gr. 50 requirements for design and construction of steel girder bridges.

PREQUALIFICTION STUDY

ASTM A1010 was an unknown material to Oregon Department of Transportation therefore there was a need to learn about the mechanical properties of the material. Literature reviews indicated there was no steel girder that has been fabricated utilizing ASTM A1010 for highway bridges.

The Oregon Department of Transportation also found that there is no prequalified welding procedure in AWS D1.5 for ASTM A1010. ArcelorMittal, the steel producer of Duracorr®, has investigated weldability and the welding procedure for one-inch plate thickness of ASTM A1010 steel. Their study is based on an interpass temperature boundaries of 210 °F to 225 °F with a range of heat input from 25 kJ/in to70 kJ/in. The State of Oregon's steel bridge fabricators felt that this limiting heat interpass temperature significantly impacts the fabrication cost of steel girders. The cost of the fabricated girders was believed to be optimized if the interpass temperature was allowed to be more than 225 °F. Therefore further study with different welding parameters had to be conducted.

ACTION PLAN

ArcelorMittal had an extensive testing program on ASTM A1010; therefore it was assumed further research on the base metal was not needed. The following investigations were performed:

- Groove weld (Submerged Arc Welding process)
- Fillet weld single and double pass (Submerged Arc and FLUX Core Arc Welding)
- Accelerated Corrosion Test
- Machinability of ASTM A1010

It was decided to first duplicate the weld prequalification tests done by ISG and to evaluate the outcomes. ISG's prequalification tests were based on AWS D1.6, so confirmation to AWS D1.5 was necessary. The investigation could be continued only after the weld sample could pass all AWS D1.5 requirements. The welding parameters for full penetration groove weld were set to 450 Amps, 34 Volts, 17 inch/minute travel and 54 kJ/in heat input.

ArcelorMittal recommends using Lincoln Blue Max ER309L, 3/32 inch diameter electrode for Submerged Arc Welding and Lincoln Blue Max 2000 Flux for fillet welding. ER309L has more than 22% Cr and more than 12% Ni. This consumable is expensive and does not require pre or post-heating. Another Lincoln Electric consumable that can be used with ASTM A1010 is ER410NiMo, a soft martensitic electrode with 12% Cr and 4.5% Ni. ER410 is a less expensive consumable than ER309L and has a recommended pre heating of 300-480 °F. Lincoln Electric specifies that it also requires 1373 °F preferred post-heating after cooling slowly to room temperature. This process also may result in an increase in fabrication cost and therefore is not recommended by the mill.

ArcelorMittal reported encouraging results after extensive testing of ASTM A1010. These tests included important materials properties, as well as Charpy V-notch Impact energy at different temperatures.

Based on test report 200-5 "Application Qualification Testing of Bethlehem Steel DURACORR Stainless Steel Base Plate Material Using Nelson Mild Steel and Stainless Steel 18-8 Studs" and the ArcelorMittal report on the installation of Nelson Studs on Duracorr, welded Nelson stud on Duracorr steel meets AWS D1.5 Bridge Welding Code requirements.

LESSON LEARNED FROM FIRST TEST

The AASHTO LRFD Bridge Design Specifications and Bridge Welding Code AASHTO/AWD D1.5 do not require Charpy V-notch tests from the heat affected zone of a welded steel member. However, it was felt that there is a need to check toughness of the heat affected zone of the ASTM A1010 since there was no prequalified weld procedure available for fabrication of ASTM A1010 girder bridges. All Charpy V-notch test results in this paper are from the heat affected zone of welded samples.

The first submerged arc welding test was completed using welding parameters for a full penetration weld at an interpass temperature of 225 °F which is specified in ArcelorMittal's report with no preheating. Test results from the first test samples confirmed the mill's report and supported increasing the interpass temperature to the maximum allowed in the AWS D1.5 for production purposes.

A significant amount of time was required in order to cool the specimens to a 225 °F interpass temperature. To shorten the cooling time a high pressure hose was used to blow air under the weld sample. It took almost six hours to complete 26 inches of butt weld on a one-inch-thick plate. During this test the sample plate was distorted and the distortion resulted in breaking the tack welds and the plate separated from its support (Fig. 3 a). To continue the weld test, the lifted part of the test sample was restrained. This observation raised the issue of distortion levels, residual stress and the need to perform a comparison with conventional steel bridge fabrication. It was decided to examine and measure the distortion level of a carbon steel and ASTM A1010. It was determined that distortion using the ER309L consumable is much greater than carbon steel consumable. Figure 3b shows distortion of carbon steel (CS-2) and ASTM A1010 steel (SS-2).

Figure 3. (a) Angular distortions (b) Carbon steel and stainless steel distortion

The Charpy V-notch requirement for less than 2-inch-thick steel plate in the AASHTO LRFD Bridge Design Specifications for steel grades 36 and 50 for a fracture-critical member in zone 2 (40 °F) is 25 ft-lbs. Similarly for HPS 50W, the Charpy V-notch requirement for less than 4-inch-thick steel plate for a fracture critical member in zone 2 (10 °F) is 30 ft-lbs. Two specimens of A1010 steel were tested at 40 °F. The test results were 71 ft-lbs and 76 ft-lbs.

ADDITIONAL SET OF TESTS

The reported test results met all requirements of AWS D1.5 and indicated that there was room to increase the weld interpass temperature. The outcome of the test was encouraging enough that it was decided to run additional tests with 300 °F, 400 °F and 450 °F interpass temperatures (Fig. 4).

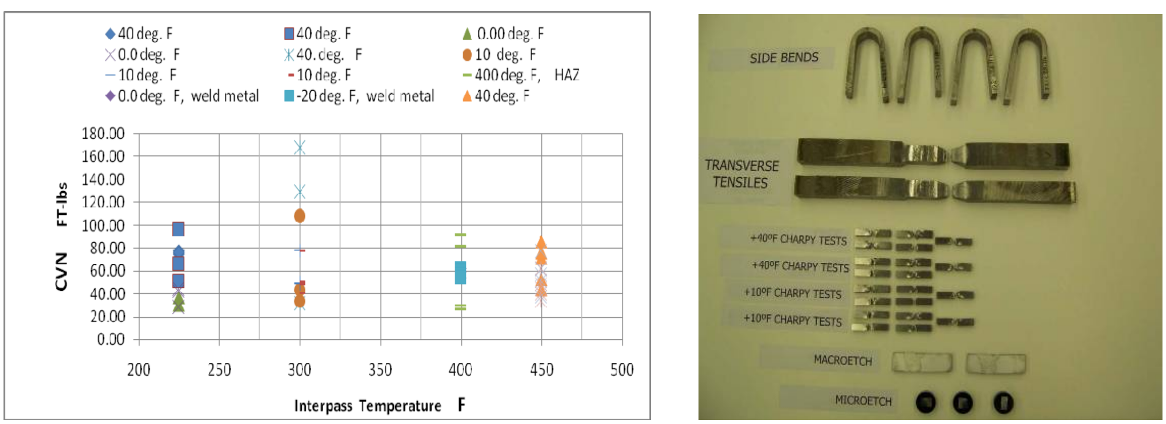

Figure 4. (a) Charpy V-Notch Impacts Test Results (b) test samples of welding porcess

The fabricator reported that the transverse tensile samples exhibited a separation within the fracture zone not found in the carbon steel tensile samples. This indication is shown in Fig. 5 and seemed like a lamination defect. The fabricator inspected all transverse tensile samples with straight beam ultrasonic testing and reported that no lamellar indication was observed.

Figure 5. Transverse Tensile Test, no lamellar indication was observed.

MACHINABILITY OF ASTM A1010

A Cincinnati Bickford drill machine was used to drill holes in 1-inch thick ASTM A1010 and A572 Grade 50 steel. The fabricator drilled 3 holes with the same feed and speed on each sample plate and reported no abnormal wear on the drill bit or on the quality of the holes.

A Do-All commercial band saw was used to cut samples of 1-inch thick Duracorr and ASTM A572 Grade 50 steel. The fabricator reported ASTM A1010 is tougher than A572 Grade 50, but without any abnormal wear of the saw blade.

ACCELERATED CORROSION TEST

The testing plan included an accelerated corrosion test for simulating coastal service conditions. This test was performed in the research section of the Oregon Department of Transportation. Weathering steel and high performance steel were used in this study to have a basis for performance comparison between these steels and ASTM A1010. Test samples were exposed to three different environments, fresh water plus drying, fresh water and salt water plus drying, and an aggressive condition of salt water and high humidity. Crevice corrosion was investigated by attaching rubber stoppers to selected specimens which were held in place with O-rings. Fig. 6 shows the test set up for different environments. Performance of test samples after two years are shown in Fig. 7.

All specimens (A1010, A588 and HPS 70W) were 1”x1.5”x2.5” plates and were ground smooth to a roughness of 0.0005 inches. The specimens were conditioned by being sprayed with distilled water twice each week for 6 weeks prior to exposing them to the test environmental conditions.

Figure 6. Test setup. Photo on the left shows the samples hanging in basins (two left) for fresh water spraying and the fan on the top for drying and similarly the two right basins for fresh water and salt water plus drying. Photo on the right shows the salt spray-only samples inside the covered container.

The Federal Highway Administration found in publication number: FHWA-HRT-11-061 in July 2011 that "Its corrosion resistance makes ASTM A1010 capable of lasting in structures for long periods of time—125 years, as considered in this study—without the need for initial painting or maintenance (i.e., repainting). Accordingly, the economic benefit of ASTM A1010 is gauged on its lower life-cycle-cost compared to that of a conventional painted bridge steel." (2)

TEST RESULT

Interpass temperatures ranging from 225 °F to the maximum production interpass temperature of 450 °F were investigated. The heat input for the submerged arc welding process was set at 55kJ.

Average Charpy V-notch impact results from heat affected zone for test samples with 225 °F, 300 °F, 400 °F and 450 °F interpass temperatures exceeded AASHTO LRFD Bridge Design Specifications requirements for base materials. Side bend tests were performed according to AWS D1.5 requirements. No cracks were observed. All test samples surpassed the standard requirement set for tensile strength except for one sample at 300 °F interpass temperature. However, it passed when the test was repeated. Macro and Micro metallurgical samples indicated good fusion and grain structures.

The angular distortion that resulted from SAW in ASTM A1010 is much greater than distortion resulting from SAW in ASTM A709 Grade 50. The ASTM A1010 distortion is almost twice the ASTM A709 Grade 50. The distortion of ASTM A1010 can be controlled by proper welding procedures. Figure 3b shows control of distortion for an ASTM A1010 sample (SS1) and Carbon Steel (CS1)

Four ASTM A1010 tee welded samples (fillet weld, single and two pass) were made using an automatic submerged arc and semi-automatic flux core welding process. All test samples were cut in 1 inch long sections per AWS D1.5 and stressed to failure. All of the samples had ductile failure and fractured in the weld and the fracture path was through the weld metal as expected.

A Cincinnati Bickford drill machine was used to drill holes on 1" thick ASTM A1010 and A572 Grade 50 steel. The fabricator drilled 3 holes with the same feed and speed on each sample plate and reported no abnormal wear on the drill bit and there was no difference in the quality of the holes.

A Do-All commercial bandsaw was used to cut samples of 1" thick ASTM A1010 and ASTM A572 steel Grade 50. The fabricator reported ASTM A1010 is tougher than A572 Grade 50, but there was no abnormal wear of the saw blade.

First ASTM A1010 Bridge

The encouraging test results convinced the Oregon Department Transportation to go ahead with a trial project including design and fabrication of the first public ASTM A1010 steel plate girder bridge. FHWA supported Oregon Department of Transportation's proposal by awarding an IBRD grant to cover the extra cost for design and fabrication of the corrosion resistant steel plate girders.

One of the concerns was the possibility of unforeseen situations that may impact the design and/or fabrication of the girders. Generally unforeseen issues in fabrication will be more costly to the Owner if they result in delays to the project or cause addition traffic delays. In order to mitigate the risk of delays due to unknowns with the new material, Oregon Department of Transportation elected to use a prepurchase contract for steel supply, fabrication and storage of the finished girders. Oregon's general contractors do not generally support prepurchasing of major project materials because they feel these types of contracts will cause them to lose construction control of the fabrication and delivery schedule. However, in this case the Oregon AGC representatives recognized the benefits of having ODOT work directly with the Fabricator to work out new welding procedures and fabrication processes that might be needed with the trail use of A1010. The Oregon Department of Transportation was interested in gaining some experience with prepurchasing steel girders and so elected to use that contracting method for the trial project. Prepurchasing steel girders is done through a contract directly between the owner and a steel fabricator. The general contractor is not involved in this contract, but there are some provisions included in the prepurchase contract to set limits on the timing of delivery of the girders when the substructure is ready for girder erection.

ASTM limits maximum A1010 plate thickness to 1-inch but the trial design for the Dodge Creek Bridge requires 1¾- inch-thick plates. It was anticipated that the steel mill will need to do some development work on processes for rolling the A1010 plate since the needed thickness is beyond the allowable thicknesses in the ASTM specifications.

DESIGN PARAMETERS

The Dodge Creek trial bridge was designed in accordance with the 2010 edition of the AASHTO LRFD Design Specifications with allowance of 25 pound per square foot for future wearing surface. The structural steel was designed to conforming to the requirements of HPS 50W. The modulus of elasticity and the thermal coefficient of expansion were assumed to be 29000 ksi and 6.5×10^{-6} in./in./°F, respectively.

Because A1010 was a new material, the Construction Specifications required extra testing requirements to ensure the material met the requirements of ASTM A709 Grade HPS 50W properties. The extra testing requirements were as follows:

(a) Fresh water exposure 4/day.

(b) Fresh water exposure 4/day and salt spray 2/ week.

(c) Sealed container with water reservoir and salt spray 2/week.

Figure 7. Samples after 2 years of exposure.

- Check samples from both ends of each plate are required. Each check sample shall meet the following:

  - Charpy V-notch fracture toughness of 30 ft-lb at 10°F.
  - Meet yield and tensile strength of the HPS 50W.
  - Young's Modulus of 29000 ksi.
  - The Oregon Department of Transportation's weldability study was limited to 1-inch-thick plate but the Project Special Provision required weld procedure prequalification of full penetration weld for ½" and 1¾" plate thicknesses. This requirement is covering a broad base for examination of the base metal for full penetration weld procedure and quality. This requirement is consistent with AWS D1.5-96 which was established for new material and requires weld procedure prequalification for ¾ inch thick plate and the maximum plate thickness.

FABRICATION

ASTM A1010 steel is a stainless steel with minimum of 11 percent of chromium and therefore it has to be plasma cut rather than oxyfuel cut. The Fabricator decided to subcontract stripping plates to other shops, which have plasma cutters with water tables.   There were not many other steel shops with fully equipped plasma cutting equipment. The water table absorbs the smoke generated from plasma cutting and reduces the health concern (Figure 8).

The Fabricator first received plates less than 1½" thick. Check samples were taken at the fabrication plant from both ends of plates.   The test results met the specification requirements except for two plates that were returned to the steel mill. The State of Oregon decided to add a metallurgist to the team to assist in determining the cause of the failure.

Figure 8. plasma cutter with water table.

Figure 9. Crack observed after plasma cutting in 1¾" plate.

The Fabricator subcontracted 1½" and 1¾" thick plates to two different steel shops with plasma cutting capability to strip bottom flange plates. The Fabricator observed cracks in stripped plates from one of the 1¾-inch thick rolled plates (Figure 9). The Oregon Department of Transportation, the Fabricator and the Steel Mill's representative who was the ASTM A1010 project manager had a meeting to discuss the material properties of the steel plates and find a resolution to failing test results. It was decided that the steel mill's expert and Oregon Department of Transportation's metallurgist would study the cause of observed cracks in one of the rolled 1¾-inch thick plates. Figure 10 shows Charpy test results for all plates.

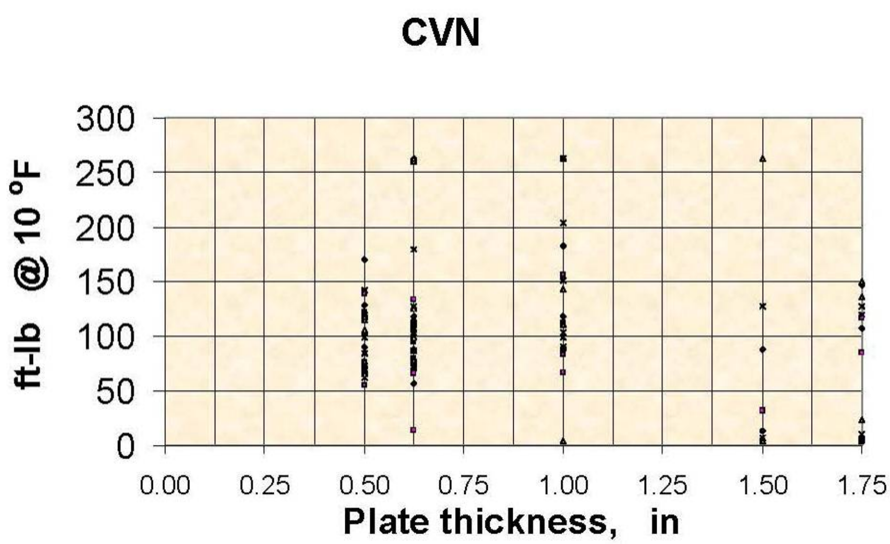

Figure 10. Charpy test result of all plates

It was decided to replace all bottom flange plates with new rolled plate using an improved process developed and tested by the mill. The steel mill determined causes that could contribute to cracking 1¾-inch-thick plate on plasma cut edges and to mill rolled new plates. The steel mill reported very good test results from the new processing that indicating steel properties exceeded the construction specifications. Charpy V-notch test results for 1", 1½" and 1¾" of the replaced rolled plate are shown in Figure 11. The acceptable Charpy V-notch test is 30 ft-lb at 10°F. No cracking was found on the plasma cut edges of the new rolled plates.

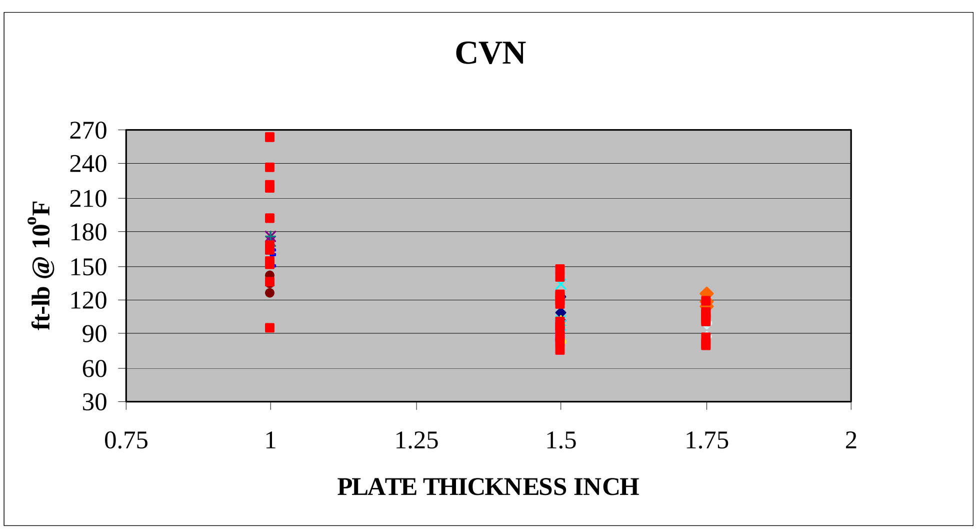

Figure 11. Charpy test result of new 1", 1½" and 1¾" rolled plate with improved processing

PROJECT SELECTION AND RISK MANAGEMENT

Fabricating main load carrying structural members with a new material for the first time requires thorough investigation and evaluation. This investigation is not limited to material testing and assuring the suitability of the material for the project. The lessons learned by the Oregon Department of Transportation for Dodge Creek Bridge project were as follows:

- ArcelorMittal is currently the only active producer of ASTM A1010 therefore project schedules are dependent on the steel mill and their production schedule. One of the risks that an owner has to consider is possible delays in steel availability and production.

- Production of the A1010 steel plate more than 1” is new territory for steel mills and producing the steel more than 1” thick may require different processing. Changing the processing and training the operators can cause delays and there is possibility that steel mills find it is not as efficient as desirable.

- The weld procedures for ASTM A1010 are new for the majority of the fabricators in the State of Oregon and there is a learning curve for the fabricator. This may delay projects in two ways:

    - Training of welders.

    - Having enough steel plate for training.

- The Oregon Department of Transportation’s weldability study was limited to 1” thick plate but the Project Special Provision requires the contractor to provide weld procedure qualifications (WPS) for welding of ½” and 1¾” plate thicknesses for the Engineer’s approval. This requirement covers a broader range of the base metal for full penetration weld testing. This requirement is consistent with AWS D1.5-96 which was established for new material and requires weld procedure qualification for ¾ inch thick plate and maximum plate thickness. This requirement may cause complexity in the development of weld procedures and requires extra time.

- There might be a need to redesign the girders if the plate does not meet the specification requirements or the approved weld procedure. Therefore, there might be a need to change the girder plate dimensions and potentially a need to order replacement plates from steel mill.

- One important key for success in this project was team work. The Oregon Department of Transportation had no knowledge which contractor will be awarded a contract to fabricate the steel girders and how the fabricator will react when facing an unforeseen situation involving a new material.

MITIGATION PLAN

To mitigate potential construction delays, which may result in an adverse affect on traveling public it was necessary to consider measures for assumed risks and unforeseen problems. But, an owner can not expect to resolve all problems in advance. An excellent working team is critical in overcoming unforeseen obstacles. It is essential from an asset management, service life, and construction time, and public perception standpoint to minimize construction delays. Oregon Department of Transportation took measures to ease difficulties when problem arose.

PREPURCHASING CONTRACT

The use of a prepurchasing contract is a good option because it may provide enough time to cover fabrication delays from unforeseen difficulties or at least reduce those delays. This type of contract may help owners in some cases by obligating funds at two different dates by separating the contract in two segments. The Prepurchasing Contract divides the contract document in two parts, as follows:

- The first part is limiting contract documents to the steel fabrication drawings, specifications, special provisions, storage and hauling girders to the project site. The Oregon steel bridge fabricators are interested in this type of contract because they have more control over their work and they appreciate dealing directly with the owner. Normally, the general contractor has no involvement. This contract can be awarded a few months prior to contracting the remaining portion of the construction project and gives the fabricator more lead time.

- The second part of the contract is for the remaining portion of the construction work to complete the project, including substructure construction and approach work. The second part is awarded a few months after the first part of the contract has been awarded. If there is a time lapse between these two contracts, communication between the two contractors takes place thru the Project Manager.

Also, this type of contracting facilitates direct communication between the Fabricator and the Owner's Engineer, which can result in time savings and less paper work.

PROJECT SELECTION

Project selection is important because construction delays affect the traveling public and can be a safety concern. Projects in higher traffic zones affect the traveling public more, so selecting a project in a location with lower average daily traffic is desirable.

It is logical to select a bridge when the Project Team decides to have a replacement bridge on a different highway alignment. The Oregon Department of Transportation chose the Dodge Creek Bridge on HWY 138 because it is one of two bridges in a bridge replacement project being constructed on a new alignment to avoid stage construction (Fig 12).

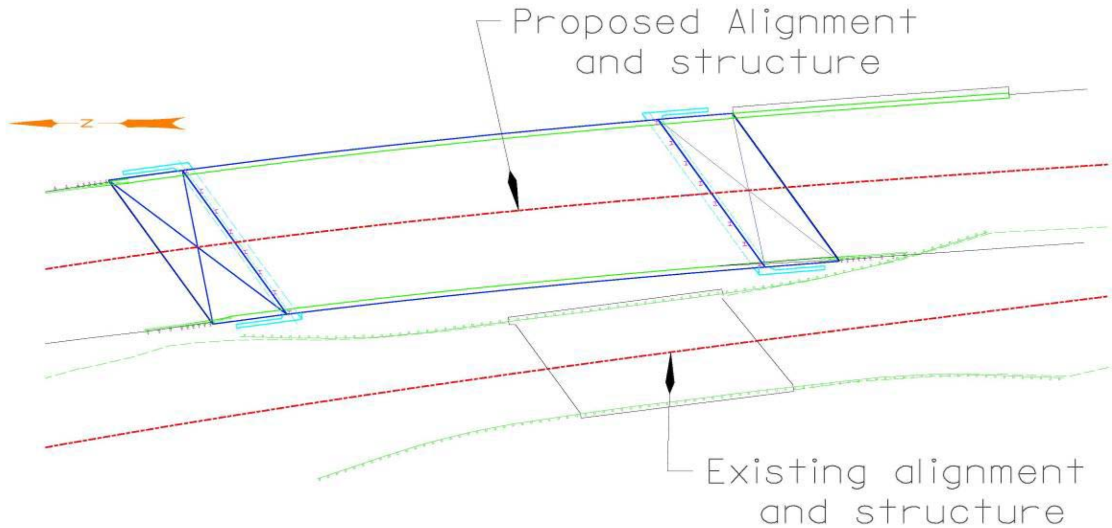

Figure 12. Existing and Proposed alignments and bridges.

SUMMARY AND CONCLUSIONS

The Oregon Department of Transportation had planned to use a unique option for reducing the impact to the traveling public while steel girders were fabricated of a new material and hauled to the project site. Everything did not go as it was planned and caused delays in the girder fabrication. The prepurchasing contract was not advertised far enough in advanced as it was planned, therefore the fabrication contractor did not have enough recovery time for unforeseen problems.

A few of the steel plates delivered to the fabricator did not meet the contract specification and were rejected. Rejected plates were hauled to the steel mill for replacement with plate meeting the contract specifications. Also, it was necessary to find out why the steel mechanical properties did not meet the contract specification requirements. It took several months to complete an independent report based on investigations done by the Oregon Department of Transpiration's hired metallurgist and ArcelorMittal.

When the Project faced problems, some non-productive communications caused some concern. The Oregon Department of Transportation, the contractor and the steel mill focused on the problems to find appropriate solutions. The Contractor and the steel mill did some excellent work to complete the project. The mill's willingness to resolve the problems and to provide support to the contractor and support to Oregon Department of Transportation's project was exceptional. ODOT was pleased to have such a cohesive and productive team work.

The impact to the traveling public and their safety during construction work is one of the major concerns on any project. Oregon Department of Transportation used all available options in project selection for the first public A1010 plate girder bridge. Even with all the effort expended on this project, the steel girders were not fabricated on time. However, impact to the traveling public was minimized. This success was the result of selecting a bridge which was constructed on new alignment, the use of prepurchasing, excellent cooperation between all parties involved, and some persistence in taking measures to fully implement a new steel production process.

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