


U.S. Department of Transportation
Federal Highway Administration

Steel Bridge Design Handbook

Structural Steel Bridge Shop Drawings

Publication No. FHWA-IF-12-052 - Vol. 3

November 2012

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16. Abstract

The preparation of shop drawings is a very specialized process with its own language and methods. The drawings and data for fabrication are developed from information presented on the contract drawings. These drawings contain the basic bridge geometry, pier and sub-structure locations and design, as well as the sizes of all material, weld and bolt sizes and the basic connection information. Fabrication, thus the shop drawings, must adhere to all the applicable specifications and the information on the contract plans. With this in mind, the detailers, shop drawing producers, must have experience, knowledge and ability to translate contract information into shop drawings. Steel bridge fabrication is a field unlike any others such as building construction, therefore most detailers who prepare steel bridge shop drawings specialize in bridges, and very few of them detail buildings or other steel structures. This document contains the history, present practices, and illustrations of the fundamentals of shop detail drawings for steel bridges, and is not intended to cover every type of bridge structure. The purpose is to familiarize engineers, detailers and other individuals involved with steel bridge fabrication on the preparation and use of shop detail drawings.

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Steel Bridge Design Handbook: Structural Steel Bridge Shop Drawings

Table of Contents

List of Figures

FOREWORD

It took an act of Congress to provide funding for the development of this comprehensive handbook in steel bridge design. This handbook covers a full range of topics and design examples to provide bridge engineers with the information needed to make knowledgeable decisions regarding the selection, design, fabrication, and construction of steel bridges. The handbook is based on the Fifth Edition, including the 2010 Interims, of the AASHTO LRFD Bridge Design Specifications. The hard work of the National Steel Bridge Alliance (NSBA) and prime consultant, HDR Engineering and their sub-consultants in producing this handbook is gratefully acknowledged. This is the culmination of seven years of effort beginning in 2005.

The new *Steel Bridge Design Handbook* is divided into several topics and design examples as follows:

- Bridge Steels and Their Properties
- Bridge Fabrication
- Steel Bridge Shop Drawings
- Structural Behavior
- Selecting the Right Bridge Type
- Stringer Bridges
- Loads and Combinations
- Structural Analysis
- Redundancy
- Limit States
- Design for Constructibility
- Design for Fatigue
- Bracing System Design
- Splice Design
- Bearings
- Substructure Design
- Deck Design
- Load Rating
- Corrosion Protection of Bridges
- Design Example: Three-span Continuous Straight I-Girder Bridge
- Design Example: Two-span Continuous Straight I-Girder Bridge
- Design Example: Two-span Continuous Straight Wide-Flange Beam Bridge
- Design Example: Three-span Continuous Straight Tub-Girder Bridge
- Design Example: Three-span Continuous Curved I-Girder Beam Bridge
- Design Example: Three-span Continuous Curved Tub-Girder Bridge

These topics and design examples are published separately for ease of use, and available for free download at the NSBA and FHWA websites: http://www.steelbridges.org, and http://www.fhwa.dot.gov/bridge, respectively.

The contributions and constructive review comments during the preparation of the handbook from many engineering processionals are very much appreciated. The readers are encouraged to submit ideas and suggestions for enhancements of future edition of the handbook to Myint Lwin at the following address: Federal Highway Administration, 1200 New Jersey Avenue, S.E., Washington, DC 20590.

M. Myint Lwin, Director
Office of Bridge Technology

1.0 INTRODUCTION

This document contains the history, present practices, and illustrations of the fundamentals of shop detail drawings for steel bridges, and is not intended to cover every type of bridge structure. The purpose is to familiarize engineers, detailers and other individuals involved with steel bridge fabrication on the preparation and use of shop detail drawings.

Over the years the fabrication of steel bridges has been totally dependent upon the shop drawings. They are used or referenced throughout the entire fabrication process, as well as for shipping and erection. In recent years, the shop drawing process has changed dramatically.

The preparation of shop drawings is a very specialized process with its own language and methods. The drawings and data for fabrication are developed from information presented on the contract drawings. These drawings contain the basic bridge geometry, pier and sub-structure locations and design, as well as the sizes of all material, weld and bolt sizes and the basic connection information. These are usually prepared by a consulting engineer for the owner.

Fabrication, thus the shop drawings, must adhere to all the applicable specifications and the information on the contract plans. With this in mind, the detailers, shop drawing producers, must have experience, knowledge and ability to translate contract information into shop drawings. Steel bridge fabrication is a field unlike any others such as building construction, therefore most detailers who prepare steel bridge shop drawings specialize in bridges, and very few of them detail buildings or other steel structures.

Most bridge fabricators contract their shop drawing production to independent detailing offices. There are a few fabricators that maintain their own in house detailing capabilities. Even these fabricators utilize outside sub-let offices for a significant amount of their shop drawings. Sub-let detailing offices must provide shop drawings that not only meet all the contract drawings information, the controlling specifications, but also must satisfy the unique requirements of the fabricator for which they are working.

The shop drawings are a significant part of fabrication and have a significant impact on the success of the project. The detailer's experience and ability to produce a timely and accurate set of shop detail drawings will influence the success or failure of the project. During the process of producing shop drawings there are almost always questions arising about the contract documents. These problems must be resolved in a timely manner and it is the detailer's responsibility to resolve these. The communication between detailer and owner or owner's representative is critical in order to complete the shop drawings efficiently and on time.

Another step in the process of shop drawing detailing cycle is the owner's review of the drawings, or "approval" process. Fabrication cannot begin without the owner's approval of the shop drawings. This can be a lengthy process, which delays and adds cost to the fabrication and construction cycle. The production and approval of shop drawings take up to half of the required time for the fabrication process, and therefore plays an important role in the timely completion of the entire project.

2.0 HISTORY

2.1 Origin

Shop drawings for steel bridges started over one hundred years ago. They were hand drawn in ink, usually on linen sheets, or by pencil on vellum. This was done in order to produce a clear blueprint, white lines on blue background, and to have high archival qualities. This method of detailing was used up until the 1950's.

2.2 Mid 1950's

Sometime in the mid-50's new copying equipment was introduced. These machines used an ammonia process which permitted the use of sepias or reproductions on translucent materials like mylar and vellum. This made a major impact on the time it took to produce a shop drawing. Masters or generic type drawings were used to create the picture and the detailer added the dimensions by hand. These originals were then printed using ammonia copying machines that produced a black or blue line on a white background.

2.3 Mid 1980's

In the mid-80's, CAD (computer aided drafting) software became available and evolved whereby in the mid- 90's, many detail drawings were made exclusively by software and CAD systems. The current process of digital printing permits multiple collated sets of almost any size. This, in conjunction with CAD eliminates the original hard copy drawings by replacing them with an electronic file.

3.0 SHOP DRAWING USAGE

3.1 Original Use

The original use of shop drawings was to give shop personnel detailed drawings of each member and to prepare other items such as material orders and erection plans. From these drawings full size templates would be made usually from cardboard or sometimes wood. Templates would then be used to make gusset plates, web stiffeners, connection angles, etc. by placing them on the material and marking the steel to burn and locate holes. Using the shop drawings, larger members were laid out by hand showing edges that were to be burned, and hole locations that were to be drilled or punched. Manual assembly of parts and main members was then done using shop drawings as a reference. Marking by hand stenciling was required in order to identify all pieces.

3.2 Current Use

The current use of drawings varies greatly, but also incorporates many of the items discussed in the original use. The uses that have changed are quite significant and must be recognized in order to understand how shop drawings are used now. Material orders are created by detailers, many of them automatically after basic contract data has been input into detailing software packages. Most fabricating shops now use CNC (computer numerically controlled) machines, to burn drill and punch parts such as gusset plates, web stiffeners, connection angles, etc. Templates are still used only by a small number of shops. The CNC machines are driven by machine code produced either from full size CAD shop drawings or by inputting data from shop drawings. Many large pieces such as web plates are now burned and marked by using CNC burning machines thus eliminating hand marking. Automated stenciling and bar coding systems are now being used to eliminate the tedious and time consuming process of piece marking. Three dimensional (3D), computer generated models are now assisting in the shipping and erection areas which allows much more precise predictions of shipping and erection loads. Today, shop drawings are not only used by the fabricator, but also by the owner. Shop drawings are used for approval of contract drawing interpretation, shop inspection, field reference and final records.

3.3 Future Use

As we examine the progress and automation the fabrication and detailing industry has made in the last decade, it becomes obvious that shop detail drawings as we have known them for the last 100 years will change even more drastically than they have in the last 10 years.

As more and more sophisticated computer-driven machines for burning, marking, drilling and measuring are developed and used, traditional fully detailed shop drawings will be virtually eliminated, since detail information in the form of electronic files will be forwarded to CNC equipment directly from the detailer.

In the future it is anticipated that much of the assembly work will be automated and manual assembly will be minimal.

Shop detail drawings in the future may be no more than expanded versions of the designer's contract plans, showing standard connections, basic dimensions, and location of members for field placement (Erection Placement Plans). Detailers and fabricators are already preparing the information for the CNC machines and several major bridges have been fabricated without the fabricators making any templates or any layouts on the steel. We have included a sample of what a set of shop drawings might look like in the future. (See Figure 15 thru Figure 25).

4.0 DRAWING PRODUCTION PROCESS

4.1 Manual Process

There are two basic methods to calculate data and produce shop drawings. The process may be completed manually or in any variation from manual to computer automated. During the manual process, which may still be used for the many simple type structures, data from the design contract drawings is used to accomplish the calculations using hand held calculators. Drawings for erection plans and shop details are then produced by hand or using some CAD software. All material orders are usually prepared manually along with checking of all calculations drawings and material orders.

4.2 Computer Generated Process

The use of the automated / computer generated process is accomplished by entering data from information shown on the design contract drawings into a software package that will execute all required calculations. All roadway definitions such as horizontal and vertical alignment along with roadway cross slope is input. Material size for plate girders and dead load deflection as shown on the design contract drawings is also input. The next step is checking and verifying all data input. Resolutions to any discrepancies between output and design contract drawings must be resolved before proceeding. This is accomplished through direct contact with the design engineer, which is preferred, or by transmitting an RFI (request for information) to the appropriate parties, usually including the design engineer (the owner if different) and the contractor.

Output from the software package may include material orders, data for CNC equipment and various types of shop drawings. Other output might be framing plans and calculation plans. Material data can be formatted so that it may be used to place material orders with the rolling mills. Output data for CNC may include web plate burning information, including all camber ordinates, length and width. Additional output may locate stiffeners and, with some additional input, holes can be located on the material using CNC marking. The role of the detailer has changed from just making drawings, to the production of data to run automated equipment.

Traditional shop drawings are produced using a CAD, computer aided drafting, system. The CAD system is used to detail main and secondary members such as diaphragms, cross frames, lateral bracing, etc. This is done interactively using appropriately developed menus and user developed mini-programs. The most popular CAD software is Auto Cad or Micro Station. It should be noted that no matter what system is used they become very customized and unique. Therefore, CAD files are not easily read by another user even though they both may be using the same software package.

For this reason sending native files for others to use is highly discouraged and some companies prohibit this to prevent misuse and avoid liabilities. In lieu of sending native CAD files, electronic generic secure files may be utilized. Most CAD files can be converted to either TIFF or PDF files which are raster type files and can be compared to a hard copy of the CAD file. Secure systems are available to prevent or record any notations or changes to these files. TIFF or

PDF are now being used quite effectively for review and approval of shop drawings. This process has dramatically expedited the approval review.

5.0 SHOP DRAWING TYPES AND REQUIREMENTS

5.1 Example Shop Drawings

5.1.1 Calculation Plans or Work Sheets "WS"

All bridge structures require geometric calculations. Since most bridges are on grade and have cross-slopes or super-elevations, calculations are required to determine sloping lengths of members, differences in elevation at all connections between members and the effect of camber on the fabricated shape of each component.

The outputs from these calculations are presented on drawings which are labeled "WS" (work sheet). These drawings may show horizontal control dimensions, developed lengths, differences in elevation, horizontal lengths of cross-frames or diaphragms and the angular relationship between members at their connection points. (See Figure 1)

Many of these drawings today are created by specialized software programs which have been developed by the individual detailing firms or fabricators' engineering offices. The information on these drawings and the accuracy of the calculations are the total responsibility of the fabricator or their detailer, and are not required to be checked by the approver. The approving engineer should spot check basic control information to insure the geometry is consistent with the basic control information presented on the contract plans.

5.1.2 Typical Details ("TD")

TD drawings are layouts of typical details for cross frame, lateral bracing and floor beam connections. These are basically working drawings for the detailer's use, and are not required for fabrication. These do not have to be reviewed as shop fabrication drawings. These drawings are for dimensional control, and to check fabrication and erection clearances. They may or may not show shop welding. These drawings are normally drawn to scale. (See Figure 2)

5.1.3 General Notes ("GN","G","N")

The general notes sheet is required for all bridge contracts. The contents of the general notes usually includes, but is not limited to, listing any publications including interims and special provisions used by the engineer in the design of the structure, applicable state publications, and welding codes. From these publications job specific information such as material types as well as grade and testing, fabrication and workmanship criteria, procedures for welding and testing, cleaning and painting requirements, and various standard details that are relevant to the structure are listed.

The paint scheme for some bridge structures is very complicated. When this is the case a separate sheet, usually prefixed with a "P", is used to adequately cover all the cleaning and painting requirements. Any details pertinent to painting are shown on this sheet. All cleaning and painting information, with the exception of a reference to the "P" sheet will be deleted from the general notes. (See Figure 3)

5.1.4 Camber and Web Splicing Drawings ("WC","C","BG")

Camber diagrams are used by the fabricator to burn the cambered shape into the girder web plates. The lengths on these diagrams will vary from the theoretical horizontal design dimensions since the dimensions shown have been adjusted for grade, geometric camber and the effects of dead-load deflections.

Usually the ends of the girder sections have been adjusted for grade and the rotation due to dead-load camber. On straight girders, the flange plate splicing diagrams may also be shown. Web to flange welding may or may not be shown on these drawings. Some fabricators refer to these as basic girder assembly drawings, "BG" sheets. (See Figure 4)

5.1.5 Flange Plate Curving & Splicing Diagram ("FS","FC","BG")

This type of drawing gives the shop the information required to burn the flange plates to a horizontally curved shape. Fabricators burn the flange plates to the required shape or heat curve when allowed by DOT limitations. All shops use heat to correct any differences between the theoretical curved shape as opposed to the actual fabricated shape, since heat from welding of the splices, and burning the plates may create shrinkage and distortion.

Any horizontal geometry can be accommodated either by cutting or heating to provide the shape. (See Figure 5)

5.1.6 Horizontal Curving Diagrams ("HC")

Most fabricators require a HC diagram which provides data sufficient to check the "girder sweep" and determine if any heat correcting is required. (See Figure 6)

5.1.7 Shop Assembly Diagrams ("SA" or "BD")

Shop Assembly diagrams or blocking diagrams are furnished to the fabricator by the detailer in order to give the fabricator the necessary dimensions in which to assemble the girder sections in such a manner as to achieve the correct cambered shape. The information furnished usually consists of vertical offsets from a baseline to each field splice, bearing point, and mid-span. In the case of a horizontally curved bridge, information would also include horizontal offsets to the same points.

Most fabricators will use this assembly information to set the correct location of field splices and then drill the holes in the girders using templates or use the actual splice plates as a template. This insures the correct fit of all holes at a field splice. The length of an assembly shall conform to requirements of the individual DOT. Some complex structures will require a full bridge assembly. (See Figure 7)

5.1.8 Standard Detail Drawings (“X”, “M”)

Most fabricators require a detail of each of individual assembly piece on separate drawings called “job standards”. Assembly pieces for girders will consist of stiffener details, splice plate details and any fitting piece that will be shipped either welded or bolted to a girder. The standard sheets for girders are usually called “X” sheets, and all assembly marks on these drawings are prefixed with an “X”. (See Figure 8 and & Figure 9)

The standard sheets for members other than girders are sometimes called “M” sheets and all assembly marks on these drawings are prefixed with an “M”. These can be details of cross frame gusset plates, connection plates and angles for members other than girders. (See Figure 11)

5.1.9 Girder or Stringer Details

The girder and stringer detail drawings show the fabricator all the pieces required to build the assembly. An elevation of the girder/stringer is shown with the individual piece marks called out and sections taken as needed to show dimensional positioning and welding of each component. Additional details are shown to further clarify hard to see areas. Also shown on the sheet is a bill of material itemizing all the pieces required to build the assembly. In most cases only one sheet is required to show all the information needed for assembly. (See Figure 10)

When more than one sheet is required, show the elevation on the first drawing along with sections and miscellaneous details. Any additional drawings should show the bill of material and any other information not able to fit on the first drawing.

5.1.10 Cross frame & Diaphragm Details (Numbered sheets)

Cross frame & Diaphragm details are prepared for the fabricators use. When preparing the drawings the detailer can combine a range of drops, usually +- 3/16, to minimize the number of assemblies. Special conditions for painting, when required, will usually be noted on the details.

When built-up cross frames, as apposed to knock-down, are used the shop can make a jig to aid in fabrication increasing shop efficiency. The jig can be adjusted to the exact dimensions on the cross frame details. This reduces the amount of setup time the shop has to do and reduces the chance of error. Built-up cross frames require less handing and their is usually only one piece to track for any given cross frame location. (See Figure 12 and Figure 13)

Knock-down cross frames contain several pieces at each cross frame location. Each piece requires a unique mark which both the Fabricator and Erector have to track. Due to having to track and erect more pieces knock-down cross frames are less efficient than built-up cross frames.

5.1.11 Erection Framing Plan ("E")

An erection drawing shows the Erector the location and orientation of all the shipping assemblies. Any special field requirements are noted and additional details are placed on the erection plan. (See Figure 14)

5.1.12 Field Bolt List ("E" or Numbered sheet)

The field bolt list is for use by the Erector. Connections to be made in the field are categorized in a table describing which the elements are to be bolted together. The quantity of bolts per each connection is giving along with the size and type of bolt required. A detail is shown for any connection that can not be adequately described.

Most fabricators require the field bolt list to be included on the Erection Framing Plans while others place it on a numbered detail drawing. (See Figure 14)

5.2 Special Conditions

5.2.1 Skewed Bearing Lines

Skewed bearing lines result in many additional requirements for drawings. Connections of end and interior cross frames/diaphragms must utilize either skewed or bent plates. Additional details of parts, bent plates, and sections or views shown on main members are needed. Layouts are required to provide detailed dimensions of cross frames/diaphragms connections. These layouts are used to detail connection plates, cross frames/diaphragms and main members, Skewed bearing lines, depending on severity of skew, can have a significant affect on rotation due to dead load deflection. These camber and deflection effects can be one of the most difficult aspects to understand and apply. Bridges are not static during construction and use. Due to the application of dead loads and live loads after the structure is fully assembled, the individual members do not react alone but in conjunction with each other. When loads are applied and deflection occurs, the skew results in rotation transversely across the structure in addition to longitude rotation. Due to the skew the main member webs rotate transversely. (This can be a concern when a structure has a severe skew and a deflection of significant magnitude is present.) This rotation is calculated by the detailer using geometric calculations, not a structural analysis. The detailer must address this in order to determine the position and shape the cross frames or diaphragms and connection plates will be at erection.

Once the detailer has determined the position of the web and shape of the cross frame, the engineer and owner should be notified so that a decision can be made on how to detail and fabricate the cross frame in order to achieve the best final results. Sometimes the end cross frame may have to be fabricated so that the diagonal members are left loose and field welded or with oversized or slotted holes, and then be torqued after all dead load deflection has occurred.

If the cross frames are detailed to fit in the final (loaded) position, then the girder webs will have to lean and twist in order for the end cross frames to fit during erection.

If the cross frames are detailed to fit in the cambered (no dead-load) position, then the girder webs may not be vertical in the final position and could cause problems with the bearings.

In any case, the girder webs will not be truly vertical in erected or final position. Therefore it will be up to the owner to determine what solution they prefer. The detailer should notify the erector by notes on the erection plan as to what condition will occur during erection of the bridge.

5.3 Staged Construction

Staged construction with partial transverse deck placement presents unique detailing and construction problems. The longitudinal deck construction joint may be located in a bay between main members or directly over one of the main members.

These two methods present different but similar problems of differential deflection between adjacent members. The secondary members between them cannot be finally installed until after all deflection occurs. Slotted holes may accommodate some cases where there are not significant differences in deflection. However, usually field drilling or field welding after deflection is the most successful solution. Oversize holes with bolting after deflection can also be a solution. Temporary struts loosely bolted between members should be used to control the bay width during deck pours. Cross frame or diaphragms should not be finally installed in the construction joint bay prior to deflection since excessive loads will be placed on these secondary members when the adjacent dead loads are placed. The detailer, if not directed on the contract drawings, must question through the general contractor, which procedure is to be used for these secondary members in the construction joint bay.

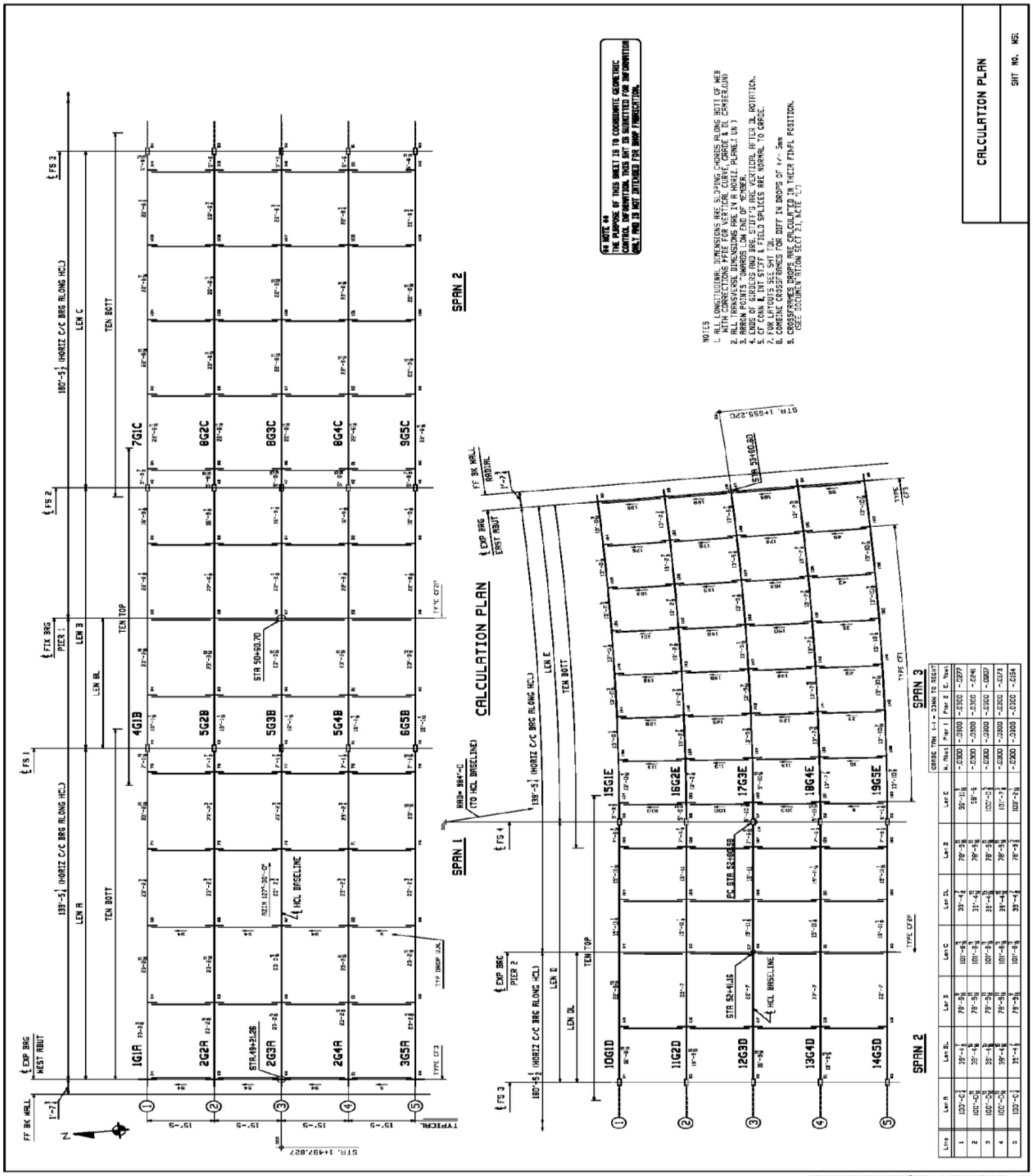

Figure 1 Example shop drawing showing the calculation plan

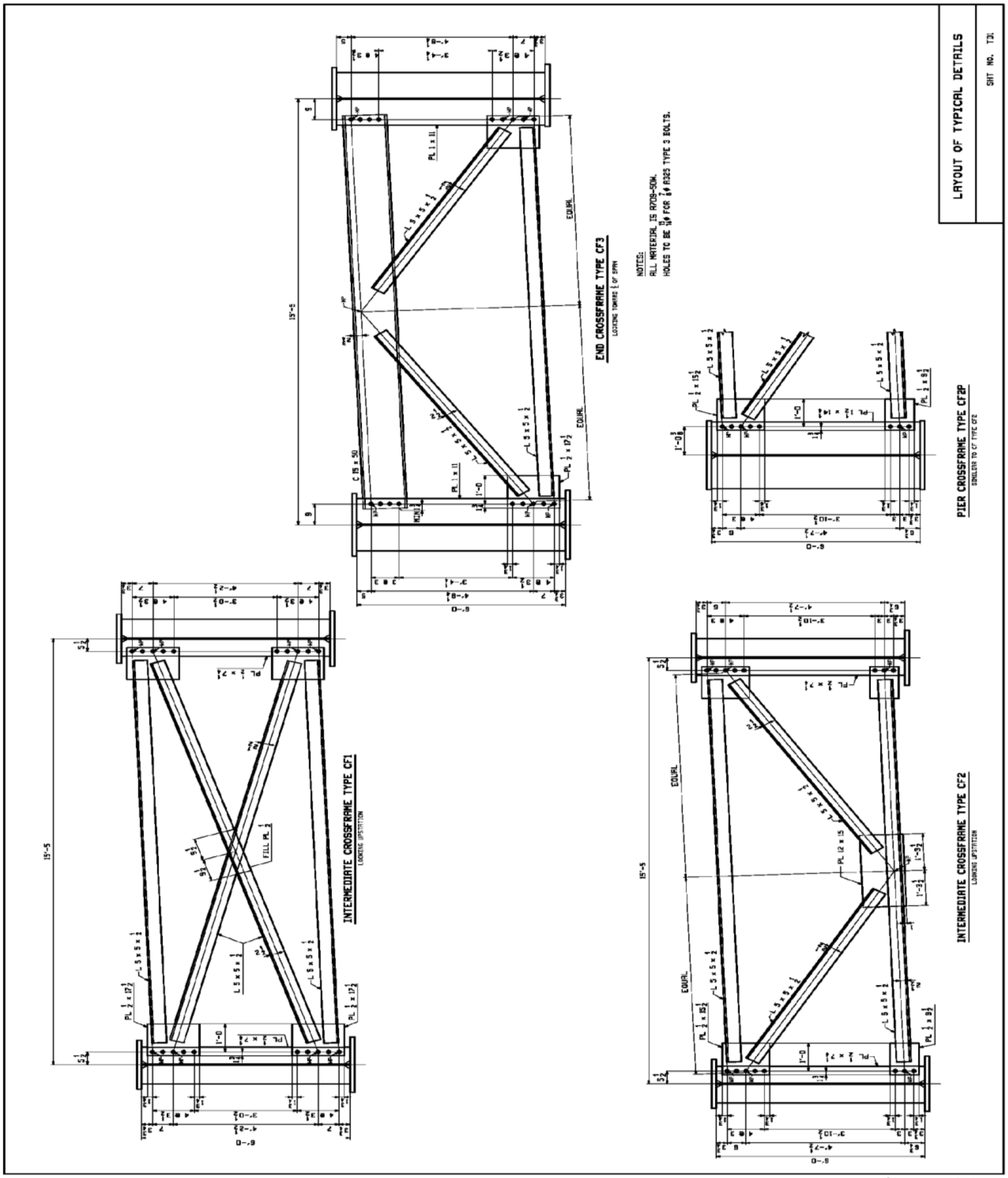

Figure 2 Example shop drawing showing the layout of typical details

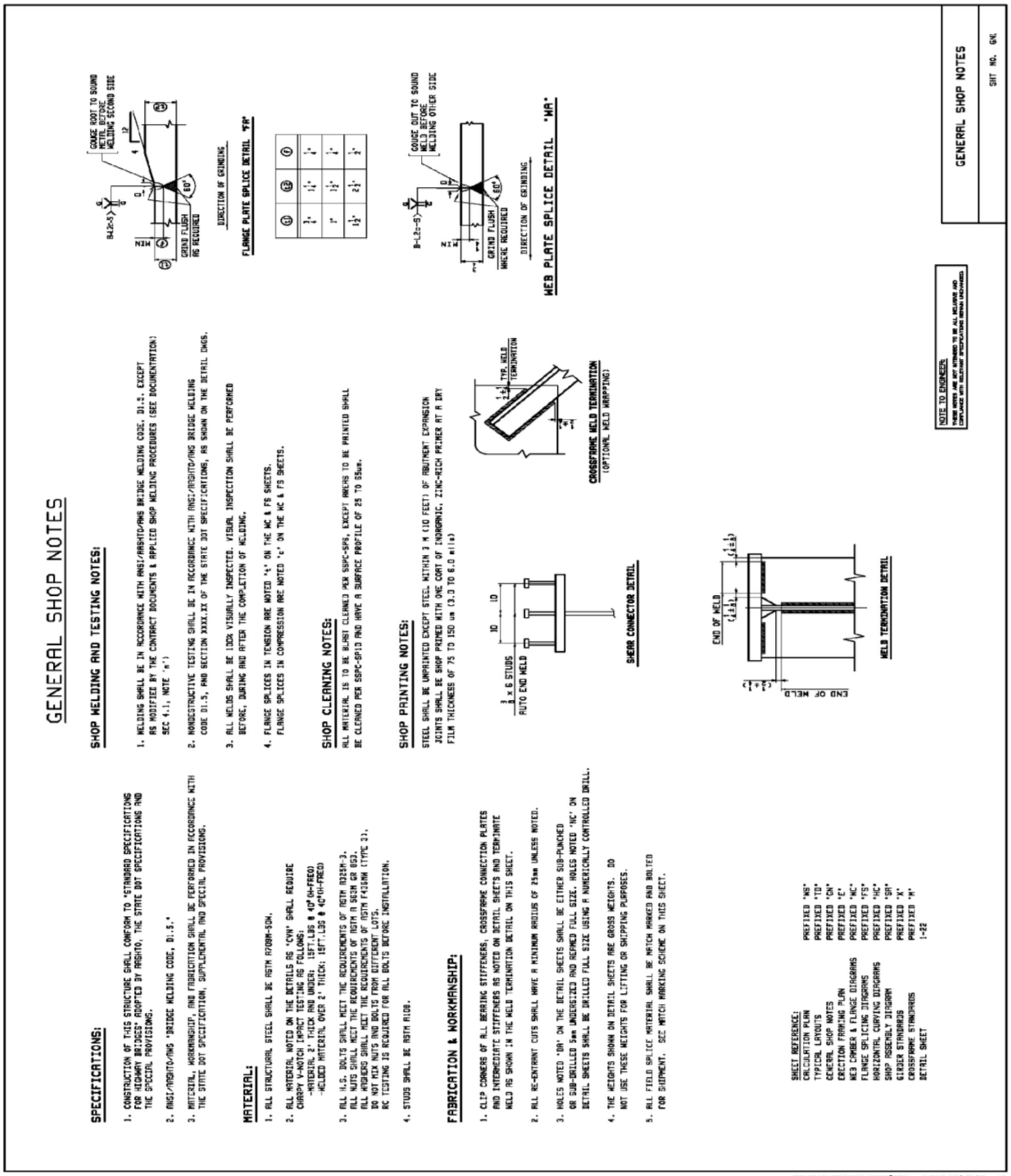

Figure 3 Example shop drawing showing the general shop notes

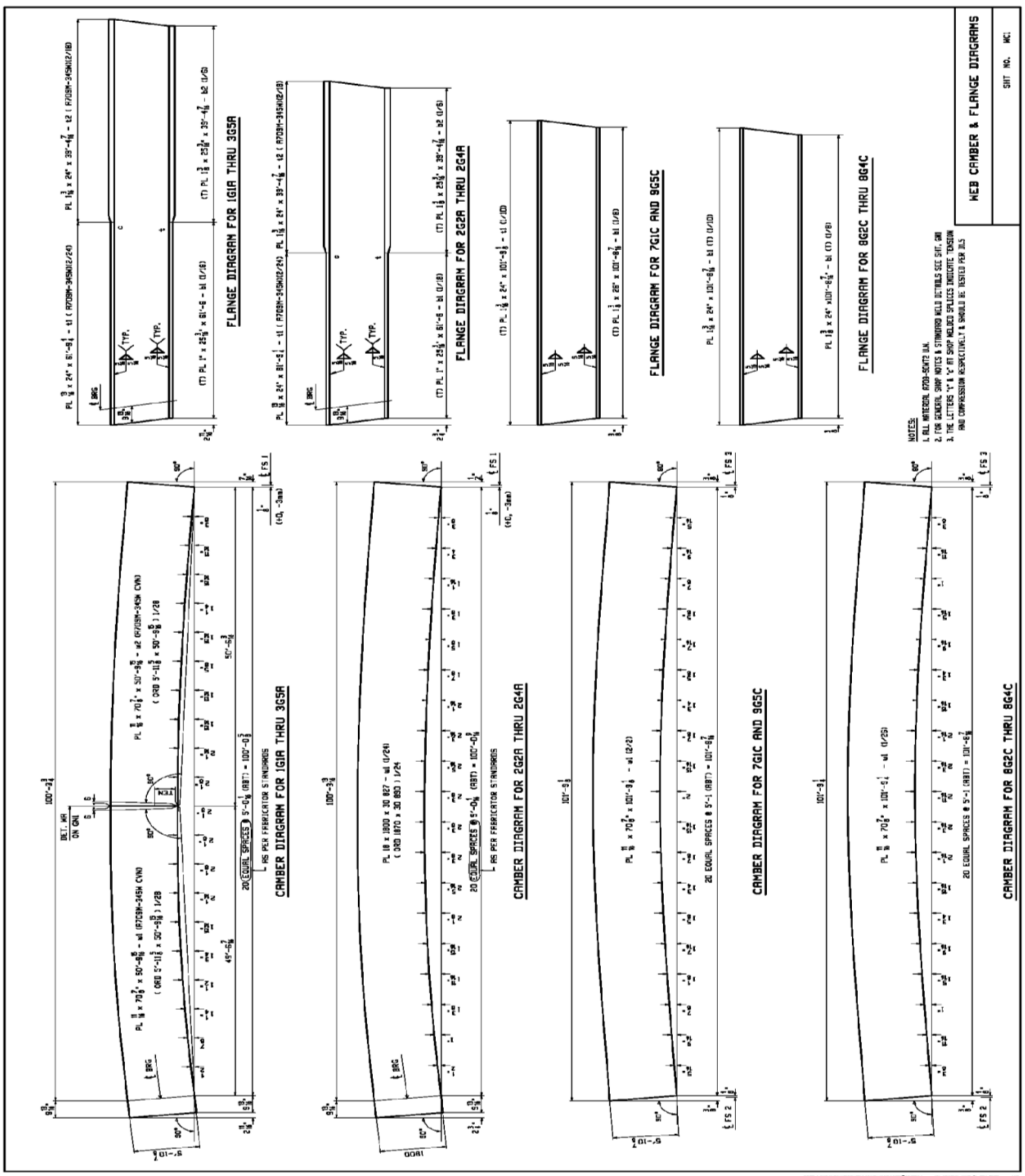

Figure 4 Example shop drawing showing the web camber and flange diagrams

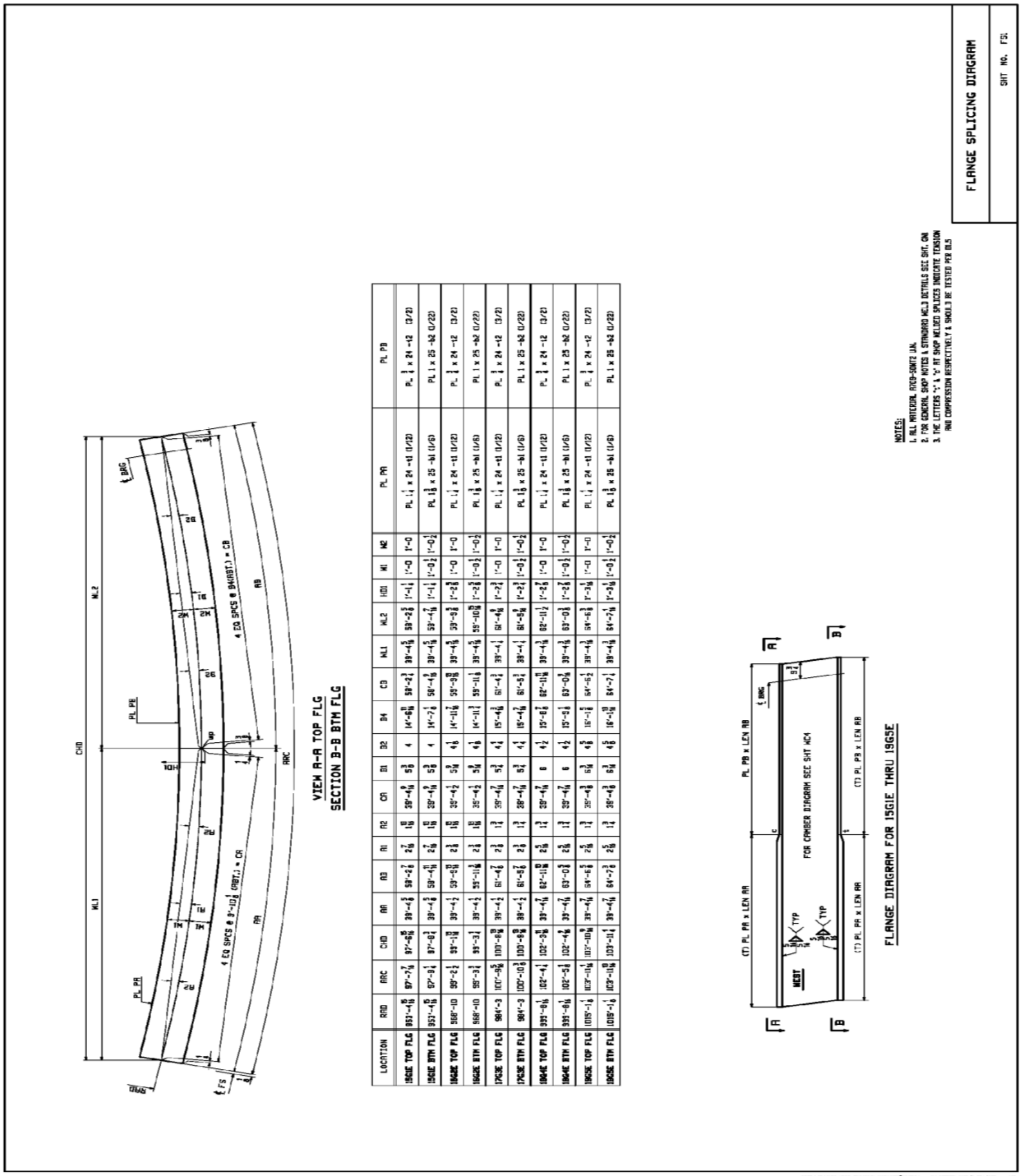

Figure 5 Example shop drawing showing a flange splicing diagram

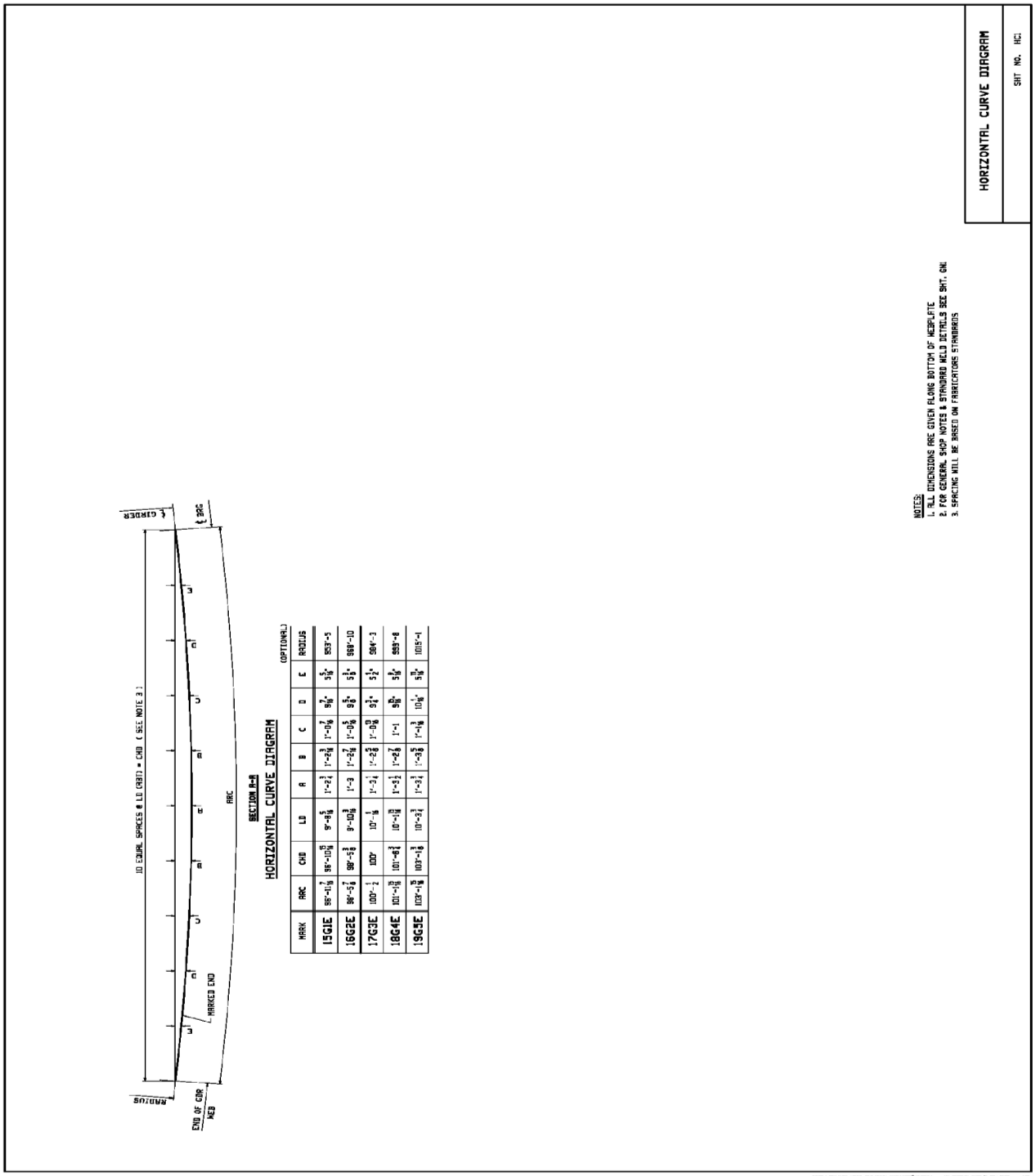

Figure 6 Example shop drawing showing a horizontal curve diagram

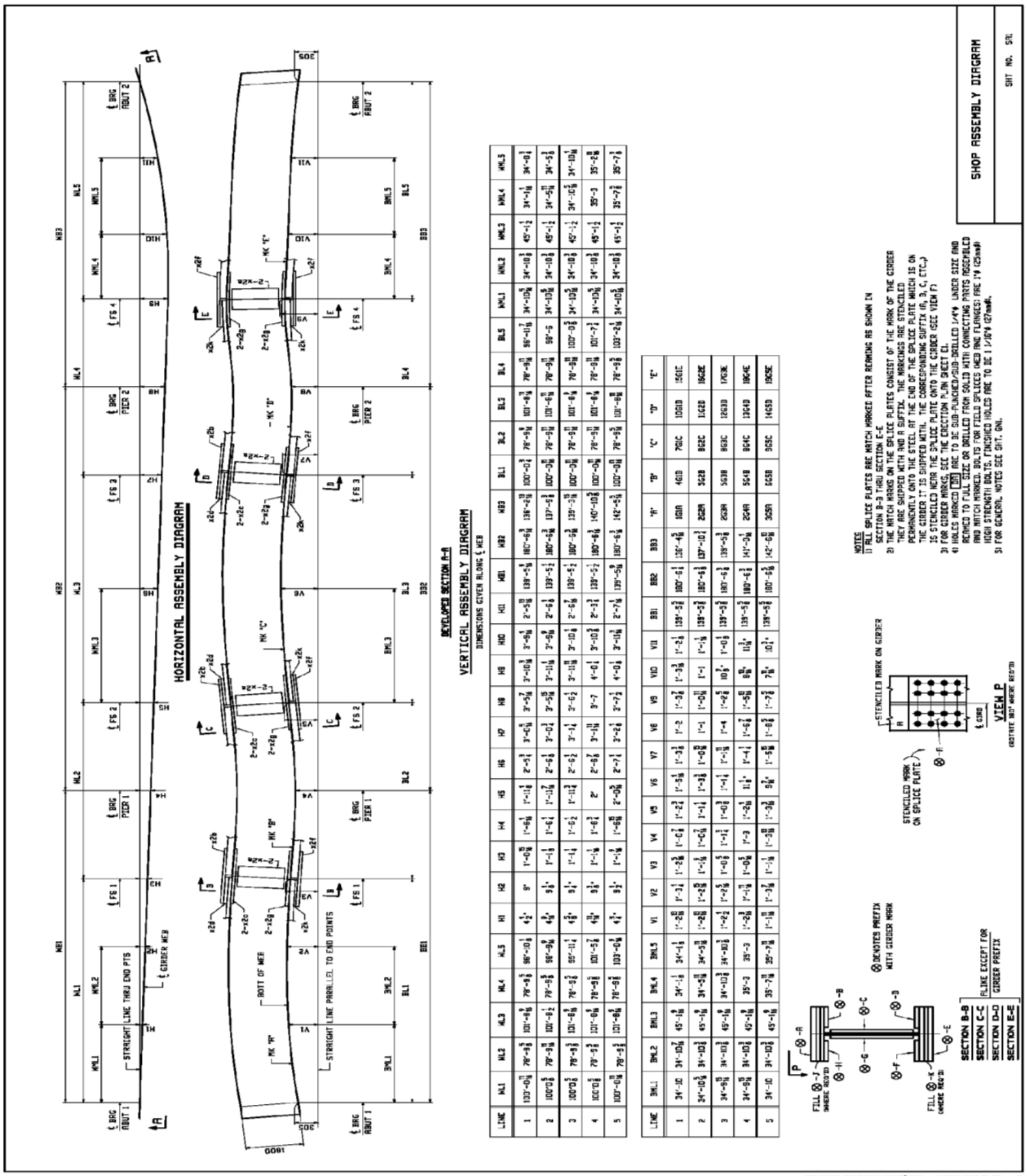

Figure 7 Example shop drawing showing a shop assembly diagram

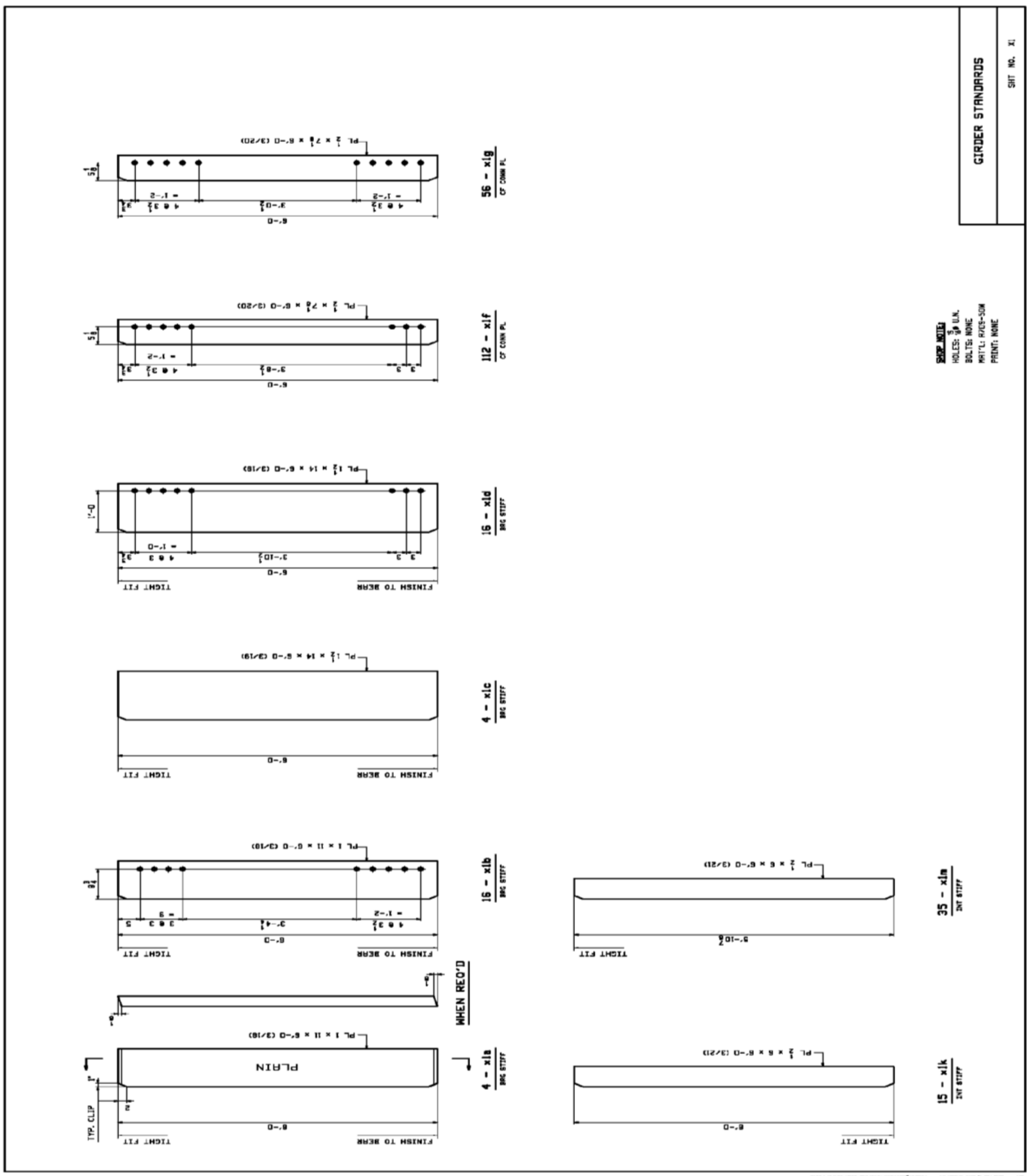

Figure 8 Example shop drawing showing girder standards (stiffeners)

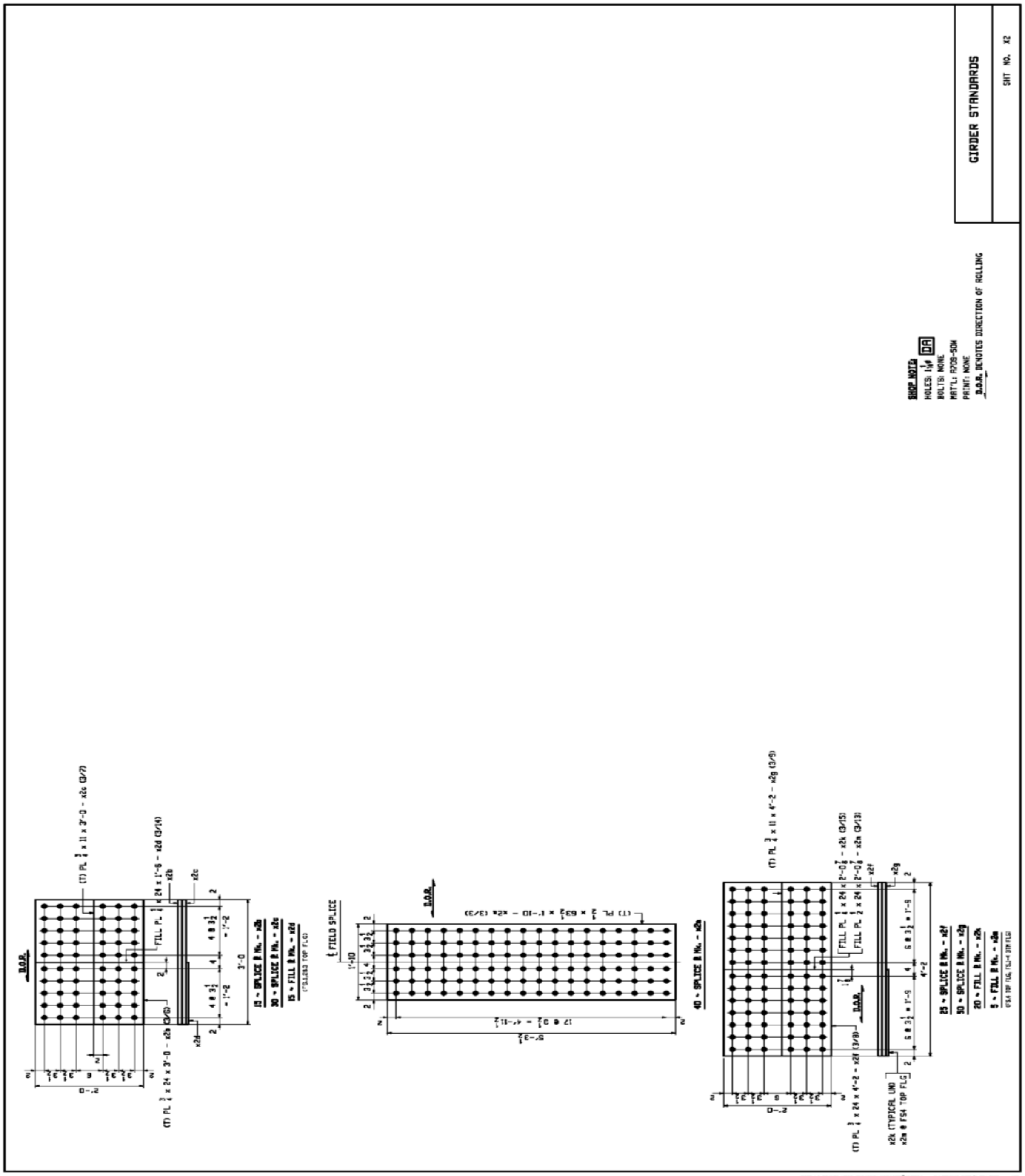

Figure 9 Example shop drawing showing girder standards (splice plates)

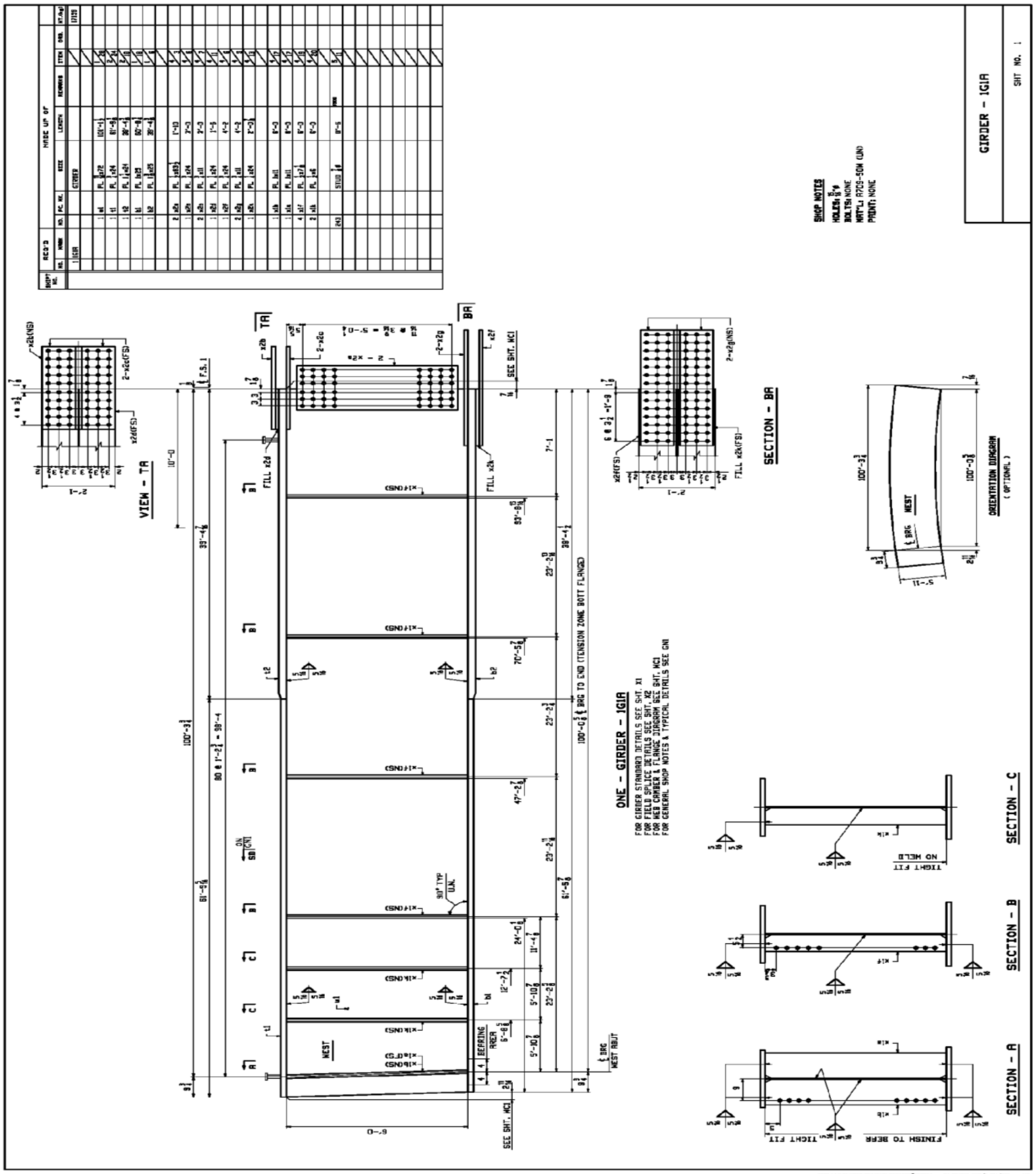

Figure 10 Example shop drawing showing a girder elevation and sections

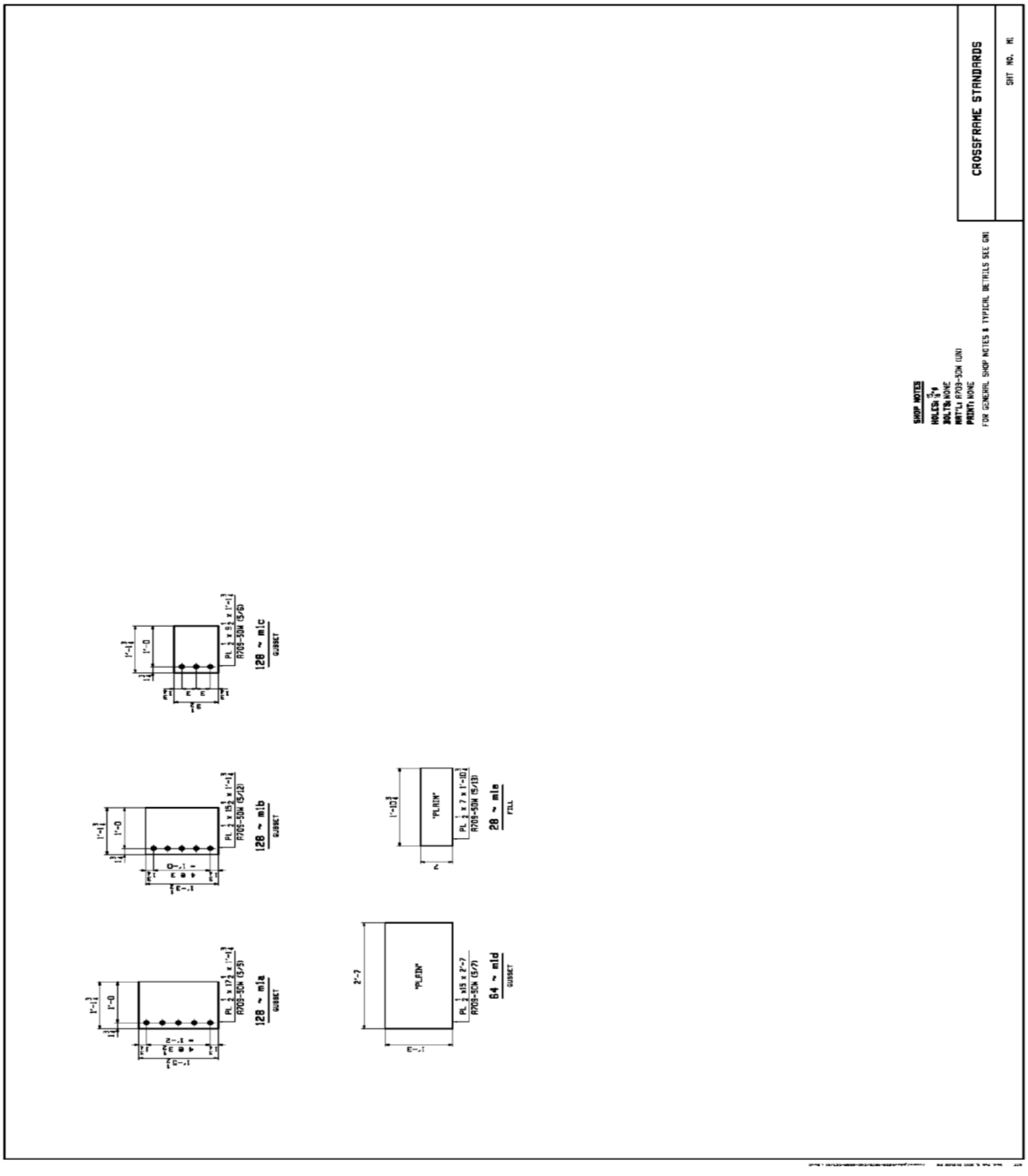

Figure 11 Example shop drawing showing cross frame standards

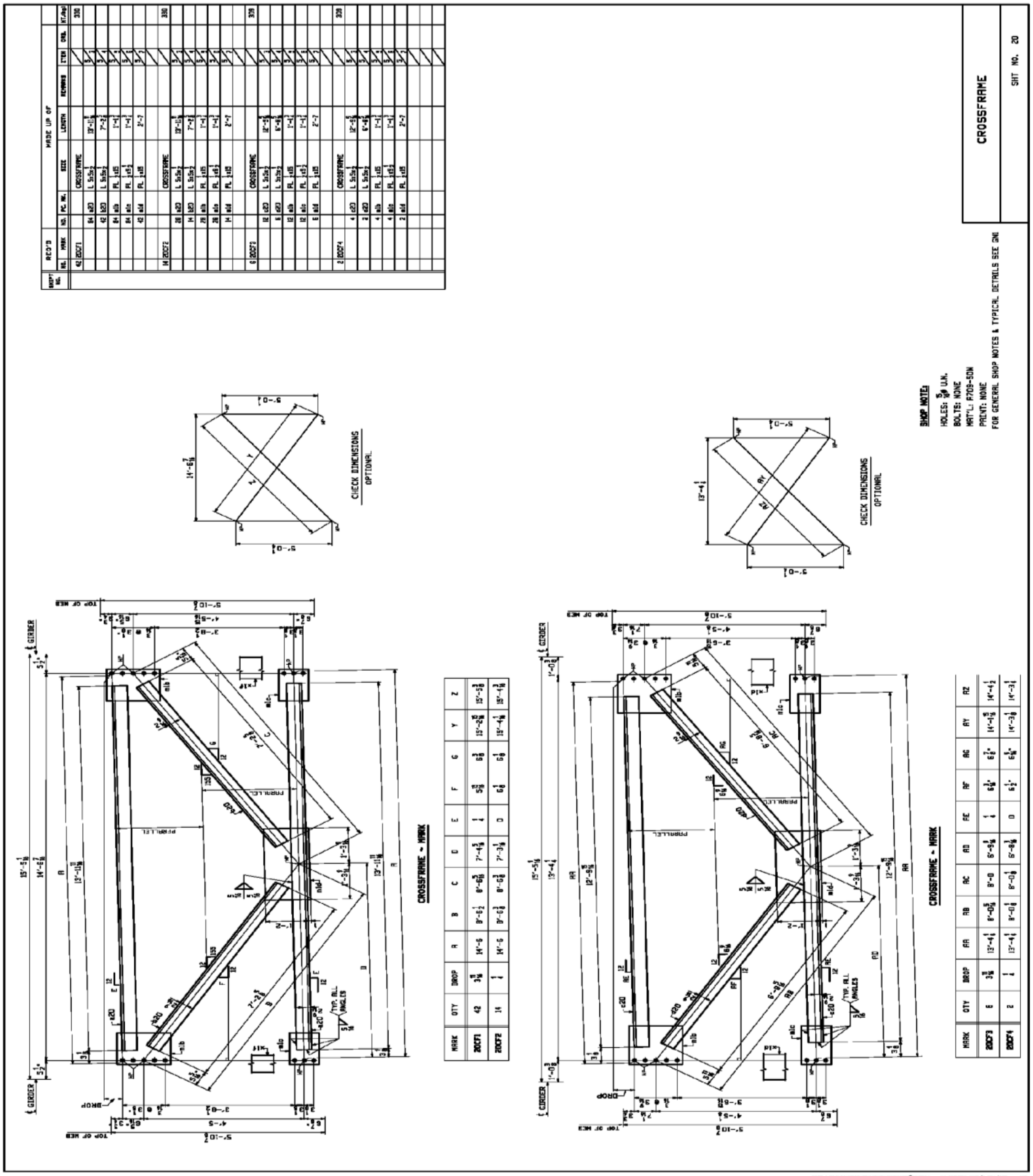

Figure 12 Example shop drawing showing a cross frame

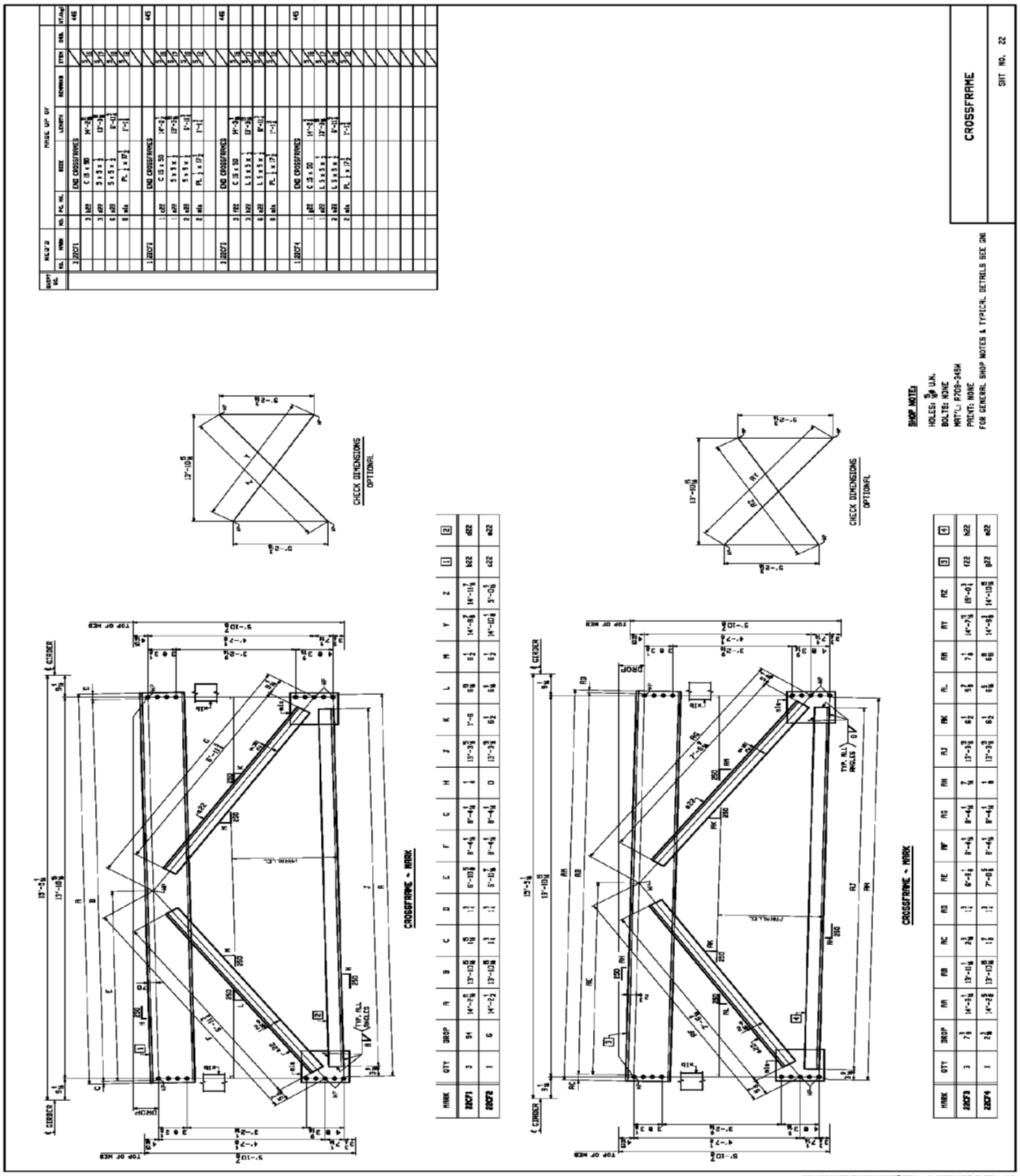

Figure 13 Example shop drawing showing a cross frame

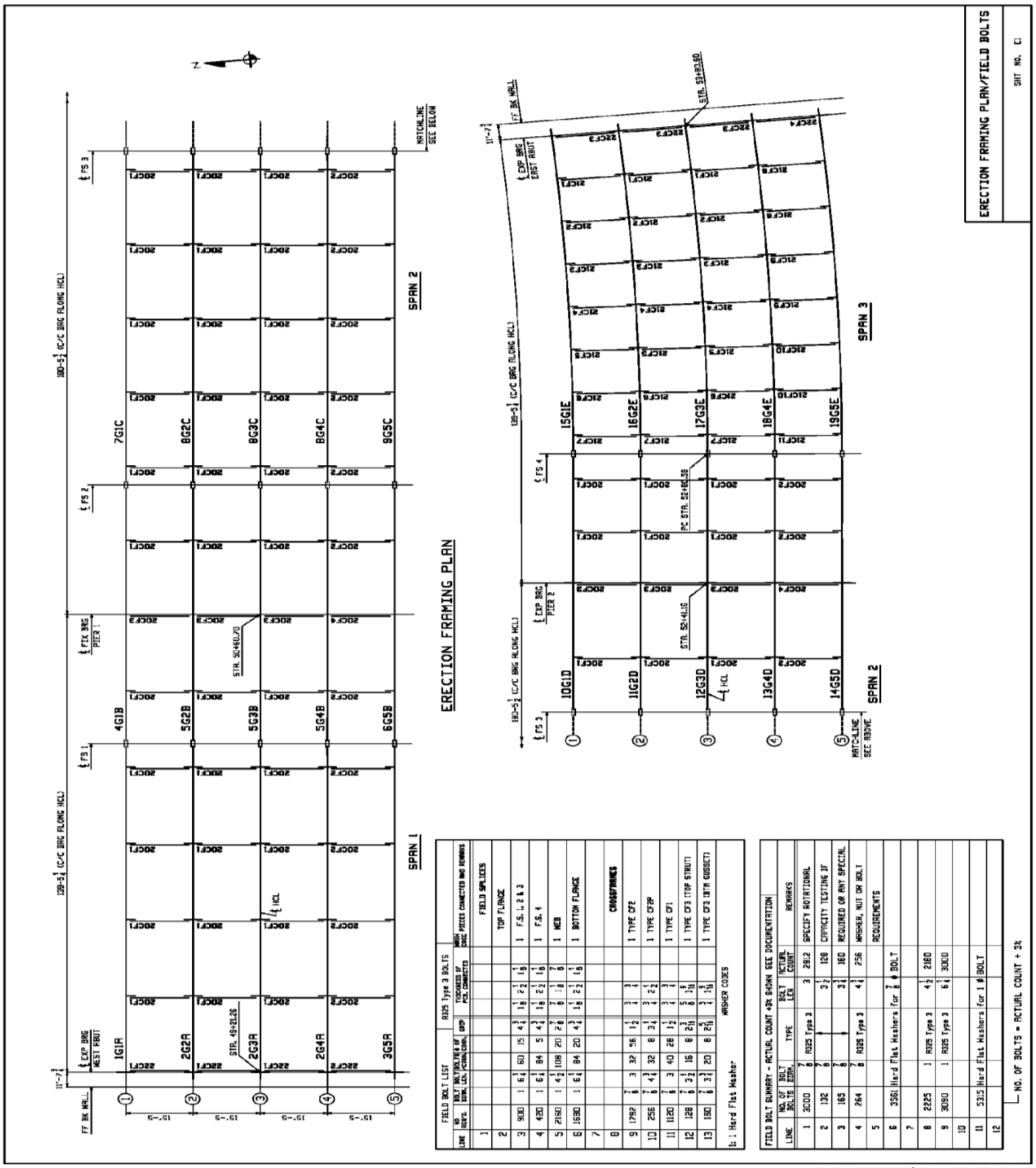

Figure 14 Example shop drawing showing the erection framing plan and field bolt list

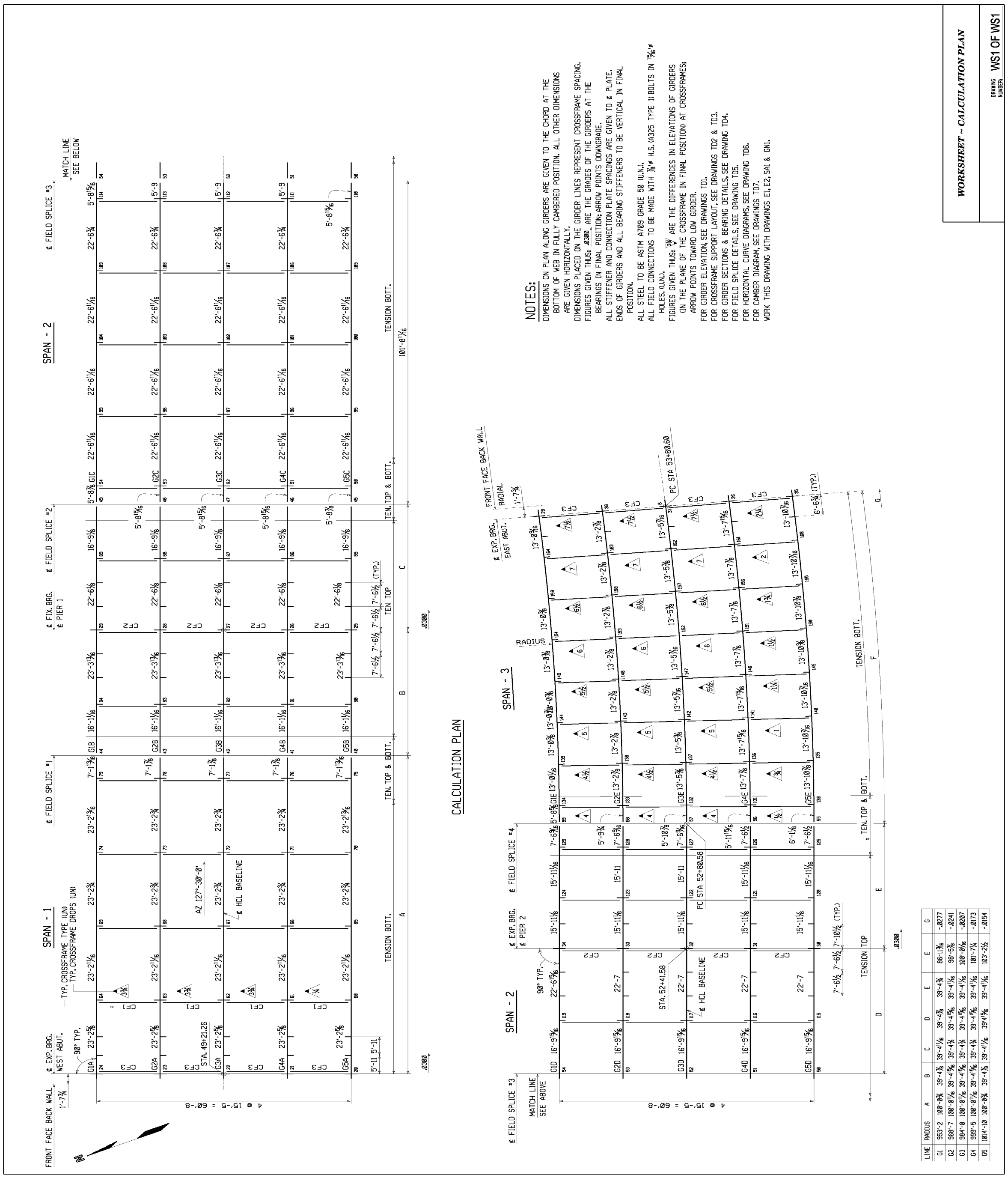

Figure 15 Example shop drawing showing a worksheet-calculation plan

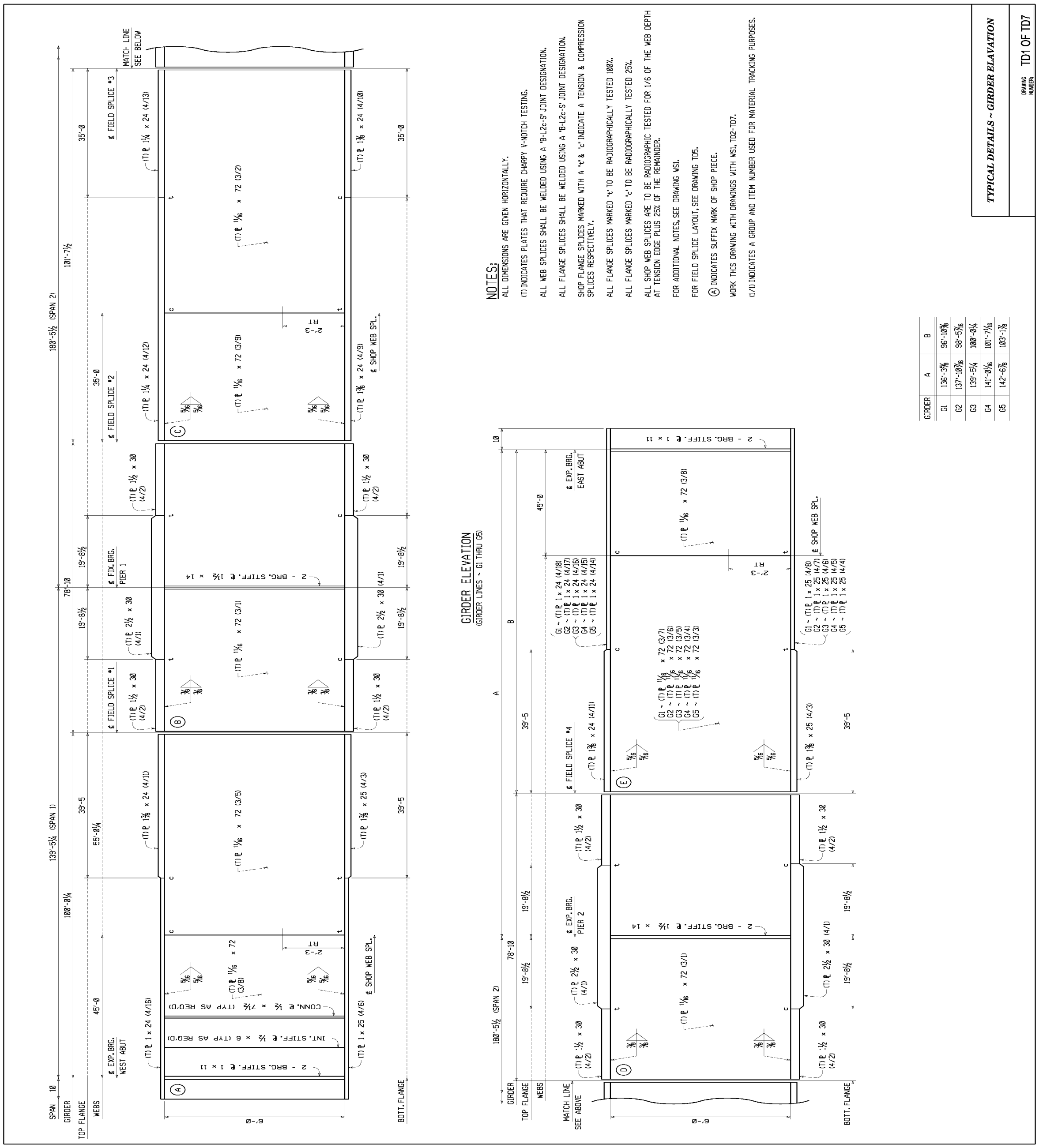

Figure 16 Example shop drawing of typical details – girder elevations

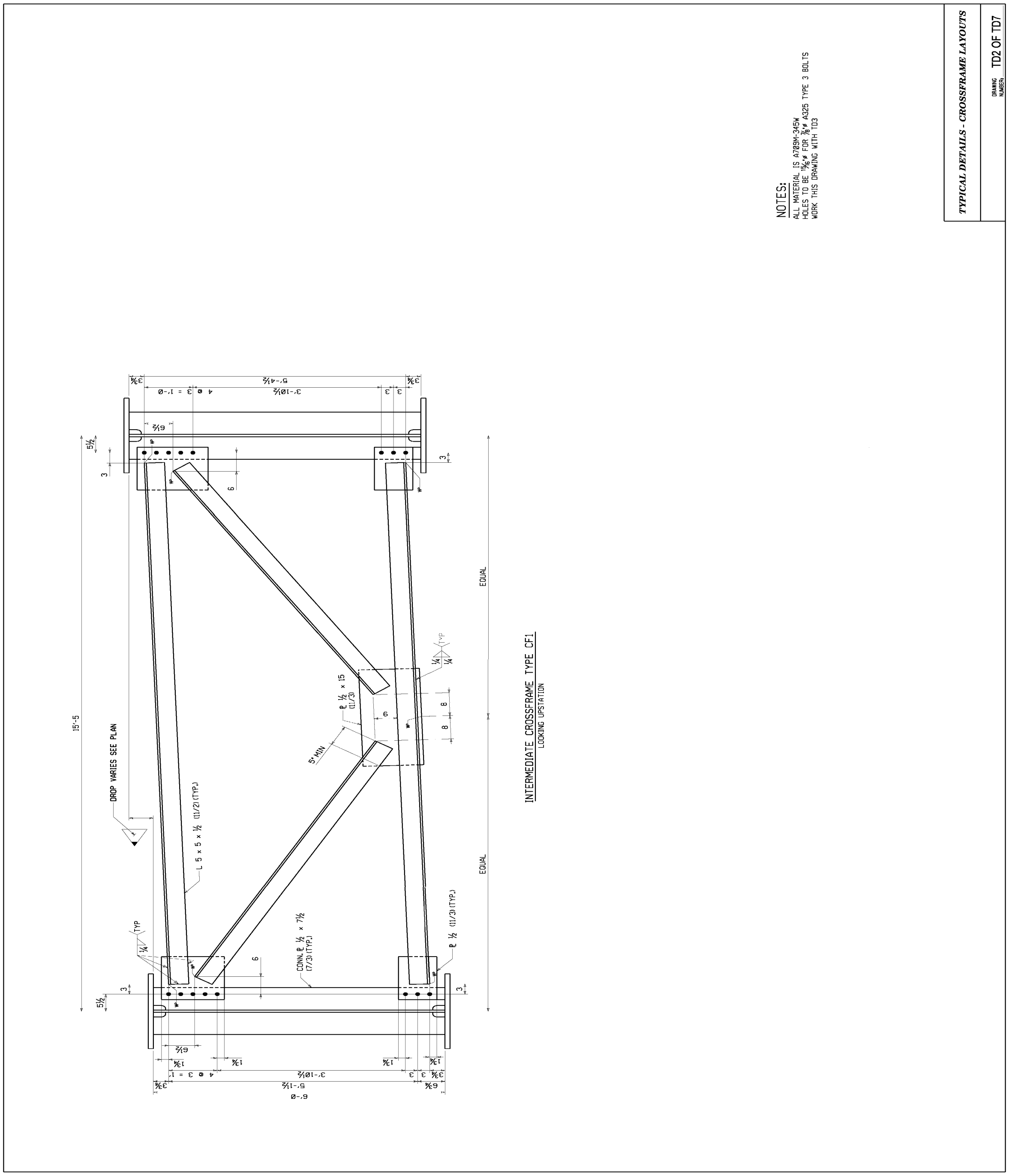

Figure 17 Example shop drawing of typical details – cross frame layouts

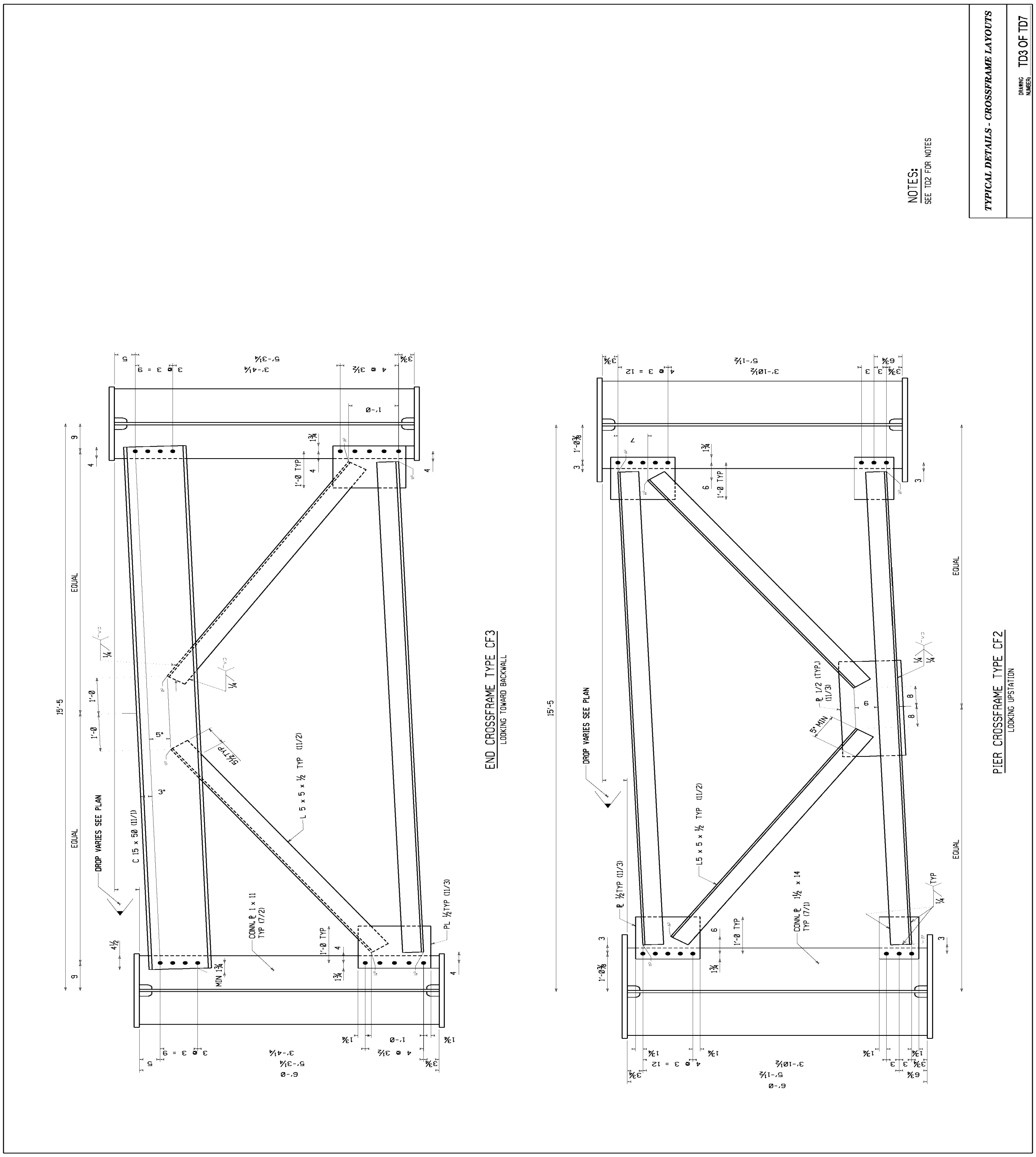

Figure 18 Example shop drawing of typical details – cross frame layouts

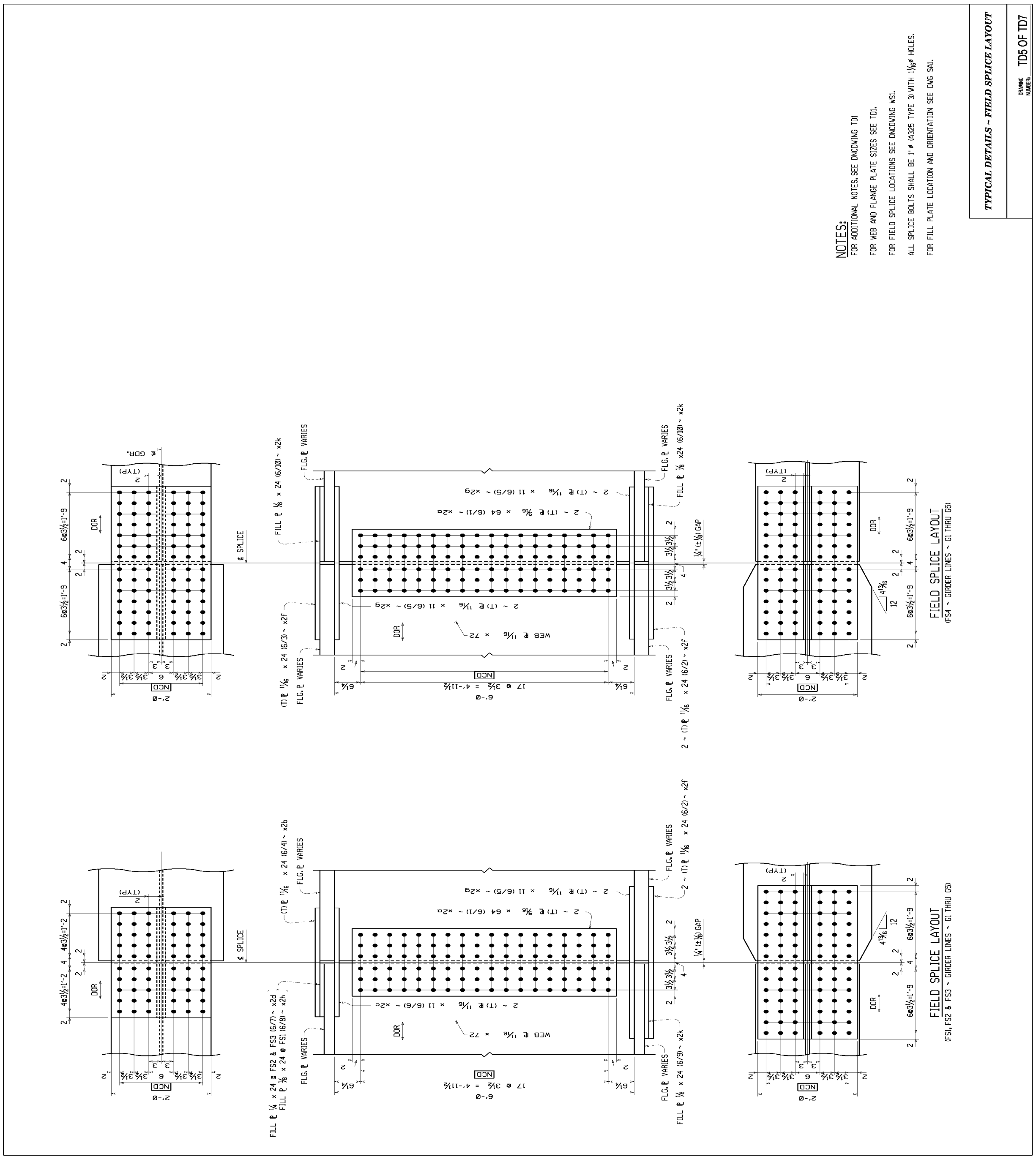

Figure 19 Example shop drawing of typical details – field splice layout

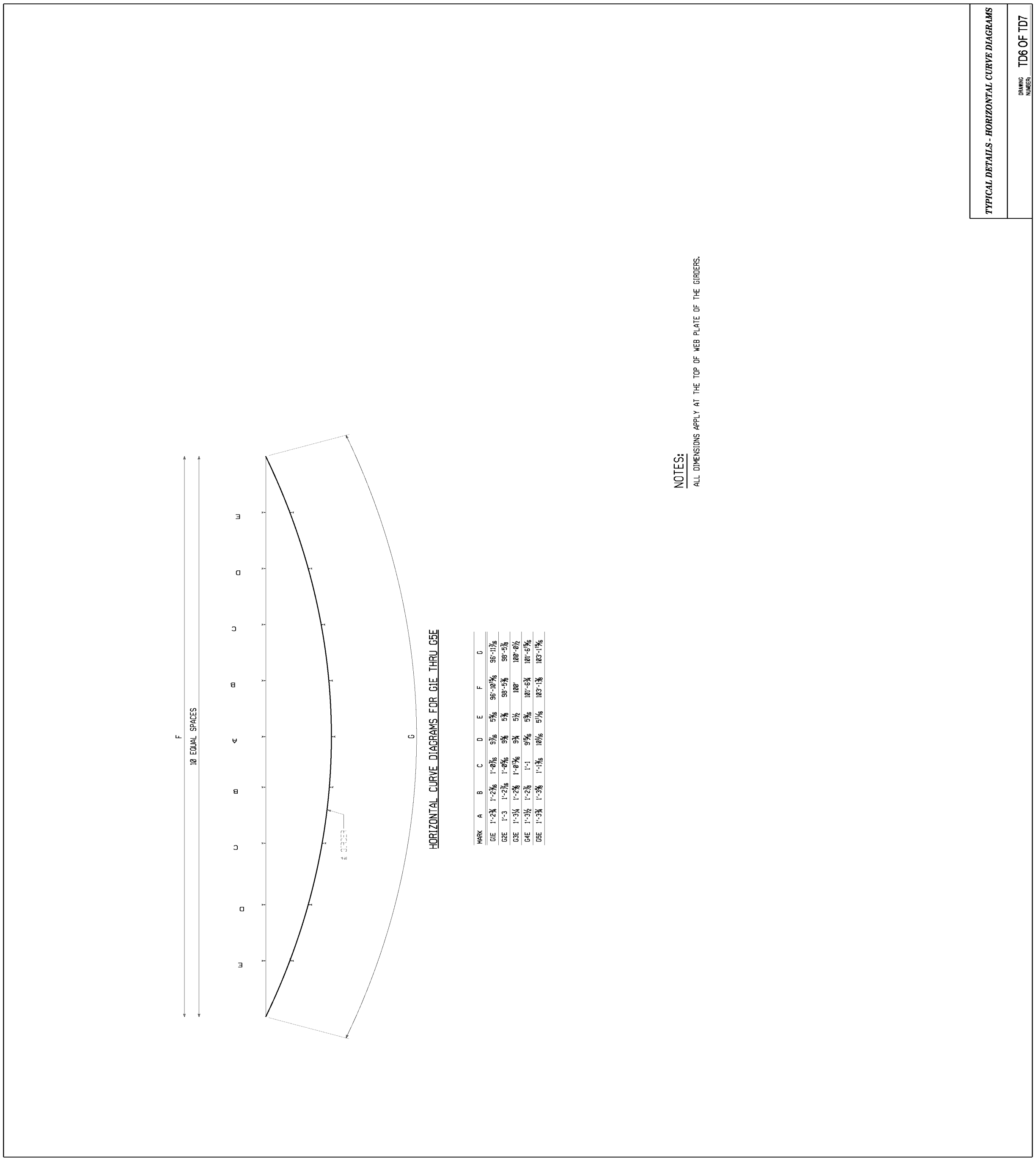

Figure 20 Example shop drawing of typical details – horizontal curve diagrams

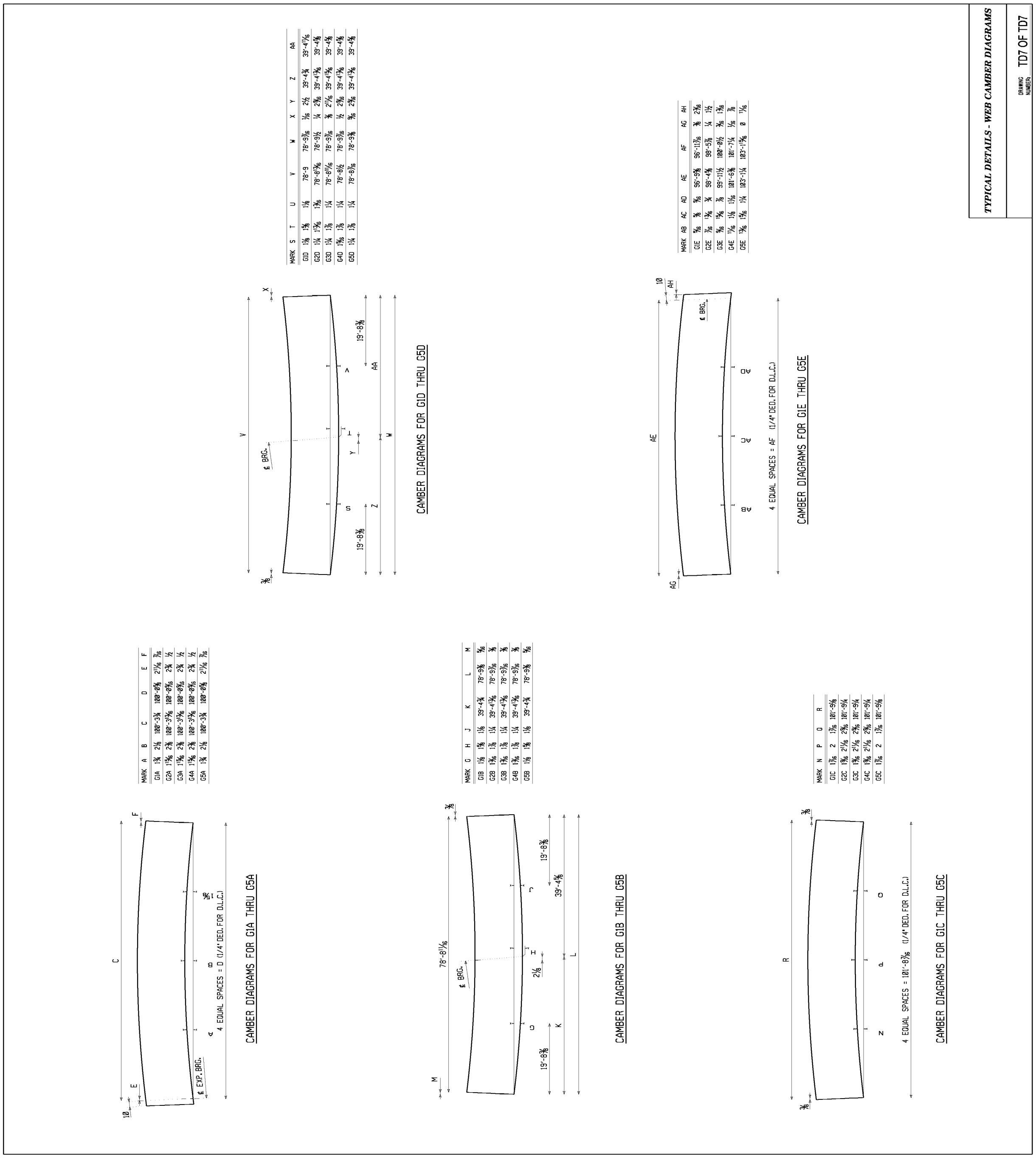

Figure 21 Example shop drawing of typical details – web camber diagrams

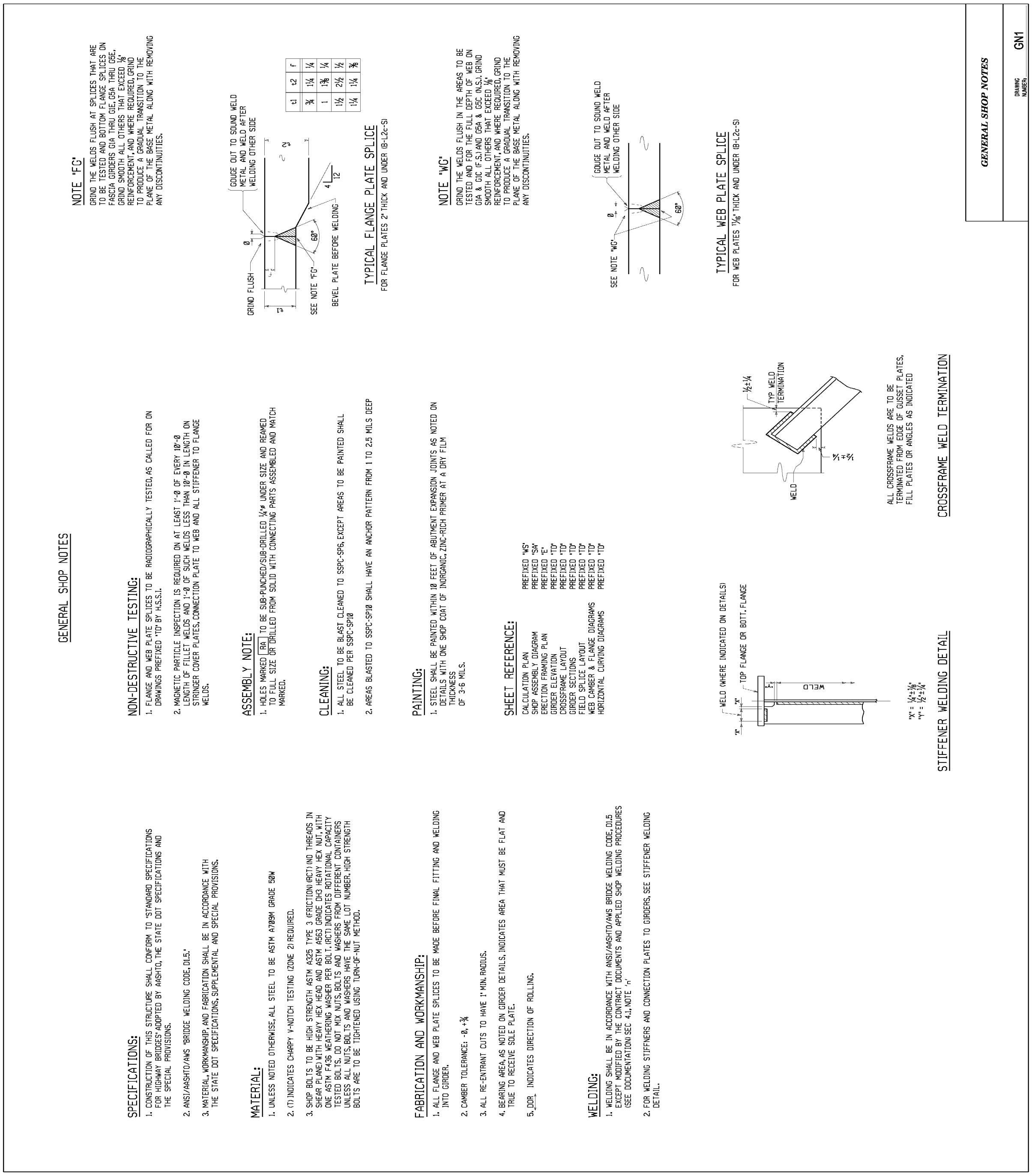

Figure 22 Example shop drawing of typical details – general shop notes

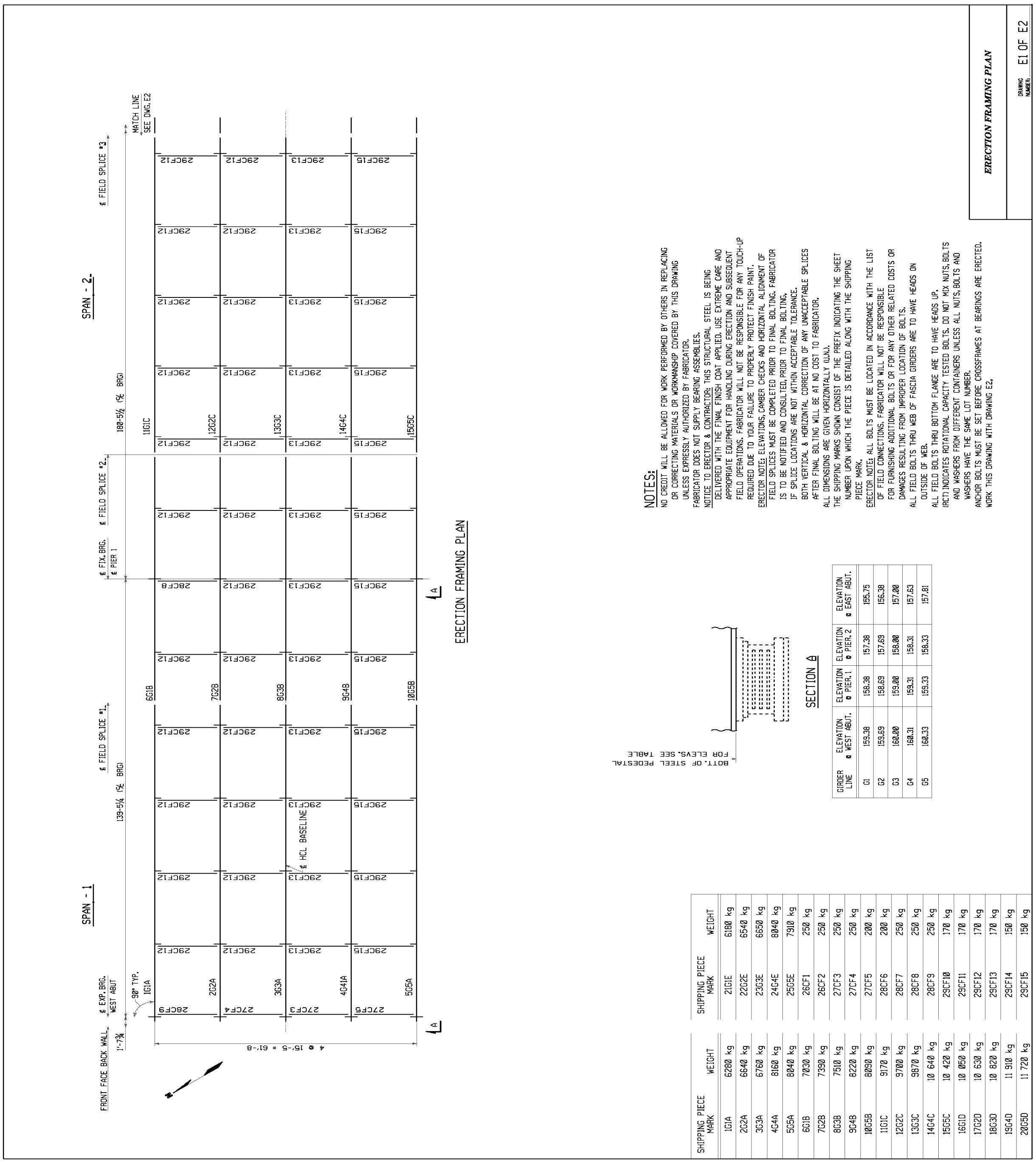

Figure 23 Example shop drawing of typical details – erection framing plan

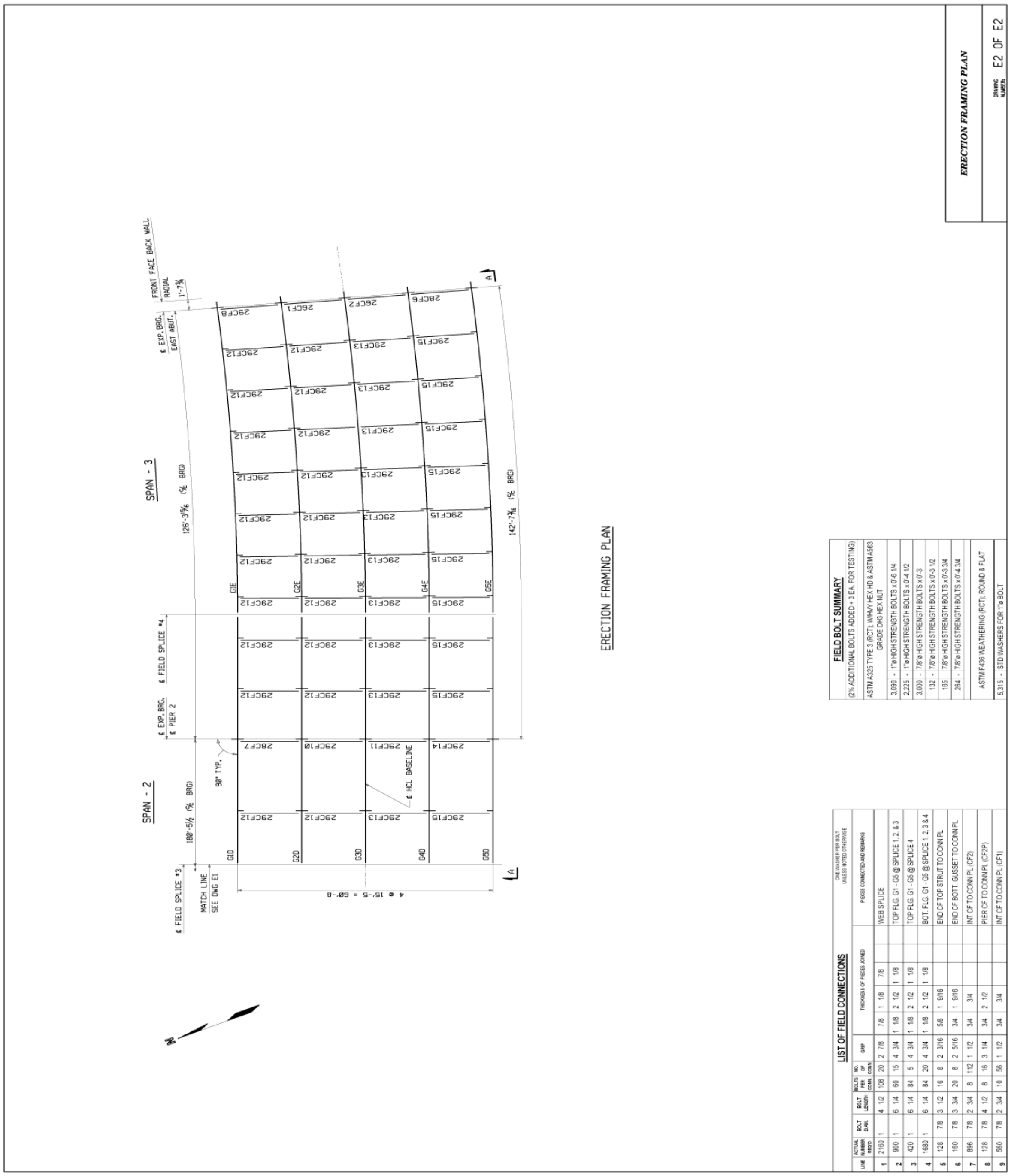

Figure 24 Example shop drawing of typical details – erection framing plan

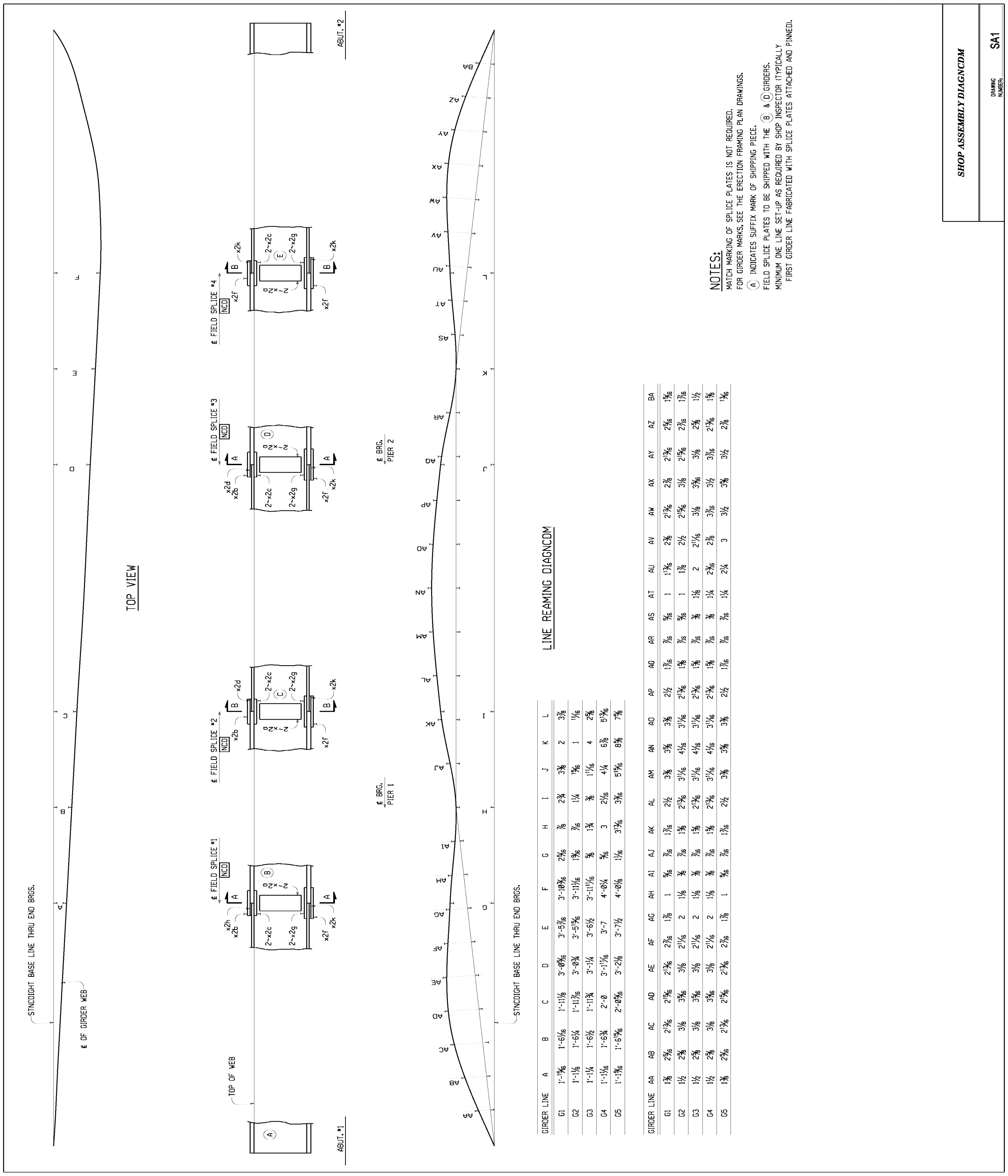

Figure 25 Example shop drawing of typical details – shop assembly diagram