Designing steel for ease of construction

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Designing Steel for Ease of Construction

Projet de ponts métalliques en vue d'une exécution aisée

Zum Entwurf montagefreundlicher Stahlkonstruktionen

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SUMMARY

The question is examined of to what extent the designer should consider the method to be used for construction when he is preparing the design. Four case histories of steel bridges provide examples, and conclusions are drawn about the appropriate involvement of the designer.

RESUME

Au stade du projet déjà, il s'agit de porter une plus grande attention aux méthodes de construction. Quatre cas de ponts métalliques sont présentés à titre d'exemple et des conclusions sont tirées en vue d'une intervention appropriée de l'ingénieur-projeteur.

ZUSAMMENFASSUNG

Es wird die Frage aufgeworfen, inwieweit das Bauverfahren von Stahlkostruktionen bereits in den Entwurf einfliessen soll. Anhand von vier Fallbeispielen aus dem Brückenbau werden Rückschlüsse auf die angemessene Beteiligung des entwerfenden Ingenieurs gezogen.

1. RESPONSIBILITY OF THE DESIGNER TO CONSIDER ERECTION

1.1 Arguments for and against

To what extent should a designer of a bridge or other structure consider the method of erection when creating the design?

In many jurisdictions the designer is responsible only for the finished product; and it is the contractor whose business it is to decide on the method of construction.

Should the designer decide on the most likely erection scheme to be adopted and then prepare his or her design to suit this scheme? Some arguments against this point of view include:

- The contractor will likely come up with his own ideas anyway;
- Construction engineering is not the business of the designer and is not his area of expertise;
- By becoming involved with the construction process the designer increases his liability for the job;
- If for any reason the designer's erection scheme should not work, or should need alteration in some form, the contractor is likely to claim against the designer for the extra costs involved; and
- The erection scheme may require the addition of material to the permanent bridge (such as increased web or flange sizes) and this would be wasted if the designer includes it but the contactor uses a different scheme.

Arguments in favour of the designer considering the erection procedure include:

- By considering erection the designer will produce a better design with economic benefit to his client, usually the owner;
- If the designer publishes an erection scheme, an imaginative contractor should be able to improve on this, so it is not surprising that the adopted scheme will be different; and

- For some bridges the erection engineering is so complex that it is not practical for bidders to completely evaluate all aspects of the design; it therefore serves the client best if the designer, who knows intimately the design of the bridge, can give guidance to bidders on what is an acceptable method. Cable-stayed bridges often fall into this category, for example.

So there are arguments both for and against the designer of a bridge taking account of the construction method when he designs the bridge. The same arguments apply for other unconventional structures.

1.2 A suggested solution

After considering all the issues, and having spent many years as a designer and many more as a construction engineer, the author offers the following course as the most appropriate.

- The designer should have in mind at least one good and economical method by which the bridge will be built;

- This construction method should be thought through by the designer in sufficient detail that the principles of the method can be accepted with confidence;

- In the tender documents the designer should give advice on the uncertainty associated with his method. For example: "The design is based on the method of erection as defined in the tender documents. The bridge will support a 50 tonne crane on the leading end. The effects of wind have not been considered. If the contractor wishes to adopt this scheme it shall be the contractor's responsibility to verify or modify it in every detail."

2. EXAMPLES

Four examples will illustrate the points that have been made. The author's company has been involved with all of them, two as designer and two as construction engineer for the steel fabricator and erector. They are discussed only in terms of the relationship between the design and the erection.

2.1 Carnes Creek Bridge, British Columbia, Canada

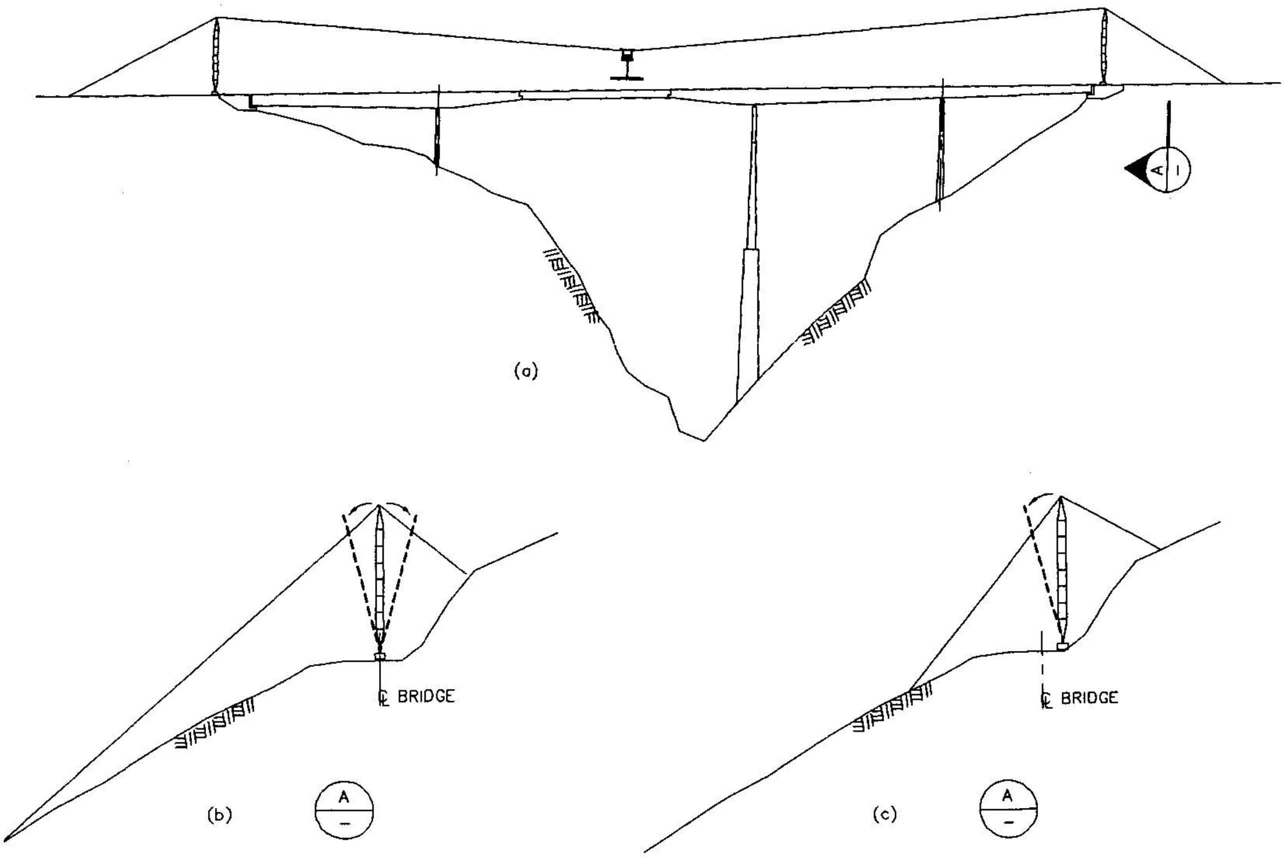

Figure 1. Carnes Creek Bridge (a) General Arrangement with highline, (b) Section A, highline centred, (c) Section A, highline offset.

Four steel plate girders span a steep gorge (Fig. 1). Although founded on rock, the design is of a cantilever and suspended span construction rather than continuous. So how is it to be erected?

Because of the hinges, it is not possible to cantilever from each end, except possibly by temporarily "fixing" the hinges.

It is not possible to launch the bridge from each abutment because of the changing depth of the girders.

Scaffolding or some other form of temporary support is not practical because of the depth of the gorge and the steepness of the sides.

Almost the only remaining method is to use a high line (Fig. 1a).

But that also has problems: The creek runs down the side of a hill, the natural slope of which is approximately the same as the preferred angle of the luffing cables (see Fig. 1b).

The final solution was to offset the high line so that it only luffed in one direction (Fig. 1c). In this manner the downhill luffing cable could be shorter and lighter.

The second serious problem was the placement of the first girders on the piers (Fig. 2). As designed, the first girder was unsymmetrically placed on the pier and wanted to fall, it could not support its own weight without bracing, and in a puff of wind it would tend to fall over laterally and rotate in line with the wind like a weathervane.

The high line did not have the capacity to lift two girders braced together, which would have been easier.

Thus the first girder needed a tie-down to prevent it falling off the pier (Fig. 2) and frames on the pier-top to prevent it rolling over or twisting in place. Further, the frames must not interfere with the placing of the second girder on the same pier, or the placing of diaphragms and bracing between the girders.

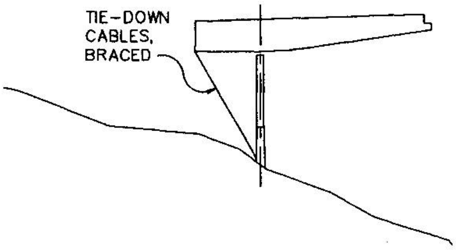

Figure 2. Carnes Creek Bridge, placement of first girder.

The reader can question whether a different design of the bridge that considered more closely the method of construction would have led to more economy, faster erection and less risk.

2.2 Pashleth Creek Bridge, British Columbia, Canada

Pashleth Creek, in the remote interior of the Coastal Mountain Range of British Columbia in Canada, runs through a "box canyon" approximately 100 m wide and 100 m deep.

At the time a bridge was required in 1982 to carry heavy "off-highway" trucks transporting huge west coast logs, there was no access to the east side of the canyon. Access to the west side was by coastal barge from Vancouver, via unpaved logging road to Owikeno Lake, along the lake by barge and then on another logging road constructed to the bridge site. Thus the cost of transport was expensive and to the west side of the bridge site only.

Another consideration was that because of the need to construct a work camp and the high wages that must be paid in a remote site, construction costs would also be high.

The design (Fig. 3a) was thus a product of three major considerations:

- The bridge must be light and easy to ship in order to minimize the cost of transport (which was up to 20% of the total cost);
- The bridge must be capable of erection from one side of the canyon only; and
- It must be quick to assemble on site in order to minimize the amount of site labour required.

The requirement for lightness was satisfied by the light truss which would just support its own weight, without deck. When the truss was in position its capacity was boosted by the addition of supporting cables underneath.

Speed of erection was achieved by small tonnage and the use of simple connections and prefabricated metal retaining walls for the abutments.

The erection scheme proposed by the designer is shown in Fig. 3b. The truss would be assembled on the west bank with cables attached loosely and posts folded horizontally. A helicopter would place a small mast, cable and winch on the east side, which would be anchored by a buried "dead man".

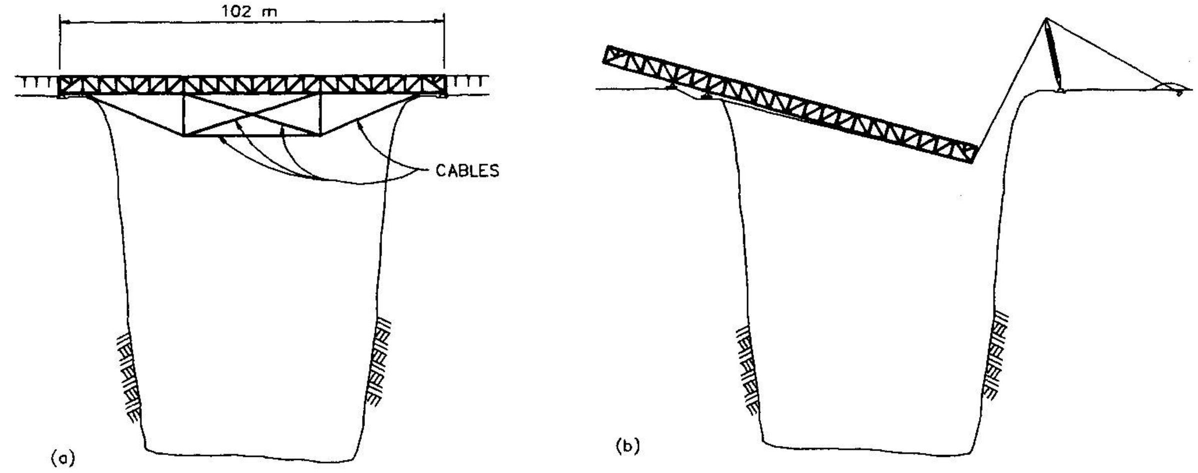

Figure 3. Pashleth Creek Bridge, (a) elevation, (b) designer's proposed erection scheme.

The front end of the truss would be attached to the lines on the east bank. The truss would be launched from the west, and when it passed the pivot point it would be allowed to rotate in a controlled manner and allowed to slide down into the canyon, held back by lines to the west side.

The light rigging on the east side would initially support only a light vertical reaction, but with the cables at a considerable angle to the vertical, which would make the tension in them more than the reaction. As the launch progressed, the vertical support requirement at the leading end would increase, but the supporting cables would become more vertical and therefore the tension would not increase as rapidly as the reaction.

Finally, the east end of the bridge would be lifted to its correct elevation and the posts folded down to be supported by the cables.

That was the designer's scheme, but the contractor decided to improve on this arrangement by launching the bridge horizontally and supporting the leading end from both sides as shown in Fig. 4. Consideration of horizontal equilibrium at the leading end shows that vertical load is supported from both sides, with the share supported by the east side varying from near zero when the east cables are their closest to horizontal, to near 100% when the east cables are almost vertical.

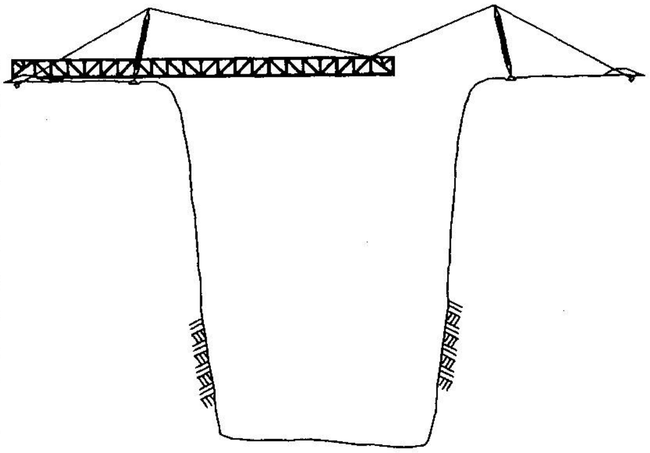

Figure 4. Pashleth Creek Bridge, erection scheme adopted by the contractor

This is a good example of the designer having a good, clear erection scheme in mind when designing the bridge, and the contractor coming up with an improved method.

2.3 Alex Fraser (Annacis) Bridge, British Columbia, Canada

When completed in 1986 the Alex Fraser Bridge (Fig. 5) was the world's longest span cable-stayed bridge.

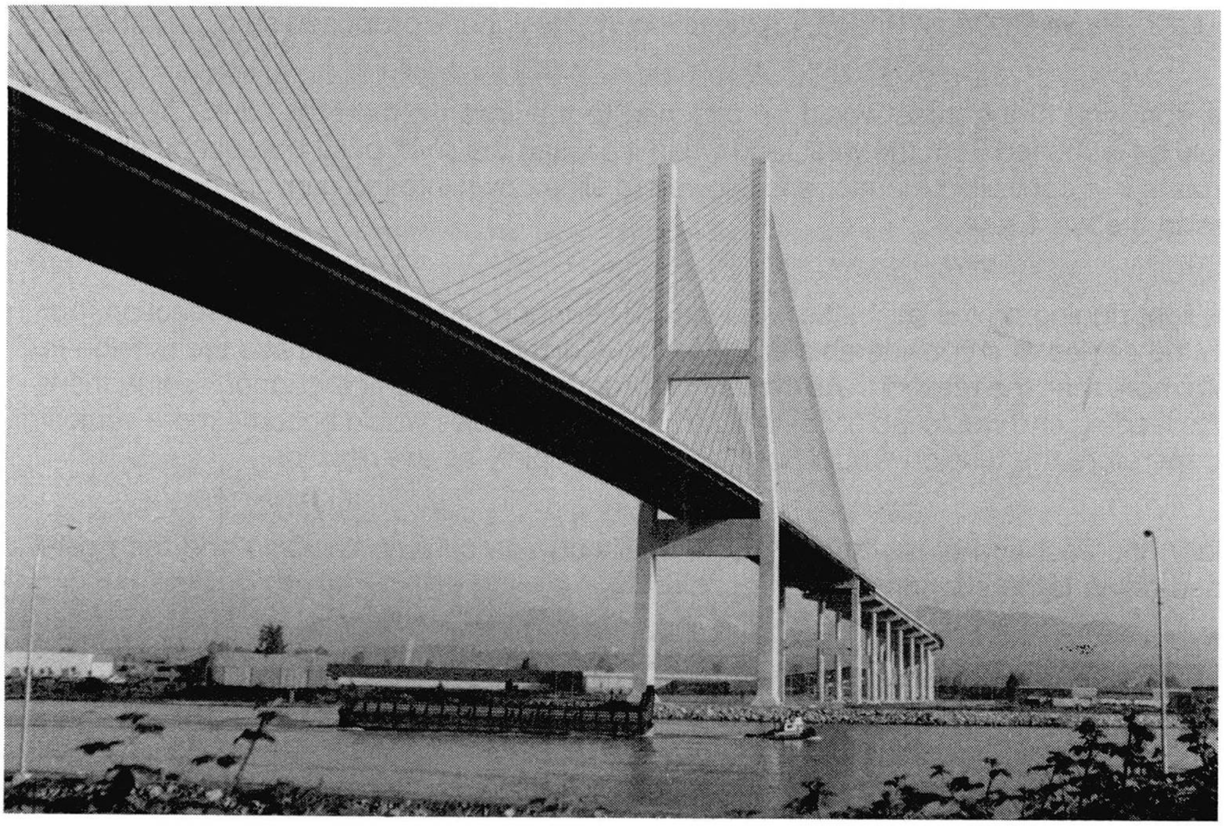

Figure 5. Alex Fraser Bridge.

To achieve both economy and quality, considerable thought was given by the designers to the method of construction. For example:

- The towers (the tallest concrete bridge towers in the world) have constant cross-section and wall thickness above the deck, and constant width below the deck. This simplifies the forming and the steel detailing;

- The cable planes are vertical, for simplicity of detailing and construction;
- Crossbeams in the towers occur only at changes of direction of the legs;
- Cables connect directly to the top flanges of the girders;
- Provision for erection and adjustment of the cables is made in the permanent design of the upper cable anchorages;
- Crossbeams under the deck are simply supported, requiring connection for shear only;
- Main girders have constant web depth and connections are simple;
- The steel design is highly repetitive in modular sequence;
- The deck is entirely composed of precast reinforced concrete panels with a small amount of cast in place concrete between panels;
- No form work was required for the cast in place concrete except at the edges. It was entirely supported on the top flanges of main girders and crossbeams;
- Shear studs were placed to avoid potential conflict with concrete reinforcing steel; and
- The bridge was designed to be erected by balanced cantilever method from each tower, with the extra length on the river side counter-balanced by tie-downs on the shore side.

The designers prepared the design on the assumption that erection would be by high line. In fact the contractor preferred to place a stiff-leg derrick at the end of each cantilever (Fig. 6). This required the bridge to be checked for the extra weight imposed at each cantilever end, but is again an example of the contractor improving on a well-developed scheme prepared by the designer. By coincidence or otherwise, the bridge was completed in 30 months, a record for a cable-stayed bridge of this size.

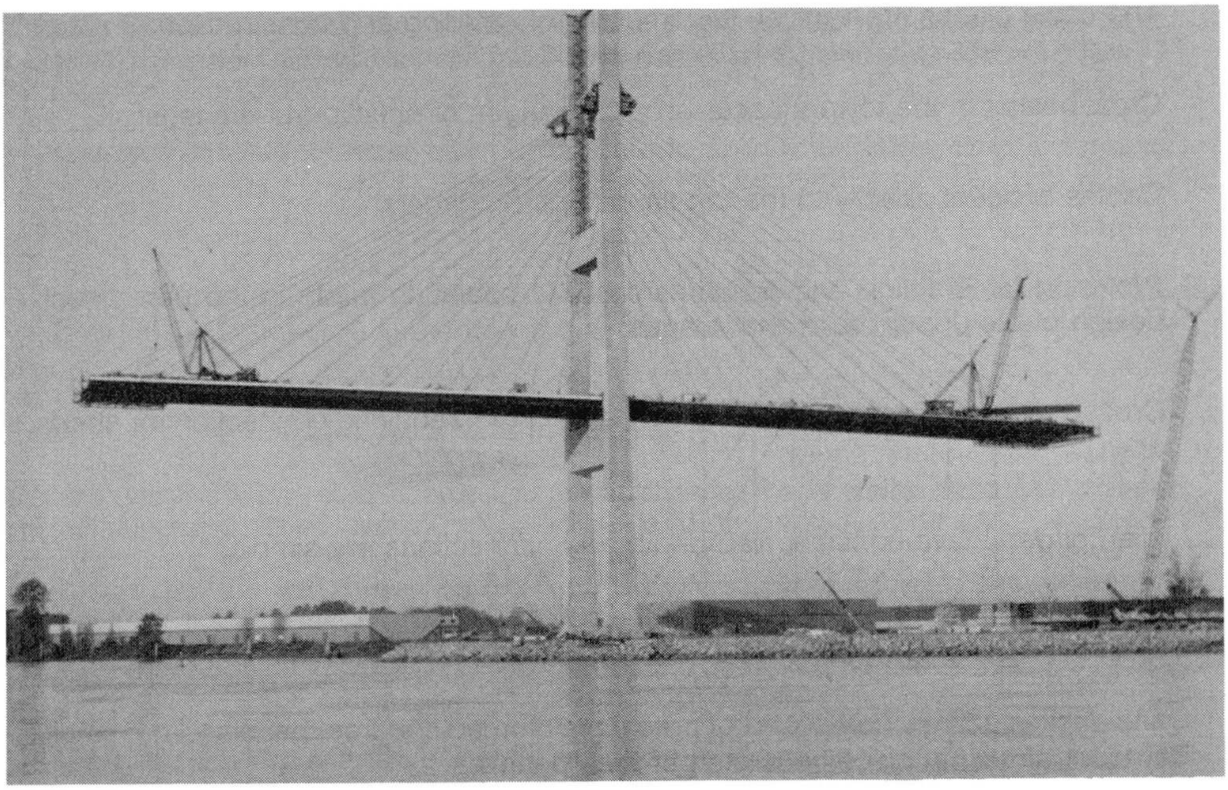

Figure 6. Alex Fraser Bridge under construction.

2.4 Peace River Bridge, Alberta, Canada

The Peace River Bridge consists of four steel plate girders, 4500 mm deep with spans of 82 - 5 at 112 - 92 m (Fig. 7). The designers considered the erection in their design and assumed assembly on the river bank and launching on rollers as the appropriate method.

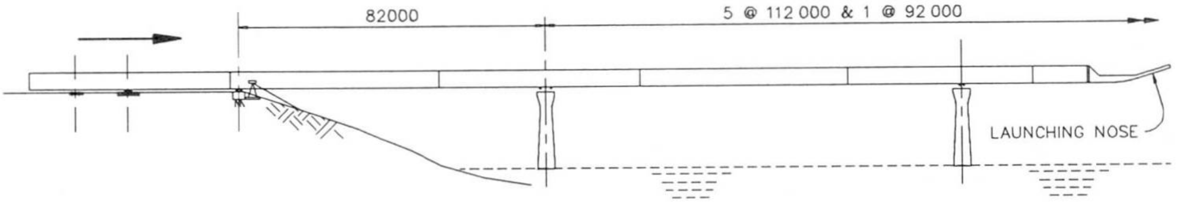

Figure 7. Peace River Bridge under construction by launching.

Their design therefore had the following features:

- A level soffit of the bottom flange, rather than a constant depth web as is more conventional (see Figs. 8a & 8b);

- Bottom flange splices designed so that during launching the middle portion can be temporarily omitted (Fig. 8b) and the flange can pass over a nest of rollers;

- Constant width bottom flanges to assist in guiding of the bridge during launching; and

- An allowance in the design to support the weight of a temporary nose 20 m long on the leading end of the girders.

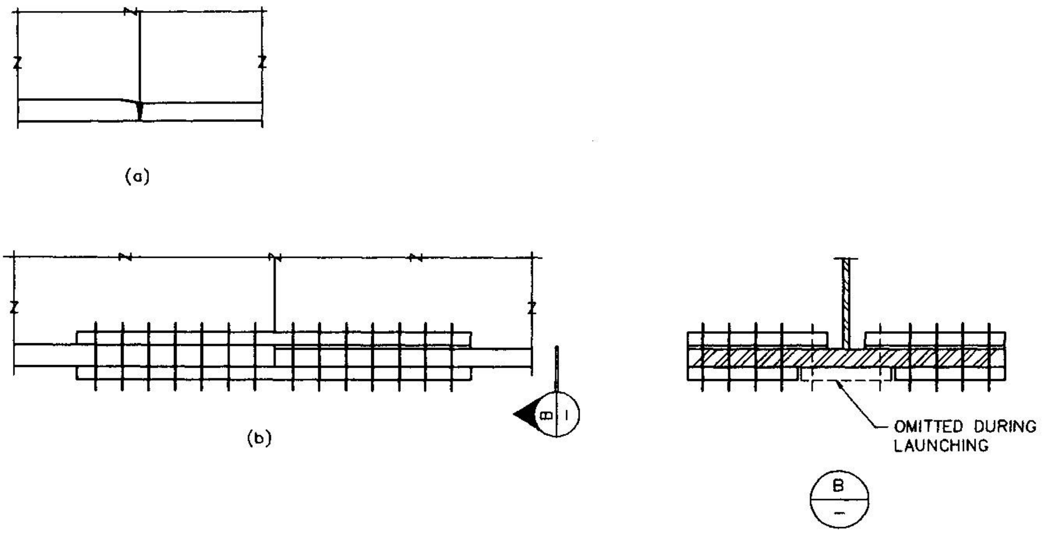

Figure 8. Peace River Bridge bottom flange details, (a) welded splice, (b) bolted splice.

The contractor concurred with all of these decisions by the designers, and found them useful for the erection of the bridge.

At the time of ordering steel the contractor requested some changes that would increase the capacities of the webs (in bearing) and some flanges and splices. Permission was readily granted by the owner.

As the erection scheme was developed further it was found that the bottom flanges did not have the capacity to resist lateral forces unless the forces were applied to at least 3 girders, instead of simply the outside ones. This requires a fairly elaborate and expensive arrangement of temporary guides to ensure uniform load sharing.

The west 45 m of the bridge, the last to be launched, had the steel plate girders splayed instead of parallel to accommodate a widening of the road. This splay proved to be of considerable difficulty for the contractor and added significantly to his expense. If the contractor had been responsible for the design he might have preferred a different design for this portion, perhaps maintaining the girders parallel.

This was a well-designed bridge for which the designer had considered the method of erection and had designed some of the vital details to facilitate the construction.

The contractor accepted this and appreciated it; and at the same time expressed the opinion that he would have preferred that either the designer would have developed the erection scheme in even more detail, or if that were not appropriate, have flagged up those aspects of erection that the designer had not considered. The final erection scheme was complex and took about 9 months to engineer. Thus not all the difficulties were apparent at the time of bidding, a situation that cost the contractor a considerable amount.

The bridge was successfully launched to Pier 3 during November and December of 1990, at which time it was halted to await the completion of Pier 4 which had been delayed by flooding and ice.

3. SUMMARY

This paper has been illustrated by four case histories of steel bridges.

In two cases the designer considered the erection scheme in detail. In both cases the contractor improved on the designer's scheme and completed ahead of schedule.

In one case the designer considered erection in principle but not in detail. This may well have been appropriate, but the contractor would have benefitted from a definition of what the designer did and did not consider.

In the other case the designer apparently did not consider erection at all when preparing the design and the question is left open as to how the economy of the bridge would have been affected if erection had been considered.

From these examples, and others in the author's experience, it is concluded that the best results are obtained when the designer has in mind at least one good and economical method of construction, thought through in sufficient detail that others can have confidence in the designer's method, even if that is not the one finally adopted.

In addition, it will reduce the contractor's uncertainty if the designer clearly states which erection conditions have been checked and which have not.