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PROCUREMENT OF BEAMS IN MULTIPLE D&B BRIDGE PROJECTS

CT. Ramanathan[1], S.P. Narayanan[2] and Taharin, M.R.[3]
[1] Project Manager, Kumpulan Liziz Sdn Bhd, 33-11-1, 1 Lorong Ruang Grace Square, Grace Square, 88000 Kota Kinabalu, Sabah, Malaysia
[2] Civil Engineering Department. Universiti Technologi PETRONAS, 31750 Tronoh, Perak.
[3] School of Engineering and Information Technology (SKTM), Universiti Malaysia Sabah, Locked Bag No. 2073, 88999 Kota Kinabalu, Sabah, Malaysia
Corresponding author: ramoo_ctr@yahoo.com

Abstract

Selected infrastructure development projects are being implemented by Design and Build (D&B) procurement system in Sabah (East Malaysia) by the Public Works Department (PWD). In the first phase 45 bridge replacement projects were awarded in 5 packages. These simultaneous multiple Bridge projects are for the development of the backward areas and hence their timely completion is utmost important. Procurement and production of bridge beams have been the critical element of construction in these rural areas and no researches has been reported on various aspects of procurement of the bridge beams in multiple D&B projects. The aspects of procurement researched in this work include the determination of a common beam element for the ease of procurement and the optimization of the construction methodology, the finalization and purchasing plate dimensions to suite the manufacturer's production range, the delivery of materials, the planning and monitoring of fabrication, the preparation and assembly, and the erection and launching of beams. The beams are optimized using element optimization techniques. The most important problems in fabricating steel girders were in planning and scheduling of materials for the fabrication and the fabrication process. Findings in all the aspects of production of steel girders are highlighted through a case study of six long span bridges at various locations in Sabah. Solutions drawn from lessons learnt which minimize wastages, and aids in timely completion of beams in multiple bridge construction are discussed.

Keywords: Beam procurement, Element optimization, D&B project, Steel girders fabrication, Multiple projects.

INTRODUCTION

The public works departments in many countries have adopted the Design and Build (D&B) procurement system for infrastructure development projects. In Sabah (East Malaysia) also selected infrastructure development projects are being implemented by Design and Build (D&B) procurement system. In the first phase 45 bridge replacement projects were awarded in 5 packages, referred to as Package A,B,C,D and E. These simultaneous projects are for the development of the backward areas and hence their timely completion is utmost important. Even though many countries have adopted this method of procurement, the literature review indicated that that the various aspects of this procurement have not been rigorously examined.

A number of decisions are to be made at three important stages of production which are Prefabrication stage, Fabrication stage and Post Fabrication stage. Prefabrication stage consists of preparing shop drawings, choosing plate dimensions, selection of supply source and fabrication methods which play important role in reducing the unnecessary time lag and wastage of steel. Fabrication stage consists of preparing materials, planning and monitoring fabrication, assembling of components (welding), applying protective coating and inspecting & dispatching the fabricated sections to site. Post Fabrication stage consists mainly of site assembly and erection of girders. It will differ based on site conditions. Truss bridges are suitable for locations requiring less free board conditions with limited vertical elevation. All structural steel complies with BS4360 and is of Grade 50B and connections utilize HSFG High friction bolts and nuts. The maximum length of a single piece beam is 12m (without splicing).

This post graduate work has undertaken detailed research on various aspects of this procurement method through a case study.

LITERATURE REVIEW

The economical competitiveness of steel bridges for shorter span range is low (Mizukami et. al, 2005). However, long span steel bridges are competitive. Modern designs give them a cleaner open look. There are different varieties of long span steel bridges such as Arch bridges, box girders, cable stayed, modern suspension bridge and the more common and popular plate-girders. The weight of the superstructure of steel girders is lower compared to concrete girders of comparable spans thus reducing the foundation cost. Since depth of steel beam is less compared to other types of beams, the approach roadway costs are significantly reduced. Different concepts in design of bridge superstructures made of high grade steel components have been discussed by Reno et al (2000). The traditional single-plate girder erection is the most common and generally the most effective. It is suitable for countries like Malaysia and has been adopted for many projects.

Literature related to procurement of plate girders for bridges is reviewed in this section. The scheduling of fabrication of plate girders is one of the most important issues in the planning and operation of fabrication systems. The problem of scheduling arises whenever a number of tasks is performed using a limited number of resources. Proper shop control systems are required to achieve the targeted production by having the right item or equipment and preventing excess inventory to hide problems which will translate into considerable direct and indirect savings (Karumanasseri et. al, 2002).

Mizukami, S et. al (2005) verified the validity of design methods through analytical and experimental studies for a new type shape-steel bridge and rationalized the fabrication and erection by integrating main girders and composite slabs with steel panels. Other methods used were the elimination of slab-haunch, simplification of connection between slab and girder, reduction of transverse stiffening structures, and the change of simple girder into continuous girder on site. The study contributed to larger application of steel bridges in bridge construction. The construction schedules were compared to those of a conventional bridge in Figure 1.

The erection, handling and launching of long span steel girders are complex due to the stability of the girders (Fasick, et. al, 2005). The long span plate girders are very flexible and unstable requiring temporary bracings, launching trusses, additional machineries and launching equipments to support and place in position. Problems in erection of the girder will differ from bridge to bridge based on site condition and the condition of the river.

Bureau of Construction and Materials in the Department of Transportation of the Commonwealth of Pennsylvania (2004) has given the Guidelines for Documentation in the part 1 of its inspection manual. The guidelines for inspection of fabricated structural steel are: “Record accurate records of each project in sufficient detail so that they may be used to facilitate the investigation of defects in structures that are identified at a later date. Do not accept any material which varies from the plans, drawings, specifications or supplements without the Department’s written approval of the specific variation. Do not approve any deviation from the shop drawings or shop details even when an error is suspected. Report and seek approval from the Structural Materials Engineer in such an event.” In line with this guideline the main factors for material selection after preparing shop drawing and before purchase procurement has been discussed.

The review conducted on various forms of procurement and production of beams in bridge construction show that research on the aspects of procurement and production process of beams for multiple D&B bridge project is lacking. The areas requiring important focuses were identified in this research. Research

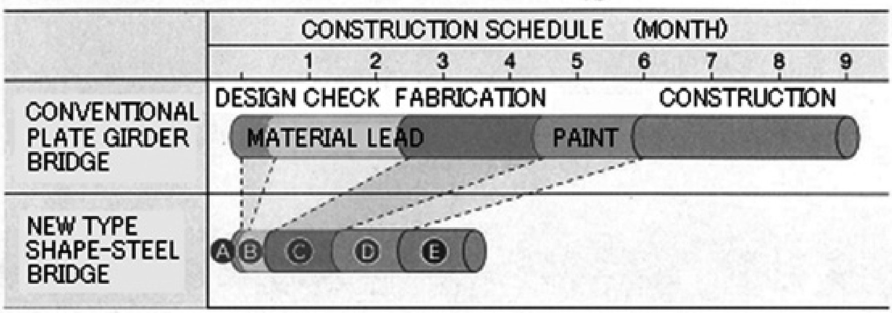

Figure 1: Comparison of Construction schedule (Mizukami et.al. 2005)

has been conducted using the case study method. The objectives and methodology are described in the following section.

OBJECTIVES OF THE RESEARCH

The objective of the research work is to investigate the following aspects of the procurement and the production of steel beams for multiple D&B bridge projects:

1. To analyse and optimize the use of different types of beam elements.
2. To investigate the methods of reducing material wastages while preparing orders to procure structural steel for fabricating plate girders.
3. To prepare the schedule plans for the fabrication sequences of multiple bridge beams.
4. To identify the sequence of the assembly and the launching of the steel girders.

METHODOLOGY

A case study was conducted on the process of selection and production of steel beams in multiple D&B Bridge projects through the following steps:

1. Preliminary design – This consisted of the conceptual design stage where the bridge elements were optimized by weight distribution analysis.
2. Shop drawing and selection of materials – This step finalizes the drawings and enables the calculation of exact material requirement.
3. Purchase procurement and delivery process - This step aims to reduce the wastage of raw materials based on proper understanding of the suppliers' capacity. It also plans the delivery pattern of materials for multiple projects.
4. Fabrication process – Discusses the major stages of production.
5. Planning and monitoring - Scheduling of the multiple bridge activities for beams production.
6. Erection / Launching – Discusses the methods of placing beams to position the final activity to complete the beam works.

A CASE STUDY

Preliminary Design

In D&B procurement method as both design and construction are considered as a single entity responsibility. The design has to be considered during the conceptual stages. Designers have the advantage of a more integrated approach to design and construction in D&B. The configuration of bridge elements needs to be developed to optimize the construction methodology, which is a primary component of the cost. This emphasizes the need for designers to approach both the superstructure and substructure design considering constructability and optimum cost. The plate girder bridges in the multiple projects had spans of 40, 50, and 62m; flange thickness of 30-40mm, and web and stiffener thickness of 15-16mm.

Weight Distribution Analysis of Different Bridge Elements

The weights of elements in five different projects (Package A, B, C, D and E), are compiled and compared in Figure 2. The weights are the cost of the manufacture of the elements calculated as a percentage of the total cost.

Figure 2 clearly shows that the contribution of "Precast, Prestressed Beam and Ancillary" and "Piling works" are major when compared to other elements of the bridge. As an example the optimization of the beam element is discussed below. The critical beam elements for each project are as follows:

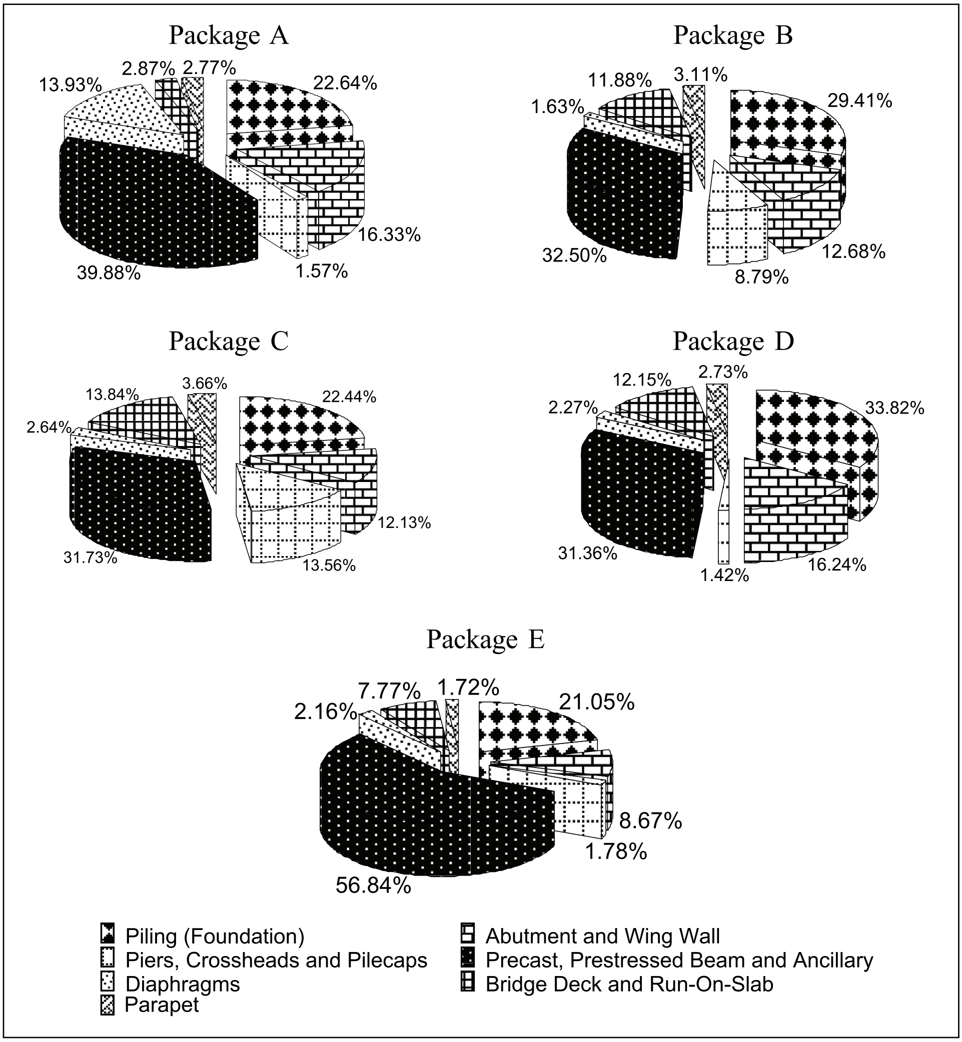

Figure 2: Element weight distribution in bridge construction for different packages

Project 1 – Package A

Critical element - Cast insitu Post tensioned beams of two shapes I-16 and I-20.

Project 2 – Package B

Critical element - Cast insitu Post tensioned beams of shapes I-16 & I-20 for 2 Bridges.
- Prestressed precast beams (from factory) for 3 Bridges.

Project 3 – Package C

Critical element - Cast insitu Post tensioned beams of shapes I-16 & I-20 for 4 Bridges.
- Prestressed precast beams (from factory) for two bridges.

Project 4 – Package D

Critical element - Cast insitu Post tensioned beams of shapes I-16 & I-20 for 6 Bridges.
- Prestressed precast beams (in factory) for 6 bridges.

Project 5 – Package E

Critical element - Cast insitu Post tensioned beams I-16 for 1 Bridge.
- Steel girders for 5 Bridges
- Steel trusses for 1 Bridge

The influence of "Precast, Prestressed Beam and Ancillary" activity on the Bridge construction is high in spite of their less quantity in physical work. This is because of their specialty nature. Hence care was taken while choosing the specialty works to suite the local availability. Eventually a few specialized designs were used for those particular elements. From this comparison, in Package E (Project 5) the Beam contribution is > 55%, which is relatively higher than other packages having prestressed concrete beams element. The weight ratio of this steel girder beam is higher due to its high cost, scarce availability/production, requirement of highly skilled specialist for fabricating the beam, etc. to manage, produce and erect these steel beams.

Designs are standardized and kept as simple as possible by maximizing the use of common details and minimizing the number of plate sizes and rolled shapes. This facilitates easy sourcing and procurement of material in time. Reducing complicated details will eventually reduce the complexity in fabrication. Designers also try to maintain the same bolt diameter for each detailing. This will reduce the complication in drilling holes for bolts.

Shop Drawing and Selection of Materials

Shop drawings are prepared according to the construction drawings. They need to be submitted to the engineer for review and approval. All the dimensions and fit to the structure will be the responsibility of the D&B contractor and fabricator.

Based on the approved shop drawing, the list of materials with dimensions are prepared and passed to the supplier. The list of materials required for the projects are shown in Table 1 and 2 in columns 1 to 5. Table 1 shows materials of grade 50B whereas table 2 shows materials of grade 43A. Malaysia produces high tensile steel G50 plates less than 30mm thick. The plates with thickness more than 30mm are outsourced (the import of materials requires Import Permits).

The maximum lengths of plate available for different plate sizes are different. The maximum length of the plate supplied by factories depends on the weight of material and procedures and equipments used by the mill (Texas Steel Quality Council, 2000). Due to these limitations Malaysia can only produce plates of maximum length 9000mm for thickness less than 30mm. Because of this, the list of steel materials is revised and the finalized Purchase orders are issued for supply and delivery. This will force the fabricator to increase the number of splice joints depending on the maximum length supplied. Thus there is an increased quantity of steel purchased than the actual requirement. The wastage of steel is proportionally increased causing cost escalations in material purchase as well as increased fabrication cost. Columns 6 to 10 of Table 1 and 2 shows the increase in the wastage due to the mismatch between the lengths specified by the designers in the construction drawing and the length limits of production in the factory. The wastage is 34% for materials in table 1 and 3% for materials in table 2.

Even the use of differing plate widths resulted in less quantity of each size, which the factory cannot economically produce, since certain minimum quantities are required. Thus, purchase order is adjusted to combine the nearest plate widths to achieve the minimum quantity of factory requirements. This has further increased

Table 1: Wastage in revising material dimensions for High Tensile Steel Plate of material BS 4360 Grade 50B

Original Size					Offer Size				
Thick mm	Width mm	Length mm	Qty No.	Total Tonnes	Thick mm	Width mm	Length mm	Qty No.	Total Tonnes
75	1200	2400	1	1695.60	75	1200	2400	1	1695.60
30	1200	2400	1	678.24	30	1500	6000	1	2119.50
25	1525	12000	2	7182.75	25	1525	9000	3	8080.59
25	1200	6000	13	18369.00	25	1525	6000	12	21548.25
20	1525	12000	2	5746.20	20	1525	9000	3	6464.48
16	1200	6000	3	2712.96	16	1525	6000	3	3447.72
15	1200	12000	6	10173.60	15	2000	9000	10	21195.00
15	1200	6000	2	1695.60					
				48253.95					64551.19
Percentage of wastage of material									34%

the percentage of wastage. The quantity of steel in "original size" column in table 1 and table 2 has certain wastages in cutting to shape. This wastage has increased to 34% for Grade 50B material and 3% for Grade 43A material due to the mismatched length and breadth limits between the construction drawing and the factory production.

The materials were purchased in accordance to the purchase order and "delivered Cost Insurance Freight [CIF] to Kota Kinabalu, Sabah". As the materials were procured from various international sources, the shipments also arrived at different times. In Multiple D&B projects there is an advantage of purchasing material in a single order which reduces the cost of material, cost of sea or road transport and handling charges. These savings compensate the additional wastage of material due to size limitation in factory production. The single time purchase for multiple projects will also enhance the schedule of fabrication with no idle time for any activities in the sequence resulting in early completion which will in turn reduce the overheads of the construction.

Purchase Procurement and Delivery Process

The fabricator will get port clearance for the imported materials and transport them

Table 2: Wastage in revising material dimensions for High Tensile Steel Plate of material BS 4360 Grade 43A

Original Size					Offer Size				
Thick mm	Width mm	Length mm	Qty No.	Total Tonnes	Thick mm	Width mm	Length mm	Qty No.	Total Tonnes
15	2000	9000	46	97497.00	15	2000	9000	46	97497.00
16	1850	9000	25	52281.00	16	1850	9000	26	54372.24
16	1830	10000	55	126416.40	16	1830	9000	65	134461.08
16	1800	12000	32	86814.72	16	1800	9000	45	91562.40
20	1500	12000	20	56520.00	20	1500	9000	28	59346.00
20	1750	12000	50	164850.00	20	1750	9000	68	168147.00
25	1500	12000	8	28260.00	25	1500	9000	13	34441.88
30	1800	12000	7	35607.60	30	1800	9000	11	41966.10
35	1680	12000	2	11077.92	35	1680	12000	2	11072.92
40	1950	9000	20	110214.00	40	1950	9000	20	110214.00
40	1950	10000	35	214305.00	40	1950	10000	35	214305.00
40	1950	10300	10	63066.90	40	1950	10300	10	63066.90
40	1950	12000	11	80823.60	40	1950	12000	11	80823.60
40	1600	12000	9	54259.20	40	1600	12000	9	54259.20
				1181993.34					1215540.32
									33546.98
Percentage of wastage of material									3%

to their factory yard and stack them bridge wise. After the shop drawing is approved the fabrication work starts in the factory. These fabricated plate girders are then delivered to the site in single sections and then connected together. The mill quality certificates for the materials are obtained and verified with the materials supplied.

Fabrication Process

The steel girder fabrication consists of five main activities, namely Manage Order, Design and Detailing, Procurement of Materials, Fabrication, Erection and their associated data items (eg. Order and Stock list) (Yusuf and Smith 1996). The sequence of fabrication activities namely planning, preparation of materials, assembly of the components, paints and protective coatings and inspection and dispatch have been discussed in Yusuf and Smith (1996).

Planning and Monitoring

The plan for fabrication activities is prepared to monitor the progress of work. The schedule of fabrication work in Multiple Bridge projects is shown in Table 3. The sequence of fabrication in table 3 is scheduled to synchronize with the master physical work program for completion of the respective bridge substructure. It is then prepared for launching.

The fabrication work in Multiple Bridge projects is shown graphically in Figures 3 and 4. The figures clearly show that the fabrication activity of one bridge is not disturbed by the other. This graphical analysis helps the manager to identify the situation when the activity of one bridge is crossed by the other. This will enable the problem to be corrected at an early stage.

Table 3: Planning and scheduling of the fabrication sequences in Multiple Bridge project

Month	**Supply**	**Cut & Drill Hole**	**Trial Assemble**	**Welding works**	**Pre - assemble**	**Sand blasting**	**Prime coat**	**Deliver to site**
1	Bridge 1-5	Bridge 5						
2		Bridge 1	Bridge 5	Bridge 5				
3		Bridge 2	Bridge 1	Bridge 5				
4		Bridge 4	Bridge 2	Bridge 1	Bridge 5	Bridge 5		
5		Bridge 3	Bridge 4	Bridge 1			Bridge 5	Bridge 5
6			Bridge 3	Bridge 2	Bridge 1	Bridge 1		
7				Bridge 2			Bridge 1	Bridge 1
8				Bridge 4	Bridge 2	Bridge 2		
9				Bridge 4			Bridge 2	Bridge 2
10				Bridge 3	Bridge 4	Bridge 4		
11				Bridge 3			Bridge 4	Bridge 4
12					Bridge 3	Bridge 3		
13							Bridge 3	Bridge 3

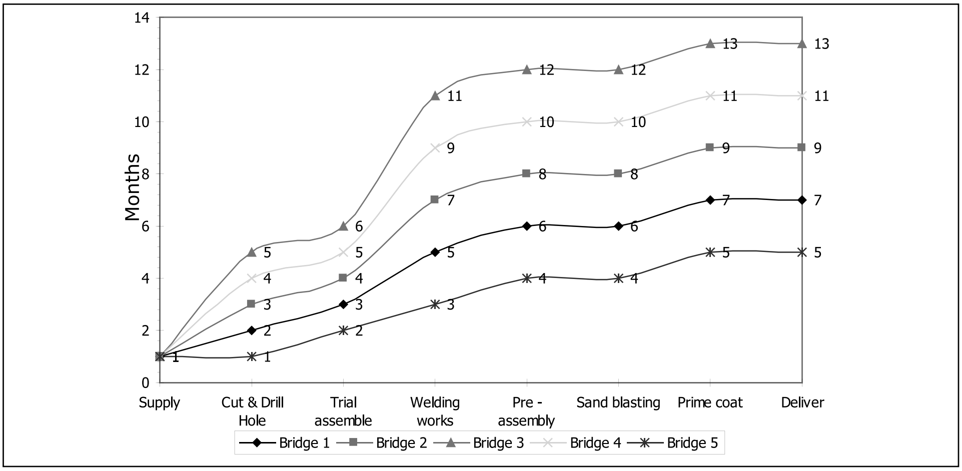

Figure 3: Activity schedule bridge wise (graphical view)

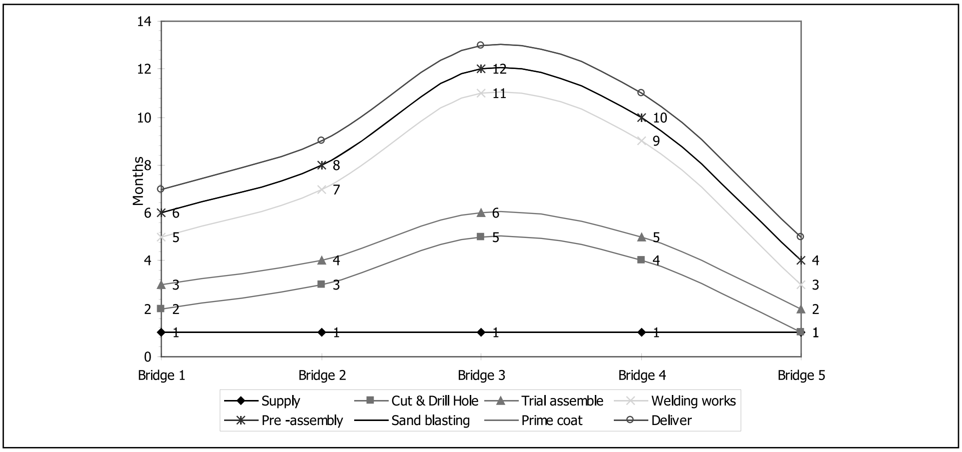

Figure 4: Bridge schedule activity wise (graphical view)

Preparation and Assembly of Materials

The steel plates for I beam girders are prepared by cutting to dimensions and punching holes for bolts at splice joints, bracing location and gusset plates. Only qualified welders are allowed to perform high grade welding. The stiffeners are cut into the required sizes and the welding is done for joining the top and bottom flange with the web and the stiffeners. A trial assembly is made to check the girder setup in the factory before delivery to site. The inspection for pre-camber is conducted for the overall appearance of camber for the entire span. Figure 5 shows the sequence of work in the fabrication yard.

During and after the fabrication work the following stages of quality control and protection work are to be

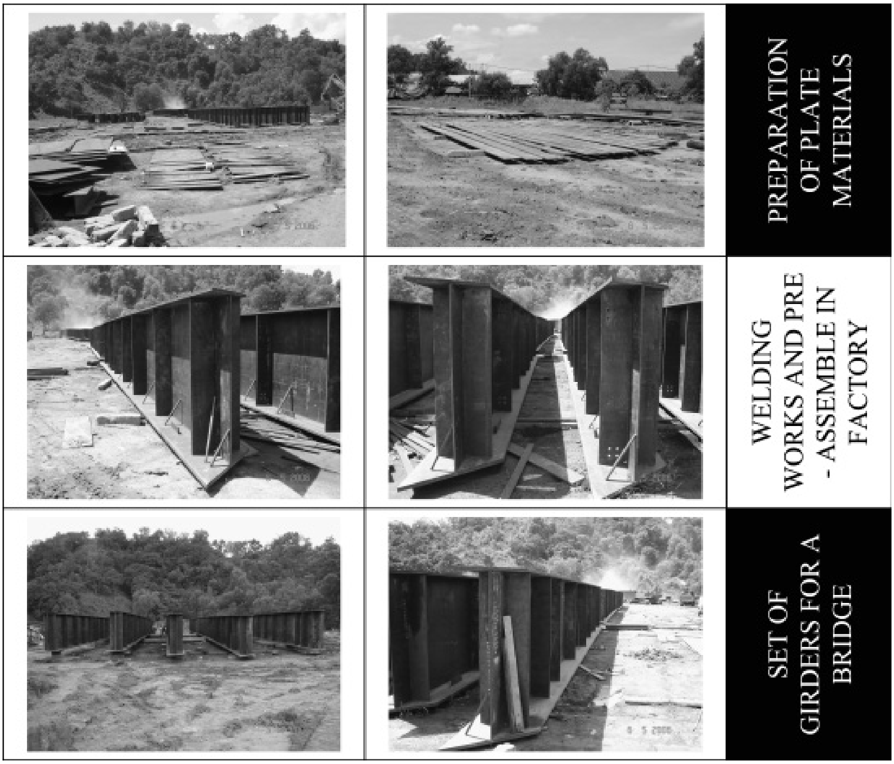

Figure 5: The sequence in the I-beam fabrication in the yard

Figure 6: Radiographic testing in the fabrication yard

carried out in the factory before delivering the beams to the site.

(i) ***Non destructive testing***

Radiographic testing is conducted on the welded joints and two sets of the test report with the X-ray films are submitted to the consultant for checking and approval. The testing methods and the procedures were according to the recommendations of the testing specialist as shown in Figure 6.

(ii) ***Protective coating on steel girders***

This consists of two stages namely cleaning and painting.

- Cleaning removes the rusty scale and gives a smooth finish (Figure 7). The perfection of the finish should be as given in the specification. The cleaning is carried out by sand blasting.
- Prime coat is applied on the cleaned surface in the fabrication yard

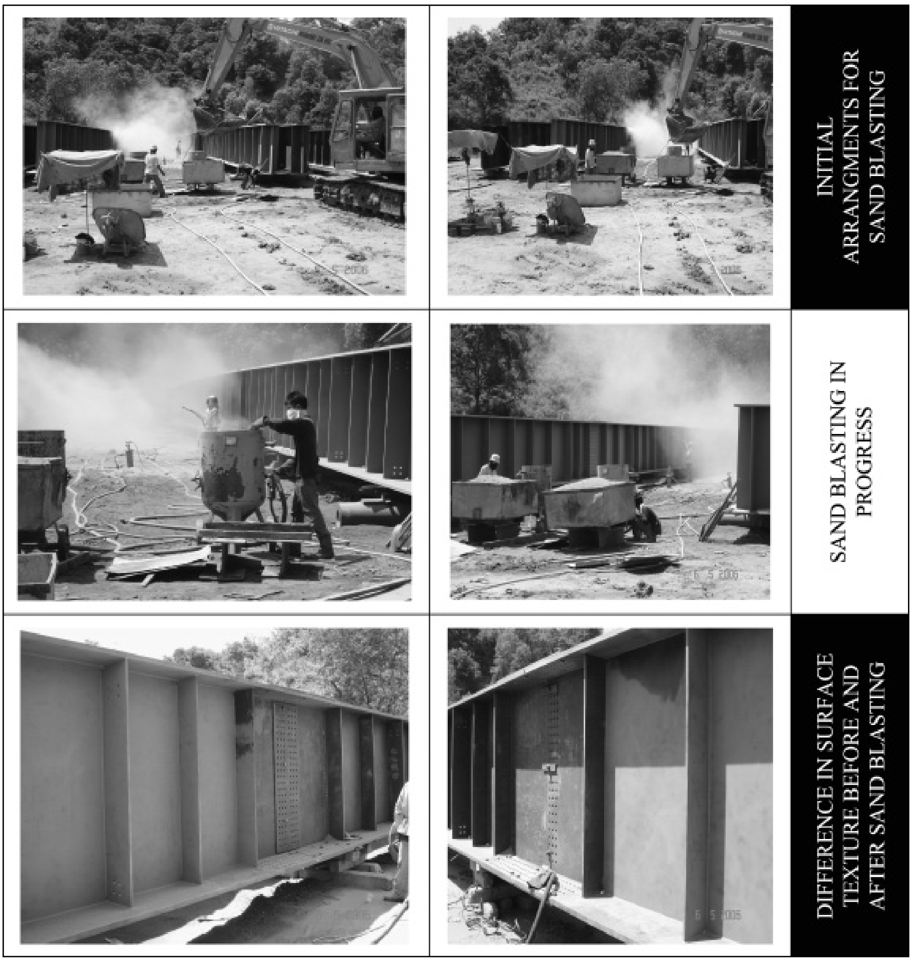

Figure 7: Performing cleaning work by sandblasting

immediately after blasting (Figure 8). The final coat of paint is applied after completion of the launching and the inspection of the erection.

(iii) ***Inspection and Dispatch***

The steel girders are checked for pre-assembly, pre-camber and protective coating by the consultant. Arrangements are made to dispatch the steel girders to the project site. These materials are unloaded at the site for final assembly or Erection and assembly based on the site conditions and launching methods that best suit the site condition.

Erection and Launching

Fasteners are installed and tightened in the field. HSFG bolts with diameter varying from 10 to 32mm were used as fasteners. In order to verify the tightness of the fasteners inspection was carried out.

The method of erection and launching of long-span steel girder are chosen based on the preference of the contractor and the site condition. Contractors have their own techniques of launching. However, the critical factor in launching the long-span steel girders is the flexibility of the material. Flexible girders may require support by holding cranes or supported with excavator arm.

The conventional launching method of handling beams by lifting and placing is not suitable for the long steel girders which are more flexible. Thus, launching trusses may be required for the girders to travel across the substructure and to finally place it in position by lifting the beams from the launching truss as shown in figure 9. After launching, the shear connectors are welded on the beams as per the drawings. This is followed by placing the soffit formwork of the deck slab. The reinforcement is placed on the formwork and the slab is cast.

The steel truss for bridge in Package 5 was launched using temporary structure across the river. The truss members were assembled horizontally and then lifted to vertical position for erection of the complete structure as shown in Figure 10.

Lessons Learned

There were many factors which contributed to the success of Multiple D&B project with steel girders. The following lessons were learnt during the execution of the bridges.

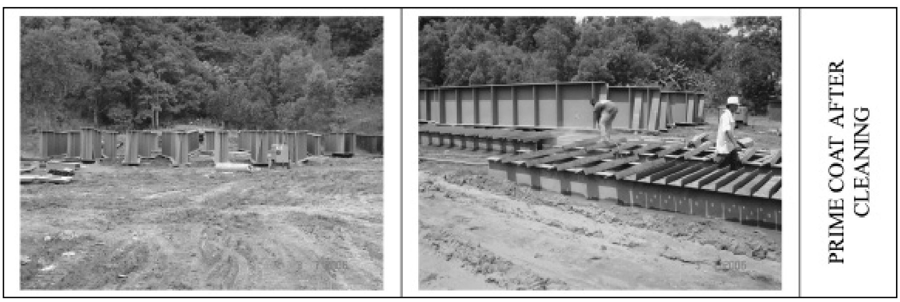

Figure 8: Application of protective prime coat to beams and angle bracings

1. Plans and shop drawings were provided to the supplier for early delivery of materials which accelerated the fabrication process from the beginning of the contract.
2. The steel fabricator was given targeted schedules of completion for all the five bridges derived from the master work program. The fabrication of beams was completed and delivered to the site on time for the respective bridge erection where the substructure was ready.
3. The steel girders were long and deep. Proper calculations were done to ensure the safe loading of girders

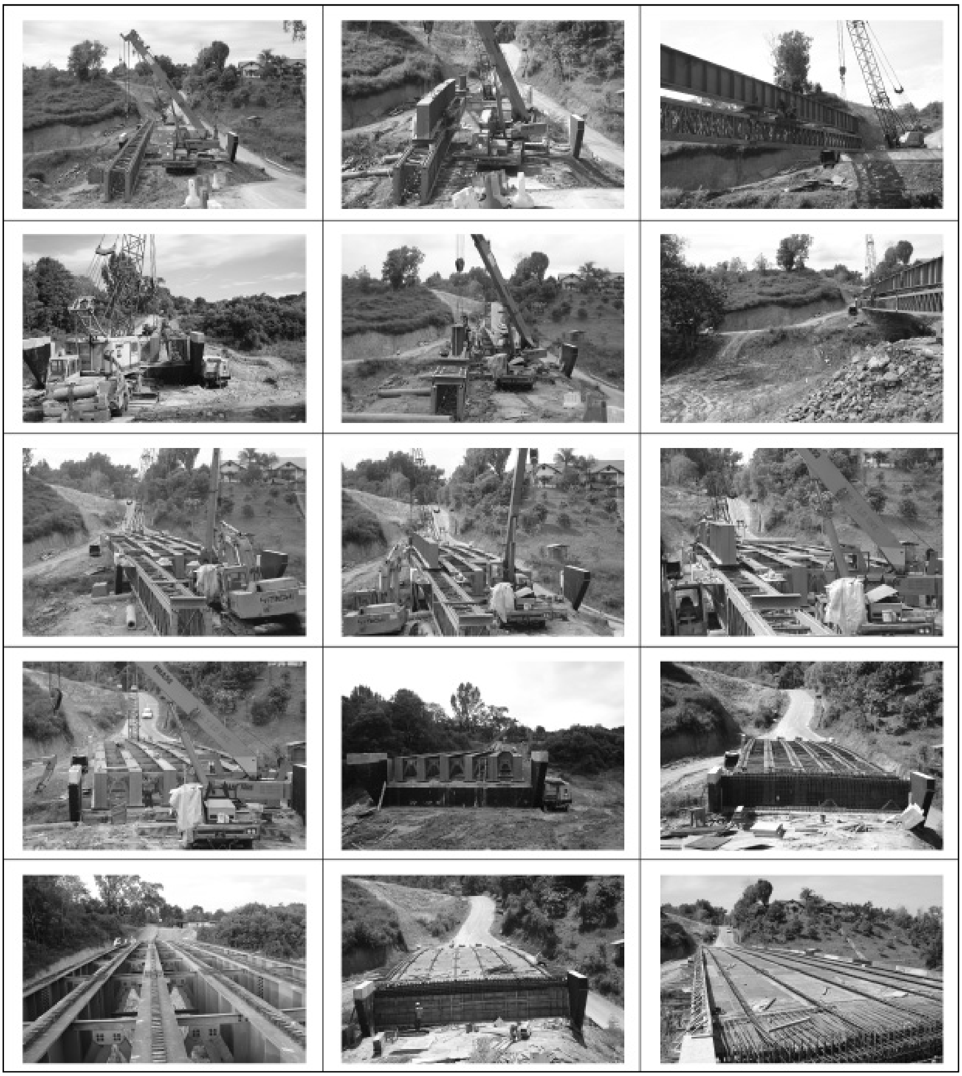

Figure 9: Sequence of erection and launching of steel girders

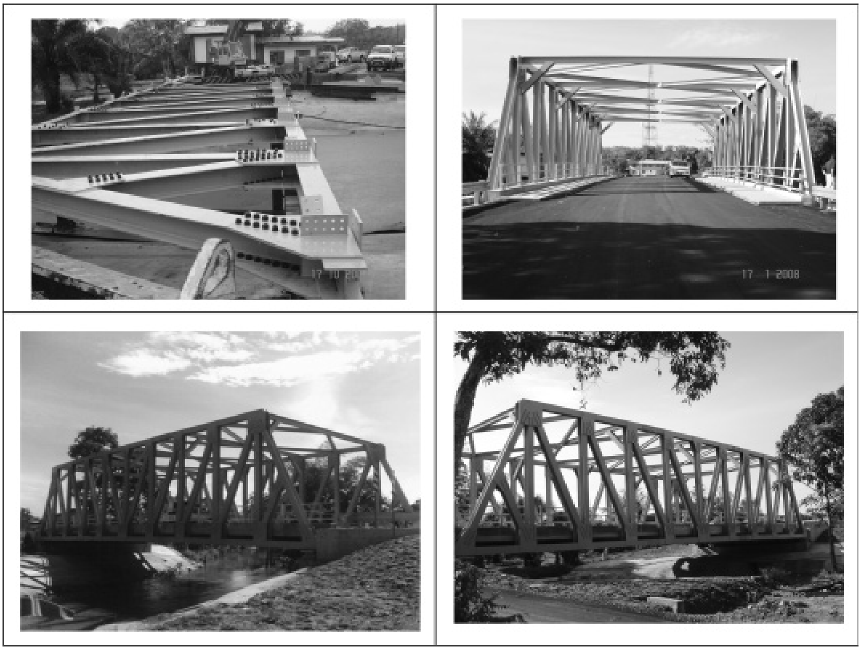

Figure 10: Erection of steel truss for bridge in Package 5

onto the trailers while transporting the beam to the site. No unforeseen problems occurred. This had reduced the time of transportation. The number of trips was also reduced by avoiding underestimated load of materials on the truck.

4. The work of steel fabrication and the beam launching were awarded to a single specialist. This resulted in efficient performance without any time lag in different activities of factory work and site work. The problems in work coordination were overcome by appointing specialist capable of performing these two tasks.
5. The designers took advantage of this integrated approach to D&B concept. Each element of the bridge was chosen to optimize the construction methodology. This helped in the cost effective completion of the project.
6. The flange width had an impact on the stability of the girder during handling and erection. Therefore all the ‘I’ girders were designed by the consultant to have a high stability ratio. Hence the girders were handled without any critical problems while launching.
7. An open joint, which allows water runoff from deck slab to reach the steel girder, is to be avoided. Special fixtures to guide the water to flow below the bottom flange need to be introduced and installed.

Some areas which need to be improved in multiple D&B bridge project are as follows:

1. A constant flange width for the entire length of the girder needs to be provided, wherever applicable. The designers should avoid flange dimension of smaller quantity as it may not be possible to source it in the market. This will also result in purchasing flanges of different sizes resulting in excess material wastage.
2. Mass production of steel bridges in multiple design projects can utilize new technology such as digital control of cutting, drilling, welding and bolting. Robotics has added another dimension to the production of steel members by providing the potential for expedited production without sacrificing quality. This has to be brought into the practice.
3. There is a need to search for new forms of steel structures with cost effective designs that could accelerate production. Development of High Performance Steel (HPS) and Hybrid structures will redefine the design of steel bridges.
4. An effective system for servicing and replacing damaged members must be implemented for the most common problems like fatigue related cracking that occurs along the welds of secondary members (stiffeners, diaphragms and lateral bracing) to the main girder. Such cracks will propagate along the weld and cause major disasters like the Minneapolis Bridge collapse in US on August 1, 2007.

CONCLUSION

- The case study has helped to identify solutions which were explained in the 'Lessons Learned" section. Solutions were based on the actions that did and did not work well. This subject has great value to construction community in managing and implementing similar projects successfully.
- Designers, D&B contractors, Fabricators and Erectors need to work together from the conceptual design stage to prepare a suitable design that is more cost effective with less wastage, less complexity in fabrication, quick production and stable section for easy launching methods.
- Splice locations are dependent on the available plate lengths. Fabricators need flexibility in detailing to make adjustments to the number and location of splices. This can be done with the designer's approval. A note to allow this point shall be added in the design details.
- The consultant should have knowledge on the availability of the local steel products and include this in their initial design to reduce wastage. The cost impact will be higher if non-availability is identified after the approval of the design.
- A thorough analysis on road conditions leading to the site is required. The designers should provide an optional field splice to avoid longer span resulting in difficulties to transport the sections to the site.

- Design and fabrication principles should be carried forward to the goal of achieving cost-effective designs that reflect the response of the structure to a life-cycle environment and result in structures that are safe, buildable, maintainable, serviceable, inspectable, and decommission able.
- The design should consider maintenance, expansion, and decommissioning.
- Steel is rapidly becoming a completely recyclable product, which benefits the environment when decommissioning takes place.

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