ELEMENT OPTIMISATION TECHNIQUES IN MULTIPLE DB BRIDGE PROJECTS

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ABSTRACT

Management of multiple bridge projects relies on the selection and optimisation of elements. Problems are avoided if construction knowledge and experience are utilised. A systematic selection process is required during design stage to maximise the use of available resources. Multiple bridge designs incorporate practical suggestions from the field personals. The case study in East Malaysia considers problems of material, labour and equipment availability. The average ratio presence of each element is calculated to show its impact. The need of element optimisation techniques in bridges is emphasised. The database is presented and also the process undertaken during the design is discussed.

Keywords: Design and Build process, Multiple project management, Bridge elements, Average ratio presence.

INTRODUCTION

Bridge structures are designed with high quality and safety standards but sometimes with not enough attention to construction methods, site conditions and details. Construction problems encountered during execution are complex and costly. Many construction problems can be avoided with proper attention and consideration of the construction process during the design phase [1]. Factors of simplicity, flexibility, sequencing, substitutions and labour skill and availability should be the part of design. The appropriate use of standardisation can have several benefits [1]. These include increased productivity and quality from the realization of repetitive field operations, reduction in design time, savings from volume discounts in purchasing, and simplified materials management. This method of standardising bridge elements may be suitable for selective projects of same nature but are less significant and more complex when constructing multiple bridge projects situated at different site conditions.

The construction process and success in management of multiple bridge projects directly relies on the selection and optimisation of their elements/ components. A systematic optimization process is adopted during the conceptual design stage to overcome the resource constraints during the construction phase. The knowledge of construction experience is also utilised during the element optimisation process.

D&B combines the design and construction functions to vests its responsibility with one entity: the design-builder. The D&B process changes some fundamental relationships between the client and the contractor. The client employs a Project Director as the

This paper was presented at the International Conference on Construction and Building Technology 2008, Kuala Lumpur, 16 - 20 June 2008

representative, whereas the contractor has to engage design consultant and manage the construction of the whole project. Owners employ only one contractor who is solely responsibility for delivering the assigned project with defined requirements, standards and conditions. Both parties are expected to aim for a successful project outcome.

BACK GROUND AND PROBLEM STATEMENT

Sabah situated on the northern tip of the island of Borneo is the second largest state in Malaysia. Over 70% of its population lives in rural area as majority are depending directly or indirectly on agriculture. The state has several development projects procured by D&B Method for Upgrading rural roads and Bridges replacement for the benefit of rural sectors contributing to the national economy. Five contract packages comprising 45 bridges located in 12 districts in the state having 76 115 square kilometer coverage area [2] and two road projects in one district was assigned to the first author's company. As summarised in Figure 1, the Bridge projects and the two road projects were handled simultaneously.

This study examines the use of element optimisation technique through a case study for managing the above multiple DB bridge projects in Sabah, East Malaysia. The data of bridge elements of all the 45 bridges were collected and compiled. The ratio of each element in individual bridges and their average ratio presence in each projects were compared for study.

RESEARCH METHODOLOGY

The element ratio comparison and analysis were made in the following steps.

1. Review of all the five projects and compilation of the summary.
2. Prepare the element ratio table and Pi chart for each bridge of all the projects and analyse the ratio of their impact on the individual bridges.
3. Compress and derive a single and common average ratio table and pi chart showing the overall impact of each elements for the entire multiple project.
4. Identify the critical and crucial elements that need attention.
5. Discussion on the element of major contributions which is to analyse the element with maximum element ratio.

ANALYSIS OF COMPONENTS OF MULTIPLE DB BRIDGE PROJECTS

Schedules of the multiple projects

The projects started at different times having simultaneous construction periods at various stages

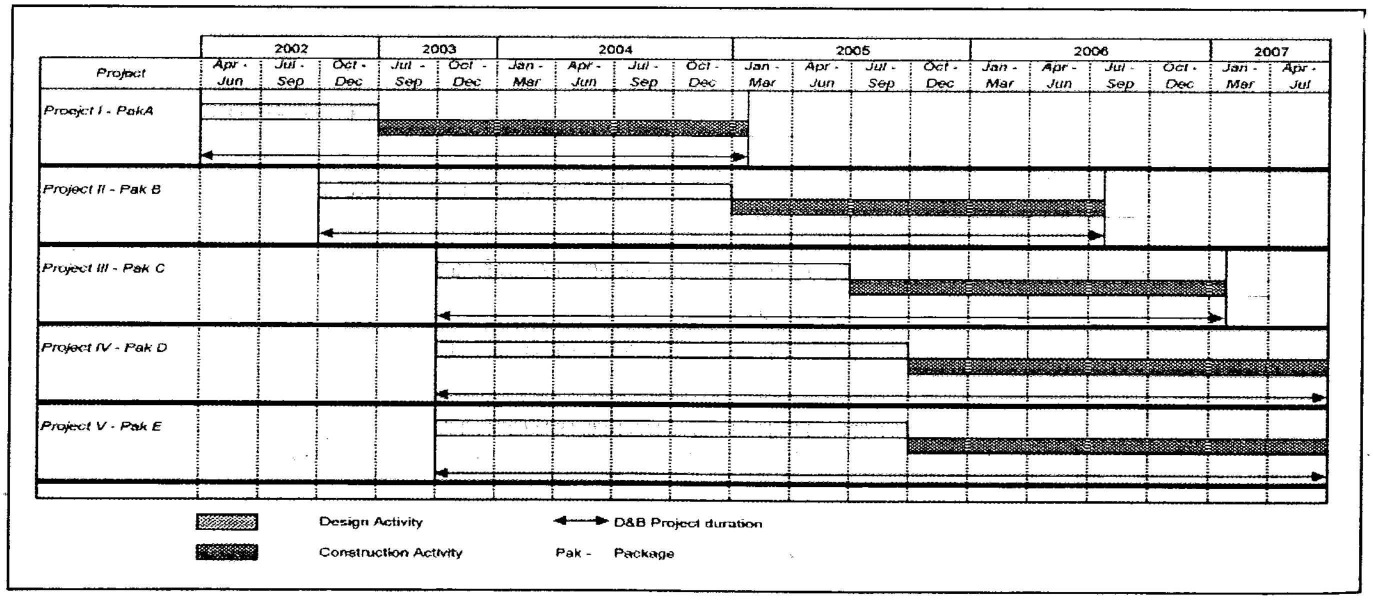

Figure 1. Duration of Multiple D&B projects in Sabah

Table 1. Schedule of Multiple contracts handled in Sabah

	Project Number	No. of Bridges	No. of districts	Project Duration	
			Locations	Months	Period
	1	12	3	18	Jul 03 – Jan 05
	2	5	3	18	Jan 05 – Jul 06
	3	8	3	18	Jul 05 – Jan 07
	4	13	3	20	Oct 05– Jun 07
	5	7	3	20	Oct 05– Jun 07
Total	7	45	12	48	Jul 03–Jun 07

of completion as shown in Table 1. The five projects involving 45 Bridges have been completed successfully and delivered to client for public usage.

Bridge element ratio

The element ratio for bridges for each project was calculated as given in the following section.

Project 1 – Package A

Table 2 and Figure 2 show the percentage presence of each element in constructing the bridges in Package A. From the weight breakdown it is clear that critical elements "Piling work (Foundation)" has greater than 20% presence and production of beams and erection has nearly 40% presence. The influence of these elements in the project is high in spite of their low quantum in physical work (20% and 40% respectively) because of their specialty nature. Hence, care should be taken while choosing these specialties works to suite the local availability and eventually use few specialised designs for those particular elements. In this manner these crucial elements in Package A were optimised in the design as follows:

Critical element No. 1: Piling works
- Steel H piles of driven type for 6 Bridges
- Micro pile of drilling type for 3 Bridges

Critical element No. 2: Beams
- Cast *in situ* Post tensioned beams of two shapes I-16 and I-20.

Table 2. Weight of each Element in bridges of Package A

Description	Ratio
Foundation (Piling)	22.64%
Abutment and Wing Wall	16.33%
Piers, Crossheads and Pilecaps	1.57%
Precast, Prestressed Beam and Ancillary	39.88%
Diaphragms	2.87%
Bridge Deck and Run-On-Slab	13.93%
Parapet	2.77%
TOTAL	100.00%

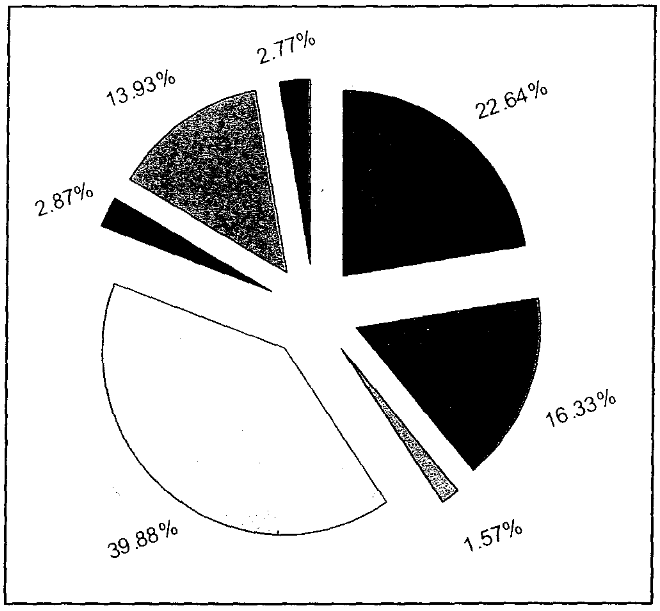

Figure 2. Weight of elements expressed as a percentage

Project 2 – Package B

Table 3 and Figure 3 show the percentage presence of each element in constructing the bridges in Package B. From the weight breakdown it is clear that critical elements are "Piling work (Foundation)" which has greater than 20% presence and "production of beams and erection" with 30% presence. The reasons as explained above for Project 1 have eventually resulted due to the use of specialised designs for those particular elements. In this manner these crucial elements in Package B were optimised in the design as follows:

Critical element No. 1: Piling works
- Micro pile for 3 Bridges
- Spun pile for 1 Bridges

Critical element No. 2: Beams
- Cast *in situ* Post-tensioned beams of two shapes I-16 and I-20 for 2 Bridges
- Prestressed precast beams (in factory) for 3 Bridges.

Table 3. Weight of each element in bridges of Package B

Description	Ratio
Foundation (Piling)	29.41%
Abutment and Wing Wall	12.68%
Piers, Crossheads and Pilecaps	8.79%
Precast, Prestressed Beam and Ancillary	32.50%
Diaphragms	1.63%
Bridge Deck and Run-On-Slab	11.88%
Parapet	3.11%
TOTAL	100.00%

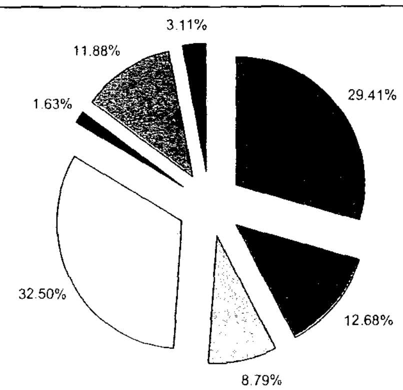

Figure 3. Weight of elements expressed in percentage

Project 3 – Package C

Table 4 and Figure 4 show the percentage presence of each element in constructing the bridges in Package C. From the weight breakdown it is clear that critical elements are again "Piling work (Foundation)" with greater than 20% presence and the "production of beams and erection" with greater than 30% presence. The reasons as explained above has eventually resulted due to the use of specialised designs for those particular elements. In this manner these crucial elements in Package C were optimised in the design as follows:

Critical element No. 1: Piling works
- Bored pile for 3 Bridges
- Micro pile for 2 Bridges
- Spun pile for 1 Bridges

Critical element No. 2: Beams
- Cast *in situ* Post tensioned beams of two shapes I-16 and I-20 for 4 Bridges.
- Prestressed precast beams (in factory) for two bridges.

Table 4. Weight of each element in bridges of Package C

Description	Ratio
Foundation	22.44%
Abutment and Wing Wall	12.13%
Piers, Crossheads and Pilecaps	13.56%
Precast, Prestressed Beam and Ancillary	31.73%
Diaphragms	2.64%
Bridge Deck and Run-On-Slab	13.84%
Parapet	3.66%
TOTAL	100.00%

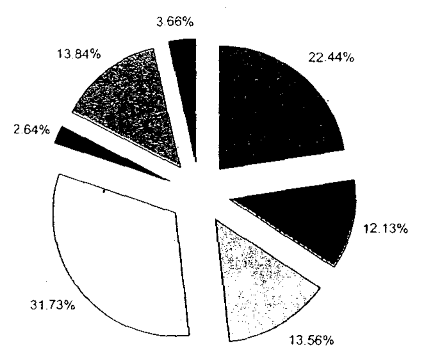

Figure 4. Weight of each element expressed in percentage

Project 4 – Package D

Table 5 and Figure 5 show the percentage presence of each element in constructing the bridges in Package D.

Critical element No. 1: Piling works
- Micro pile for 9 Bridges
- Spun pile for 2 Bridges

Critical element No. 2: Beams
- Cast *in situ* Post tensioned beams of two shapes I-16 and I-20 for 6 Bridges.
- Prestressed precast beams (in factory) for 6 bridges.

From the weight breakdown of the elements of bridge, it is clear that critical elements are "Piling work (Foundation)" has greater than 30% presence and the "production of beams and erection" with 30% presence. The reasons as explained above has eventually resulted due to the use of specialised designs for those particular elements. In this manner these crucial elements in Package D were optimised in the design as follows:

Project 5 – Package E

Table 6 and Figure 6 show the percentage presence of each element in the construction of the bridges in Package D. From the weight breakdown it is clear that critical elements are again "Piling work (Foundation)" with greater than 30% presence and the "production of beams and erection" with presence of greater than 55%. The reason is due to the design using Steel girder to suite the site condition. In this manner these crucial elements in Package E were optimised in the design as follows:

Critical element No. 1: Piling works
- Micro pile for 5 Bridges
- Spun pile for 1 Bridge

Critical element No. 2: Beams
- Cast *in situ* Post tensioned beams I-16 for 1 Bridge.
- Steel girders 5 Bridges
- Steel trusses 1 Bridge

Table 5. Weight of each element in bridges of Package D

Description	Ratio
Foundation (Piling)	33.82%
Abutment and Wing Wall	16.24%
Piers, Crossheads and Pilecaps	1.42%
Precast, Prestressed Beam and Ancillary	31.36%
Diaphragms	2.27%
Bridge Deck and Run-On-Slab	12.15%
Parapet	2.73%
TOTAL	100.00%

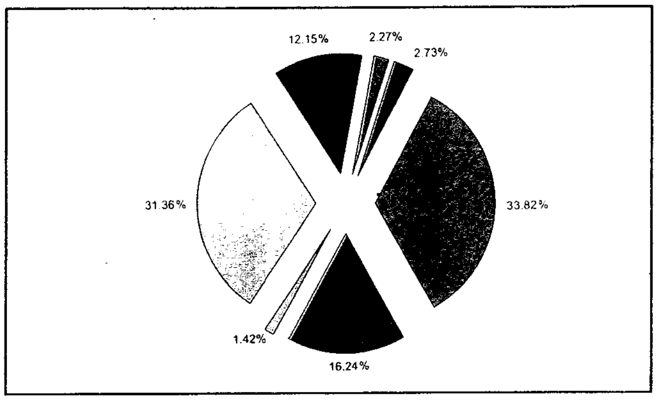

Figure 5. Weight of each element expressed in percentage

Table 6. Weight of each element in bridges of Package E

Description	Ratio
Foundation (Piling)	21.05%
Abutment and Wing Wall	8.67%
Piers, Crossheads and Pilecaps	1.78%
Precast, Prestressed Beam and Ancillary	56.84%
Diaphragms	2.16%
Bridge Deck and Run-On-Slab	7.77%
Parapet	1.72%
TOTAL	100.00%

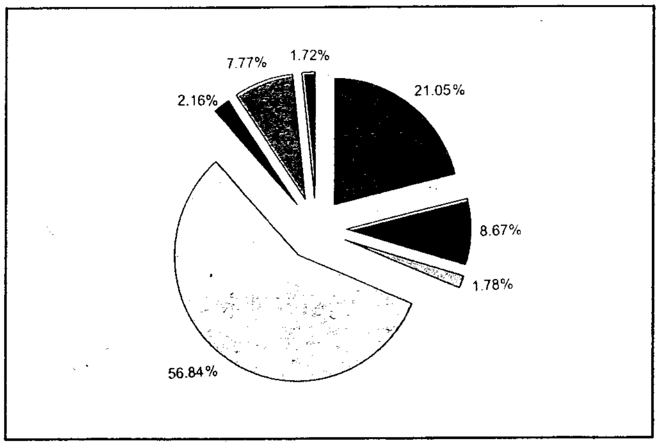

Figure 6. Weight of each element expressed as a percentage of total

Table 7. Overall weight of each element for bridges in Package A to E

	Ratio					
Description	Package A	Package B	Package C	Package D	Package E	**Average**
Foundation (Piling)	22.64%	29.41%	22.44%	33.82%	21.05%	**25.87%**
Abutment and Wing Wall	16.33%	12.68%	12.13%	16.24%	8.67%	**13.21%**
Piers, Crossheads and Pilecaps	1.57%	8.79%	13.56%	1.42%	1.78%	**5.43%**
Precast, Prestressed Beam and Ancillary	39.88%	32.50%	31.73%	31.36%	56.84%	**38.46%**
Diaphragms	2.87%	1.63%	2.64%	2.27%	2.16%	**2.32%**
Bridge Deck and Run-On-Slab	13.93%	11.88%	13.84%	12.15%	7.77%	**11.91%**
Parapet	2.77%	3.11%	3.66%	2.73%	1.72%	**2.80%**
TOTAL	100.00%	100.00%	100.00%	100.00%	100.00%	**100.00%**

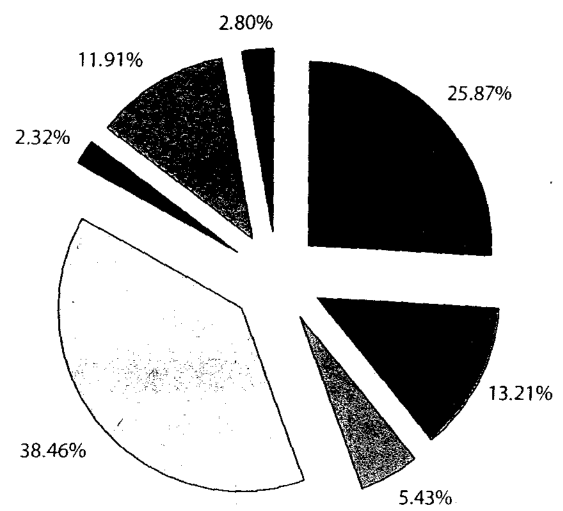

Figure 7. Overall Weight of each element expressed in percentage

Overall average ratio

The Table 7 and Figure 7 show the overall influence of these elements in the multiple projects.

Table 7 Overall Weight of Each Element for bridges in Package A to E

It was observed that the critical elements that needed more attention were "the foundation (piling) works" and "Superstructure Beam works".

Discussion of Results

The elements having high ratios (or high presence) were high impact causers. In this multiple project the overall influence of the elements "Piling" and "Beams" in bridge completion are critical. Even though the quantum of these elements were less compared to other elements of the bridges, the ratio of their influence in the construction was more due to their level of special technology, specialist availability, method of construction, risk involved and limited usage/availability of resources to produce.

Piling has 25.87% and beams have 38.46% – they have the maximum presence. The presence of these two items were more with less volume of work because of its speciality and use of uncommon materials.

Hence, extra care was given while deciding the design for these critical elements. Then, few design optimisations were adopted to reduce the complexity and to ease implementation in the field as shown in Table 8. The techniques adopted in element optimisation for the multiple bridge construction were successful and resulted in the projects being executed in time and within budget.

Table 8. Overall "Piling" and "Beam" element optimisation summary for Project 1 to 5.

SI No.	Project	No. of Bridges	Pile foundation (m)		No. of Span	Beam: Concrete beam (No.)		Beam: Steel girder
1	Project 1	12	H Piles (356x368x133 kg/m)-	6 Bridges	1 span - 12 Bridges	I-16 x 20.5m	10	
			Micro piles 300m Diameter-	3 Bridges		I-16 x 21.9m	10	
			Pad Footing	3 Bridges		I-16 x 22.0m	5	
						I-16 x 26.2m	18	
						I-16 x 27.9m	7	
						I-16 x 30.9m	10	
						I-20 x 33.8m	17	
							77	0
2	Project 2	5	Micro piles 300m Diameter-	3 Bridges	4 Bridges - 1 Span	I-16 x 16.7m	10	
			500mm dia. Spun Pile	2 Bridges	1 Bridge - 4 Spans	I-16 x 35.8m	14	
						M6 x 23.2m	16	
						M6 x 21.8m	8	
						M6 x 22.05m	8	
						UM6 x 23.2m	4	
						UM6 x 21.8m	2	
						UM6 x 22.05m	2	
							64	0
3	Project 3	8	Micro piles 300m Diameter-	2 Bridges	4 Bridges - 1 Span	I-16 x 26.4m	6	
			Bored piles 600mm dia. -	3 Bridges	1 Bridge - 2 Spans	I-16 x 24.6m	10	
			Concrete spun piles -	1 Bridge	3 Bridges - 3 Spans	I-16 x 34.6m	7	
			Pad Footing	2 Bridges		I-16 x 20.5m	5	
						M2 x 15.3m	16	
						M4 x 19.8m	32	
						UM2 x 15.3m	4	
						UM4 x 19.8m	8	
							88	0
4	Project 4	14	Micro piles 300m Diameter-	9 Bridges	12 Bridges - 1 Span	T11 - 16.75m	32	
			500mm dia. Spun Pile	3 Bridges	1 Bridge - 3 Spans	UM4 - 16.75m	4	
			Pad footing	1 Bridge		M6 - 23.20m	32	
						UM6 - 23.20m	8	
						I-20 - 29.67m	12	
						I-20 - 29.755m	12	
						I-20 - 29.770m	6	
						I-20 - 29.63m	6	
						M6 - 19.74m	8	
							120	0
5	Project 5	7	Micro piles 300m Diameter-	7 Bridges	6 Bridges - 1 Span	I-16 x 26.60m	6	6 Bridges
			500mm dia. Spun Pile	1 Bridge	1 Bridge - 3 Spans			

FINDINGS AND LESSONS LEARNED

The following findings were obtained and lessons learnt from the case study:

1. The natural tendency for more cautiousness/ attention for Girders selection was advantages in the handling and construction of all the beams (about 355 beams of five different varieties) without major problems. This enhanced the finishing of those beams as scheduled in the bridge programme.
2. Conversely, piling works on the foundation part were taken lightly at the design stage. There was no attempt to rationalise and the decision was left to the individual designers. This resulted in usage of the same micropile method in the majority of the bridges. Difficulties which arose in implementing the micropiles for many bridges were:-
   (i) Availability of specialists to perform the works was very limited in Sabah
   (ii) The risk of loosing equipment in the drilled holes requires skilled operators for drilling the

pile. There were not enough skilled operators in this field.

(iii) The component materials like API pipe G80 and permanent casings were very scarce to obtain/procure.

(iv) The method had various stages to complete one point, which is time consuming for each bridge.

Hence remedial measures were taken to catch up with the progress at the cost of spending extra resources, time and money.

CONCLUSIONS

1. In general, the Element Optimisation Technique was needed to be adopted for all the elements in compliance with the required standards. Extra importance is required for elements that have more influence in the execution and completion of the project.
2. In multiple DB projects the element optimisations have to be started well ahead during the conceptual design stage. But this optimisation should not interfere in the functional quality and the integrity of the structure which are designed for a stipulated life period.
3. In this process it is also important to consider and review the feedback from field personnel after conducting a proper study on site conditions.
4. In spite of the lag in piling works as mentioned in "lessons learned" from the case study, the company was able to make up and complete in time with recognition and credits due to the proper and timely planning in rest of the element optimisations.

ACKNOWLEDGEMENTS

The authors would like to thank the Directors of Kumpulan Liziz Sdn Bhd., Hj. Ghazali Abd Halim, Mr. Simon Liew and Mr. Liew Ah Yong for making available data regarding the multiple projects being executed by the company in Sabah.

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