High Level Cost Modelling of Elevated Deck & Linkway

- the importance of Key Performance Indicators for Cost Planning

By

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Abstract

BIM is not just about software but people and processes too. The "I" in BIM for "information", is key to the success of using BIM as a modelling tool. Otherwise, it would merely be a 3D visualization aid. To ensure the full potential of QS BIM for cost modelling, QS practices will need to organize the historical information of tendered or completed projects into key indicators for economic evaluation of design alternatives. Information from the public domain such as websites can sometimes be used, with caution, where comparable data/information may not be available.

This paper will examine how knowledge available from a firm can be used in conjunction with information from the public domain to produce a high level cost model of a suspended deck and linkway spanning between adjacent high-rise towers above a busy trafficked area. It illustrates a quantity surveyor's approach in making optimum use of available information to create a cost model where the Level of Detailing provided, of say 100, is insufficient. Since applied knowledge is a competitive edge for the QS, there is a need to consider data-mining tools to develop the firm's knowledge management (KM) base to better serve the needs of the project. How this KM base is to be developed will depend on the proper identification of key indicators for economic design evaluation.

Keywords: QS BIM, cost modelling, design evaluation, knowledge management

1.0 Introduction

1.1 With the advent of BIM, the demand for key performance indicators (KPIs) by clients at the early stage of design development will be the norm rather than the exception. BIM professionals will have to adjust to this shift to ensure that even at the early stage meaningful design evaluation and cost planning can be instituted to meet client demands.

1.2 As marketing input is now essential even at the early stage of design development to ensure the "right mix" of products at the "right price," design professionals and quantity surveyors are now expected to do more at the early stage of their appointment. For the quantity surveyor, this is not something new as building economics and cost planning is already an established domain of the QS services. What is "new" however is that the use of Key Performance Indicators (KPIs) for the economic evaluation of building designs has expanded upfront and increasingly required.

2.0 Lack of Design KPIs for Economic Evaluation

2.1 A survey of KPIs for the evaluation of building performance tends to be biased towards measurement of energy, water use, etc. once the facility is **in use** [1-4]. Very little guidance is available online or otherwise that discusses the use of KPIs at the early stage of the design to help the client determine the economic design criteria to meet his design brief. For this, we have to turn to the prevailing industry practices which are still evolving. Some of the "new" indicators are driven by major materials quantities, e.g., concrete volume per m2 of gross floor area (GFA) or steel bars poundage per m2 of GFA (see Table 1). Others are driven more by ventilation or façade design considerations, e.g., percentage of window openings of the façade or total façade area to total GFA. In the case of new project(s), once the quantity surveyor is able to benchmark the key indicators against past projects that have already been tendered out, a generalized view of the economic efficiency of the design alternative being considered can be made.

Table 1: Preliminary Design Cost Analysis

KPI Based on FT2 of GFA (figures provided are for illustration only) 3/29/2014

No	Description	Cost Plan area from QS		Based on Current/Latest Drawings (RM) Preliminaries	Architectural	Structural	M&E	Total		Concrete (m3)	Formwork (m2)	Reinforcement (kg)
1	Transfer floor (Tower 1)	1900		351,000.00		4,390,000.00		4,741,000.00		2650	5900	740,000
2	Transfer floor (Tower 2)	1000		195,000.00		2,420,000.00		2,615,000.00		1500	2300	423,000
3	Transfer floor (Tower 3)	2000		373,000.00		4,660,000.00		5,033,000.00		2800	6000	798,000
4	Tower 1	37,000		5,880,000.00	32,000,000.00	21,500,000.00	19,500,000.00	78,880,000.00		17,600	85,000	2,250,000
5	Tower 2	24,000		3,750,000.00	22,500,000.00	12,400,000.00	12,000,000.00	50,650,000.00		10,500	57,500	1,450,000
6	Tower 3	34,000		5,700,000.00	31,500,000.00	20,000,000.00	19,500,000.00	76,700,000.00		17,000	82,000	2,100,000
	Total CPA (m2)	99,900	Total	16,249,000.00	86,000,000.00	65,370,000.00	51,000,000.00	218,619,000.00	TOTAL	52,050	238,700	7,761,000
	Total CPA (ft2)	1,075,324	Cost/ft2 CPA:	15.18	80.34	61.07	47.64	204.24	Concrete/m2 CPA	0.05		
	Total CPA (ft2) w/o transfer floor	1,070,424	%	7.43	39.34	29.90	23.33	100.00	Formwork/m2 CPA		0.22	
									Reinforcement/m2 CPA			7.25

3.0 The Demand for KPIs for Economic Evaluation

3.1 Gone are the days where designers are given free rein to produce iconic designs without having to consider cost and financing constraints at the beginning. As property development becomes increasingly competitive and riskier, bankers and accountants are increasingly aware that project costs have to be managed even at the early design stage to meet investment objectives. Marketers have to do their market research and analysis of what will sell and at what price **before** the schematic or sketch designs can be firmed up. The role of the quantity surveyor has become more important than ever before. There has been a shift in emphasis on measurement (to produce bills of quantities) to that of a building or design economist to provide cost modeling or cost planning advice at the early stages not only to meet requirements of the design brief but also to address financing and marketing concerns.

3.2 It is not uncommon now for schematic designs to be revised half a dozen times or more to ensure economic design efficiency but also to address changing market conditions. For instance, a client may decide to have a flexible internal layout for the apartments by paying a little more by using an external shear wall and flat slab structural system. Later, this may prove to be a correct decision as market conditions change and the end-purchasers are not prepared to pay beyond a certain price but can accept a smaller built-up area. There are some changes required in the external shear wall structural design and the internal wall & partition layout to accommodate more units with smaller GFAs to meet changed market conditions. But the flat slab structure and lift core walls remained unchanged. The impact on the timing for submission of planning approval would be mitigated and the delay minimized. The consequences would have been serious if the entire structural system had to be revamped completely where more time would have been required to rework the design following the abortive work.

4.0 Evaluation of Structural Systems Design

4.1 The choice of adopting the external shear wall structural system would have been done after a comparative cost study made by the QS between the external and the internal shear wall structural systems. Somewhere along the line, the QS may have also been called upon to do a comparative cost study between a post-tensioned flat slab system and a conventional beam and slab system. As for the façade, a comparative cost study may have been made for a unitized glass window system, full curtain walling system and an aluminum cladding system. The QS appears to be getting busier at an early stage because of the significant role he now has to play as a cost advisor. It is clear that with this expanded role, he has to invest more in ICT, e.g., BIM and data-mining software. The Royal Institution of Surveyors Malaysia has a role to play in revamping its Building Cost Information Centre (BCIC) to meet the demands of its members for timely building cost information, which can be used for comparative cost studies. There is only so much that a few large firms can do individually on their own.

5.0 Civil Engineering Structures in the Building Domain

5.1 Recently, it has been noticed that structures that have been considered the domain of civil engineering design have crept into the building domain in Malaysia. For instance, inter-connecting elevated decks with pedestrian linkways supported by box girder structures between towers have made their appearance. These are more like civil engineering bridge structures with a broad deck on top spanning between buildings. This has made the task of using a suitable set of KPIs and benchmarks for cost modeling even more challenging for the QS. Thankfully, the M&E components for the time being have been minimal to allow as much natural ventilation and lighting as possible. Otherwise, the cost model would need to be a bit more complicated.

5.2 The elevated deck and linkway being basically bridge-like structures, requires various considerations which may not have been necessary in a typical building design. These can be briefly stated as follow:

- Traffic management & safety costs in a public thoroughfare where traffic cannot be stopped
- Temporary decks for safety and erection of permanent works thereon
- Temporary works – for temporary relocation of affected retail users
- Diversion of existing services and utilities
- Compliance with the Acts, like Railway Act to ensure primary and secondary buffer requirements are met
- For any excavation & piling works, suitable equipment that can operate in constrained working spaces and heights
- Suitable low-loaders and cranage for use in transportation and lifting of steel-framed structures according to their spans
- Special settlement monitoring devices, noise and vibration monitoring devices, etc. which must be costed in
- Increased Preliminaries for insurances, safety, signages, competent personnel, authorities' stringent approvals, etc.
- Interfacing works at tower connections and making good of works disturbed
- Temporary linkways or walkways for pedestrians including protective overhead screens
- Space unavailable for closed hoarding and for unloading of materials, components, parts, etc.
- Possibility of after office or night work which requires special permits and different wage compensations

6.0 Information from the Public Domain

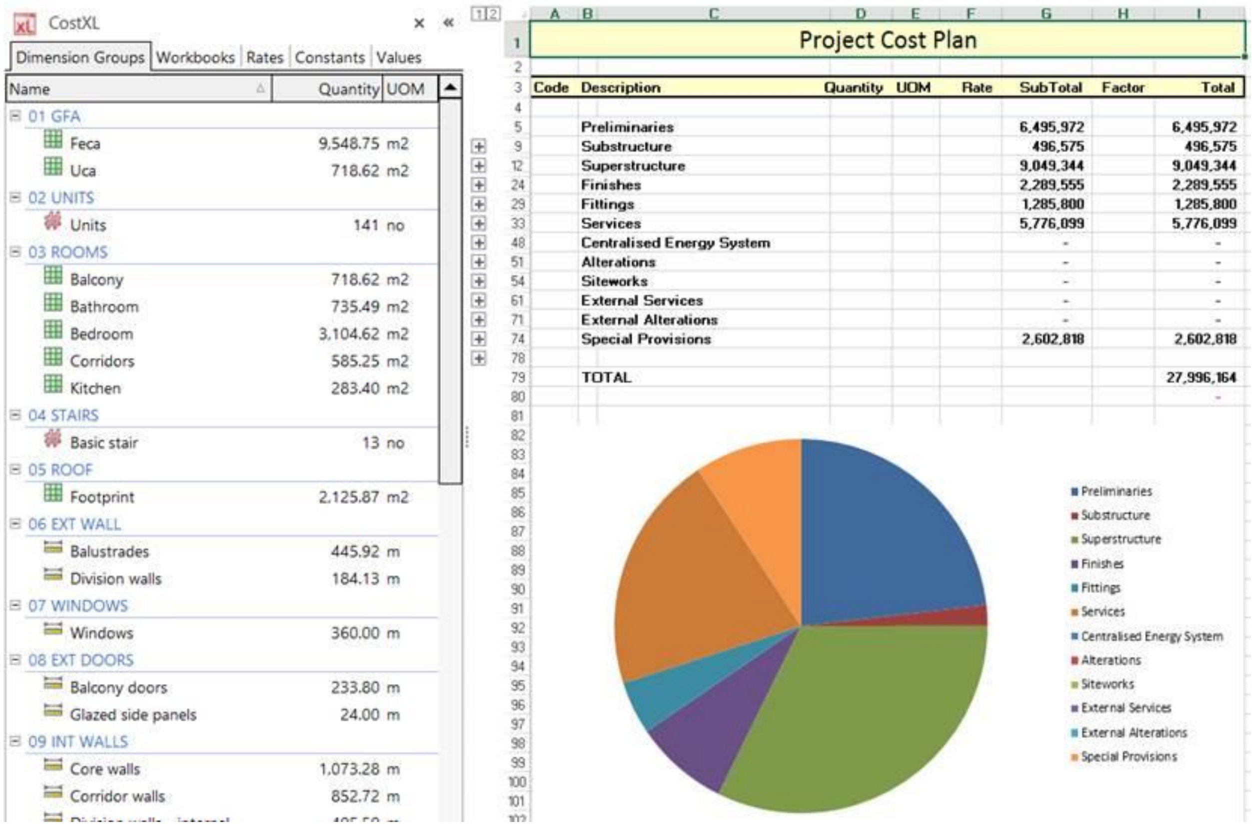
6.1 As there is very little information available of civil engineering KPIs in benchmarking bridge designs and how QSs could come up with an appropriate cost model, web research was relied upon for a recent project in Kuala Lumpur. As it turns out, B.S. 5400, the British Standard for design and construction of steel, concrete and composite bridges use in highway and railway and B.S. 5950 for the design of steel framed buildings did not provide information in terms of structural steel KPIs. This is not unexpected as both the codes are for design practices rather than benchmarks for design efficiency. Sadly for QSs, there may be a wealth of information residing in the desk tops of civil engineers waiting to be data-mined for analysis and used in economic design evaluation. Information from the public domain, properly harnessed, will benefit clients in terms of cost optimization and the reduction of wastages due to over-design. Knowledge management has to cut across the boundaries of multi-disciplines and information channels to better serve the needs of clients and projects.

7.0 Project Information Management Systems and Knowledge Management

7.1 There are a number of project information management (PIM) system software available that can be used for project team collaboration and the distribution of documents, drawings, workflow, etc. in an integrated manner. Such software may allow for data-mining and deep searches even in pdf documents to locate information which may be useful for analysis. Newforma and Aconex are two examples of such software. Apex 12.0 is also a PIM system software but lacks the deep search capability of Newforma and Aconex, but is affordable and widely used in Singapore and Malaysia. Users of Apex have the advantage of being able to upload, manage and share in-house BIM Object libraries. Those familiar with BIM will be aware that all sorts of information can be embedded by the user in any BIM object. Even if we can’t remember the word tags in a PIM system to link us to the information we want, we can always look up the BIM object model, e.g., a typical box girder bridge of a given span, *assuming this has been created*, to find out all the embedded cost information & specifications we need to analyze.

7.2 QSs familiar with Cost X may use an add-on tool such as Cost XL to extract information from Cost X files according to the chosen parameters, for analysis and graphic representations of the cost information extracted. Firms that have accumulated tons of information from projects in Cost X will find Cost XL a convenient tool for data-mining. A screen shot on the use of Cost XL for extracting information from Cost X is shown in Figure 1. For QS BIM, the more important thing is being able to assemble and make use of the vast array of information already available to the firm to create a cost model from the designer’s sketch design model, rather than the ability to use a design authoring software such as Revit per se. However, with the advent of Sky BIM, it is theoretically possible for a QS conversant with the Revit platform to produce graphical models on his own for cost modelling or for preliminary cost estimating. However, Sky BIM at the moment has not reached the stage where actual bill of quantities can be produced from the Revit “building blocks” it produces.

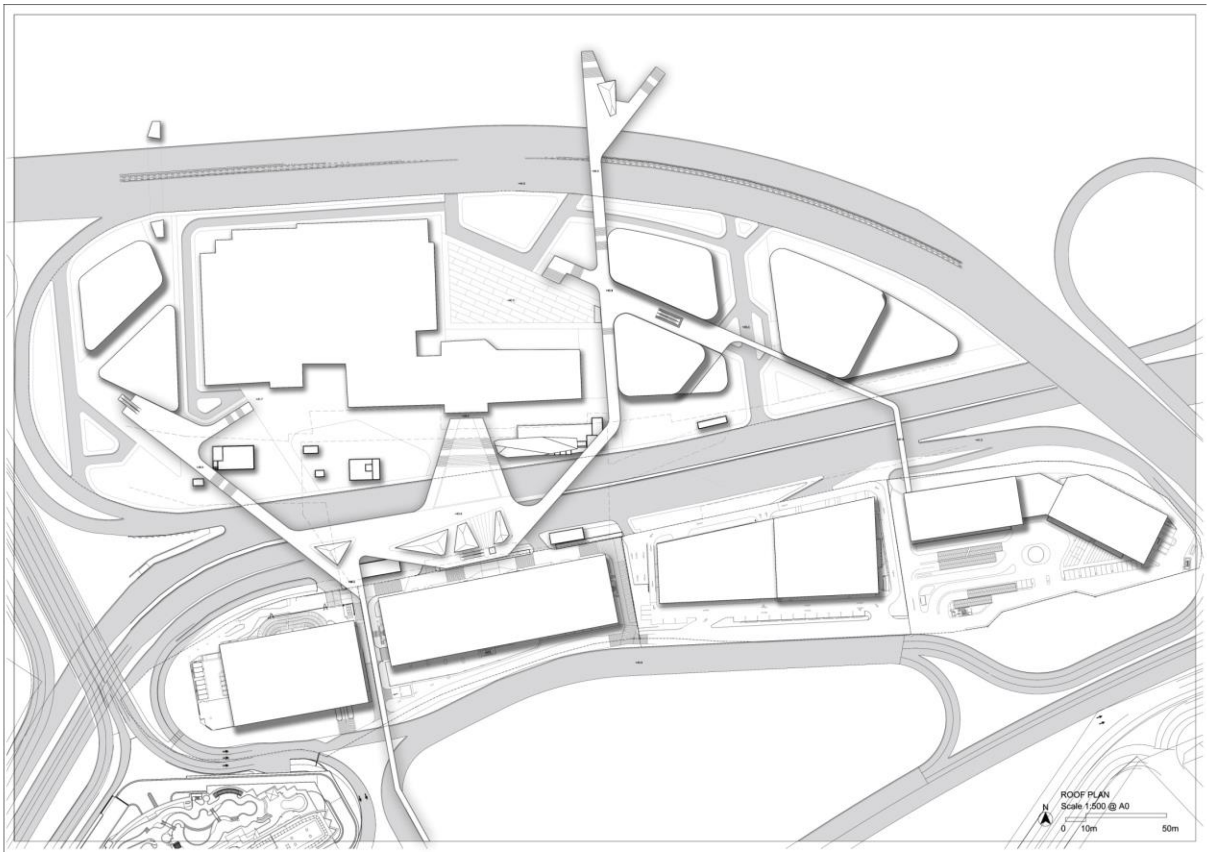
Figure 1: Use of Cost XL for information extraction from Cost X



8.0 Derivation of Cost Models

8.1 In the cost modeling for the elevated deck and linkway mentioned in this paper, I have used the paper annotated as [5] under References to compile and tabulate the information in order to arrive at some KPIs for cost analysis and modeling. This is shown in Appendix I. An abbreviated cost plan and analysis is shown in Table 2 for the preliminary design which is basically little more than "massing" drawings with 3D perspectives (see Figure 2). At the early stage, most designers will use Sketchup for visualization of the conceptual model. Although there may be plug-ins for Sketchup, extracting quantities in terms of area or volume of the various cost elements is not easy to do with a Sketchup model as the parameters are defined and structured differently from say, Revit. The QS will prefer to request for a CAD rather than a Sketchup model for measurement.

Figure 2: Conceptual Sketch Plan of Elevated Deck & Linkway Above Road (for illustration only, no relation to any approved model)



8.2 In terms of bridge cost analysis, one should take note of the differences in types of bridge designs, namely, single closed box girder composite bridge, twin girder cross-beam directly supporting bridges with cantliever, twin girder cross-beam directly supporting bridges without cantilever, multi-girder composite bridge, cross-beam composite bridges with deck local widening near abutments, variable width cross-beam composite bridge and special girder composite bridges [5].

Table 2: Brief Cost Plan for Elevated Deck & Linkway (for illustration only, cost/m2 not shown)

No.	Elements	Amount (RM)
1	Main Grid Space Truss & Non-long Span Structure	200,000,000
2	Linkway	42,000,000
3	Support columns, pile caps & bored piling - allow	10,000,000
4	Retail areas at deck (light structure) - allow	4,000,000
5	Escalator, elevator & staircase	3,000,000
6	Interfacing with existing building - allow	3,000,000
7	Diversion, underpinning, trial pits - allow	10,000,000
8	M&E installation - allow	10,000,000
9	Landscaping - allow	4,000,000
10	General Preliminaries – 15%, say	43,000,000
11	Contingencies – 10%, say	33,000,000
12	Total	362,000,000

9.0 Relationship between Span and Cost

9.1 It can be generalized that the larger the spans, the heavier the steel tonnage required. Therefore, the weight of structural steel members (in terms of kg. per m2 of deck area) increases if the span increases. From Appendix I, it can be seen that the average kg. per m2 of deck area ranges from 0.25 – 0.33 kg. per m2, depending on the box girder type, whether there are supporting cross-beams or propped cantilevers or not. The analysis in Appendix I is for bridge spans not exceeding 150m and we have used this as reference for the steel tonnage in the elevated deck and linkway project which has spans ranging between 40m to 80m.

9.2 Once we know the structural steel KPIs (kg. per m2), it is a matter of just measuring the deck areas classified according to the span and depth of the steel girders and applying the appropriate tonnage (kg. per m2). We can assume the deck slab to be reinforced concrete laid using mobile formwork launcher. The area of the deck and its thickness will give the volume of reinforced concrete and the weight of the rebar for the deck slab can be derived from the weight (kg.) per m3 of concrete given.

10.0 Price Grouping of Bridge Structures

10.1 As guidance, the following are the specific price grouping for composite bridges [5]:

No.	Price Grouping	Price Type
1	Steel frame assembly platform	Item/Lump Sum
2	Composite deck steel frame launching equipment	Item/Lump Sum
3	Mobile formwork for casting composite deck slab	Item/Lump Sum
4	Installation on permanent supports/final jacking	Item/Lump Sum
5	Steel for deck frame (kg)	Kg.
6	Studs for steel frame-concrete deck connection (kg)	Kg.
7	Steel frame assembly & installation on site	Item/Lump Sum
8	Anti-corrosion protection suitability test	Item/Lump Sum
9	Anti-corrosion protection using paint on bare steel (m2)	M2
10	Fixing rails sometimes embedded in the slab to allow immediate or future installation of services under it	M
11	An inspection platform for services, if this is foreseen	No.
12	Support inspection and closing equipment, if piers are hollow	No.
13	If deck is a box girder, its internal electrical installation should also be specified and costed, particularly lighting, possible dryers & box girder internal access systems	Item/Lump Sum
14	Post-installation support vertical adjustment if foreseen to be specified & costed, the supports concerned & the vertical adjustment heights	No.
15	Access of land made available to the Contractor for steel frame assembly operations & detail possible easements to which these areas are subject	Item/Lump Sum
16	If located beneath a retaining wall, it must be stated clearly the precautions to be taken by the Contractor during this	Item/Lump Sum

17	period. Closure of roads and obligation to use a holding winch to be stated	Item/Lump Sum

The above price grouping can be used as a check-list for preparing a Bill of Quantities for bridge projects and has much more detail compared to the abbreviated cost plan and analysis shown in Table 2 and discussed previously.

11.0 Information Packages for Bridge Structures

11.1 In terms of packaging the information to be presented for tendering purposes, the works may be divided into 2 sub-packages. Sub-Package I may contain the following drawings/information:

No.	Sub-Package I
1	Existing site drawings
2	Operational cross-section of supported road
3	Long profile & horizontal alignment of supported road
4	Plan view of bridge
5	Long cross-section of bridge
6	Deck typical cross-sections
7	Deck superstructure details
8	Steel frame details (post, stiffeners, deck-steelwork connections, directly supporting cross beams at abutments, etc.)
9	Formwork for piers & abutments
10	Geotechnical survey, i.e., soil investigation results
11	Land survey drawings for areas able to accommodate site installations & their possible access roads

11.2 Sub-Package 2 may consist of the following:

No.	Sub-Package 2
1	Drawing of launching area, if required
2	Drawing of steelwork material distribution
3	Pre-stressing cable layout (for transversely pre-stressed bridges)
4	Construction kinematics detailing steel frame launching or crane installation phases
5	and various concreting phases
6	Preliminary bill of quantities
7	Architectural study
8	Foundation preliminary design study conducted by geotechnical laboratory (not part of contract)
9	Deck reinforcement preliminary design drawings

11.3 In the case of the composite bridge deck, the following could also be provided for the Specifications section:

No.	Specifications required
1	Material origin
2	Concrete mix design & placements
3	Pre-cast concrete panels & installation
4	Paint system (anti-corrosion
5	Support bearings
6	Waterproofing course laying procedure
7	Pavement expansion joints
8	Slab transverse pre-stressing procedure, if applicable

12.0 Conclusion

12.1 With the advent of BIM, the QS role has shifted upfront whereby the implications of early stage design choices has to be costed out and made known. This is where the QS adds value at the initial and subsequent design stages for the client who wants to be apprised of the effects of design alternatives. Although this paper is focused on high level costing for an Elevated Deck and Linkway, it is clear that key indicators for cost planning need to be further developed for better knowledge management in both building and civil engineering construction projects. Admittedly, the development of key cost planning indicators for civil engineering projects may still be at its infancy but over time it is hoped that a “standardized” format for cost analysis of civil engineering structures such as bridges, etc. would be available as part of the QS knowledge management domain.

APPENDIX I - A COMPARISON OF BOX GIRDER TONNAGES [5]

A. Single Box Girder Composite Bridges

Bridge Name	Maximum span (m)	Girder Depth (m)	Total Length (m)	Deck Width (m)	Deck Area (m2)	Steel tonnage	Tonnage/m2 of deck
Doubling of Ante bridge	78	1.8-3.3	170	10.75	1827.5	525	0.29
Bonneville viaduct	71	1.61-2.87	115	15.3	1759.5	410	0.23
Monistril d'Allier viaduct	70	2.3	168	10	1680	500	0.30
Loire bridge @ Rivas	59.1	1.6	159	10.8	1717.2	400	0.23
OA3 bridge on Jenlain bypass	57.2	1.55	134	11	1474	400	0.27
Vienne bridge @ Nuoatre	55	1.2-1.9	195	12	2340	550	0.24
OA4 bridge @ Embrun	55	-	255	12	3060	650	0.21
SD bridge	51.4	1.4	378	9.5	3591	1325	0.37
Gardon bridge @ Ners	44	2.28	189	21	3969	800	0.20
Boulogne-sur-Mer viaduct	40	1.3	190	2x9.15	3477	850	0.24
Volesvre viaduce	52	1.75	208	12.2	2537.6	500	0.20
Average							0.25
Median							0.24

B. Box Girder Composite Bridges With Directly Supporting Cross-Beams

Bridge Name	Maximum span (m)	Girder Depth (m)	Total Length (m)	Deck Width (m)	Deck Area (m2)	Steel tonnage	Tonnage/m2 of deck
Lille ring road viaducts	96.7	2.75	445	13.1	5829.5	-	-
Charles de Gaulle bridge	84	2.5	208	34.9	7259.2	3000	0.41
Freney viaduct	79	2.7	207	18.2	3767.4	1150	0.31
Pont des Chevres viaduct	78	2.7	354	13	4602	1600	0.35
Moselle bridge @ Custines	62.7	1.8	125	10.3-18.93	1826.9	375	0.21
Roche Bernard viaduct	36	1.7	376	20.8	7820.8	1550	0.20
Average							0.29
Median							0.31

C. Box Girder Composite Bridges With Directly Supporting Cross-Beams and Propped Cantilevers

Bridge Name	Maximum span (m)	Girder Depth (m)	Total Length (m)	Deck Width (m)	Deck Area (m2)	Steel tonnage	Tonnage/m2 of deck
Verrieres viaduct	144	4.5	720	23.5	16920	6250	0.37
Rhone bridge @ Valence	125	4	526	22.1	11624.6	3800	0.33
Frocourt viaduct	60	2.5	284	13.3	3777.2	1150	0.30
Average							0.33
Median							0.33

(the above was extracted & re-casted by writer)

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