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Research Article

Analytical Formulation for Early Cost Estimation and Material Consumption of Road Overpass Bridges

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Abstract: Every construction project evolves through a series of stages, originating from the preliminary study followed by several design stages and finally the implementation of the design with the actual construction. Cost and material quantities estimates are produced throughout the life of a construction project and are used for different purposes depending on the available information and their expected accuracy. An easy to apply cost pre-estimating and material quantities formulation is proposed for overpass bridges based on the processing of data from fifty seven existing bridges in order to assist stakeholders in the bridge construction industry when choosing the most cost effective design solution in order to reduce the risk of failure and loss of funding.

Keywords: Bridges, construction project management, cost estimate, material quantities

INTRODUCTION

Since transport of freight and people is at the core of modern economies, creation of a sufficient road network is of significant national and international importance. For this reason a substantial proportion of government expenditure is allocated to the construction and maintenance of road infrastructure in developed countries. From data released by the American Road and Transportation Builders Association (ARTBA) (2014) the value of construction work performed on bridges continued to increase over the last five years, despite the economic recession and has risen to a record level of €27 billion in 2014, accounting for almost 22% of the total transportation construction market in US (American Road and Transportation Builders Association (ARTBA), 2014). Within the European Union (EU), the motorway network expanded by 5% from 2006 to 2010, according to EUROSTAT (2015), when the EU funded the construction of the Trans-European Transport Networks with up to €47.5 billion (Ten-Invest, 2003).

The design and construction of bridges play a significant role in the process of developing a sustainable transportation system not only when considering large bridges, but smaller ones, as well. There are cases, such as overpass and underpass bridges that even though these structures do not present significant technical difficulty, they are the key to maintaining good progress during construction as their completion is always at the top of the overall construction schedules.

Bridge construction is open to public critisism, with economy, functionality and aesthetics being the decisive parameters for a broad acceptance of the project. Decision makers are entrusted to achieve a delicate balance among all the above factors sometimes, having very little information and time for discussions. Very often, bridge construction results in cost overruns. To overcome this problem, it is crucial for decision makers to have an early estimate of the final cost based on previous experience. Comparative studies on transportation infrastructure are rare, mainly because of the lack of large, reliable and homogeneous databases, partially attributed to the reluctance of public clients to supply financial information regarding constructed projects, thereby making research in this domain difficult.

It is the aim of this research to make use of existing information from similar projects constructed previously in order to develop analytical formulations for cost pre-estimates for road overpass bridges and to provide relationships for the consumption of the most used materials.

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LITERATURE REVIEW

The relative importance of bridge construction in a large motorway project was pointed out by Maravas and Konstantinidis (2003) for the Egnatia Odos Motorway, a €7 billion project, where bridges comprise 6% of the total motorway length, but account for more than 20% of the total cost. The superstructure presents a significant impact on the construction cost of a modern concrete bridge. According to Konstantinidis and Maravas (2003), its cost ranges from 35 to 53% of the total bridge construction cost, depending on the construction method used and the design system. Consequently, analytical formulation for conceptual cost and materials' estimating for bridges appear to be necessary for planning the construction of such projects the results of which may vary depending on the type of bridge, type of deck, construction method and code of practice used.

Based on nineteen concrete highway bridges, including seven viaducts in mountainous terrain, eight valley crossing bridges and four highway bridges in urban areas, built in Switzerland between 1958 and 1985, Menn (1990) presented the total construction cost break down categorised into mobilization (8%), structure (78%) and accessories cost (14%). In addition, he presented an analytical formulation for estimating the material quantities of concrete, reinforcing and prestressing steel with the values reflecting the standards specified in the code of practice of that period. Benaim (2008), based on data from bridges designed according to UK code of practise, presented the characteristic rates of reinforcement in bridge decks with solid slabs (45-60 kg/m^3), voided slabs (110 kg/m^3), ribbed slabs (120 kg), precast Tee beams (110-130 kg/m^3) and concrete box girders with spans less than 80 m (150-180 kg/m^3) and greater than 80 m (120-160 kg/m^3). Typical rates of prestress were also presented varying from 30 to 80 kg/m^3 depending on the span/depth ratio. Lambropoulos *et al*. (2004a, 2004b) examined one single and three dual carriage way multi-span balanced cantilever bridges constructed for the Egnatia Motorway in Greece to present the average rates of concrete per deck surface area (0.86 m^3/m^2), of reinforcing steel per cubic meter of concrete in the deck (162 kg/m^3) and of prestressing steel per cubic meter of concrete in the deck (52 kg/m^3). Moreover, the average rates of concrete volume per m of pier (13 m^3/m) and reinforcing steel weight per cubic meter of concrete in the piers (227 kg/m^3) were also evaluated for the hollow section piers of the bridges. Liolios *et al*. (2005) using a similar approach and data from three dual carriageway twin leaf balanced cantilever bridges, presented the consumption of concrete per deck surface area (1.22 m^3/m^2), of reinforcing steel per cubic meter of concrete in the deck (129 kg/m^3) and of prestressing steel per cubic meter of concrete in the deck (41 kg/m^3), along with concrete volume per m of pier (30 m^3/m) and reinforcing steel weight per cubic meter of concrete in the piers (218 kg/m^3). Chen and Duan (1999) processed the data from the Japan Association of Steel Bridge Construction and presented the relation of steel consumption per unit road area and span for various types of steel bridges. Antoniou *et al*. (2015) based on the design budget from thirty four closed box section and slab frame underpasses from two recently constructed highway projects in Greece presented the total cost and cost distribution for the construction of reinforced concrete bridge underpasses along with the required material quantities of concrete, reinforcing steel, earthworks, waterproofing works, joint formation and drainage system. The above figures were also related to the theoretical volume of the underpass specified as the product of multiplication of width, length and clear breadth of the structure. Several other research focused on design optimization of reinforced and prestressed concrete road bridges as far as cost and geometry of structural members is concerned (Miles and Moore, 1991; Philbey *et al*., 1993; Lounis and Cohn, 1993; Cohn and Lounis, 1994; Aparicio *et al*., 1996; Moore *et al*., 1997; Sarma and Adeli, 1998; Sirca Jr. and Adeli, 2005; Fragkakis *et al*., 2014) in some cases also creating computer programs to assist the procedure.

METHODOLOGY

To demonstrate the variation between construction costs of overpass bridges with different characteristics, information referring to fifty seven bridges was utilised. The bridges belong to the Egnatia Motorway, which is part of the Trans-European Network for Transport and one of the most significant projects constructed in Europe during the previous decade with design life of 100 years. The Motorway was constructed as a high-speed motorway consisting of a dual carriageway with hard shoulders having a combined dual carriageway width of 24.5 m for most sections and 22 m for difficult mountainous areas.

Table 1, presents the name, the region along the Egnatia Motorway and technical characteristics of the overpasses, which were all constructed using the tranditional scoffolding system. The technical characteristics provided in Table 1 include the width of the deck, which incorporate the width of the verges as well. It also provides the maximum and minimum height of the piers and the height of the abutments in the case of one span bridge, the peak ground acceleration considered for seismic design and the year that construction was completed. The design of the bridges was according to the German DIN Standards except for seismic loading where the Greek standard was utilized, which refer to the European Standard (ENV 1998-2) supplying the structures with an inherent ductility in order to dissipate the imparted seismic energy. The superstructure consisted of overpasses with different deck types i.e., eleven with solid slab deck, six with voided slab, twenty four with prestressed slab with voids and finally, sixteen with prestressed single box

Table 1: Characteristics of Egnatia motorway overpass bridges

No	Region	Name of structure chainage	Span arrangement (m)	Total length L (m)	Deck width W (m)	Deck type	Min. Pier Height (m)	Max. Pier Height (m)	pga[6]	Constr. Year
1	4.2.2/4	Koila 42+837	27.50+45.00+27.50	100.00	29.50	ss[1]	5.46	5.83	0.16g	2001
2	4.2.2/4	Kozani 43+385	39.20	39.20	27.90	ss[1]	5.90[5]	6.14[5]	0.16g	2001
3	4.2.2/4	Drepano 2+078	15.50+29.00+12.50	57.00	27.90	ss[1]	5.95	6.14	0.16g	2001
4	15.2	T6 0+335	14.00+14.00	28.00	10.50	ss[1]	6.70	6.70	0.16g	1996
5	15.2	T1 0+536	16.05+16.05	32.10	7.00	ss[1]	7.05	7.05	0.16g	1997
6	15.2	T2 2+209	16.05+16.05	32.10	7.00	ss[1]	7.82	7.82	0.16g	1997
7	15.2	T3 4+472	16.05+16.05	32.10	10.50	ss[1]	7.46	7.46	0.16g	1997
8	15.2	T4 5+693	16.05+16.05	32.10	10.50	ss[1]	7.40	7.40	0.16g	1996
9	15.2	T14 12+339	16.05+16.05	32.10	10.50	ss[1]	7.11	7.11	0.16g	1996
10	15.2	T15 13+881	16.05+16.05	32.10	7.00	ss[1]	7.16	7.16	0.16g	1997
11	11.2	KOK22 7+162	31.50+28.75	60.25	6.50	ss[1]	6.75	6.75	0.16g	2000
12	15.3	TE2 4+219	18.65+18.65	37.30	8.50	sv[2]	6.62	6.62	0.12g	1999
13	15.3	TE6 8+083	18.65+18.65	37.30	8.50	sv[2]	6.33	6.33	0.12g	1999
14	4.2.2/4	T2 19+667	16.70+30.60+16.70	64.00	16.00	sv[2]	6.60	8.73	0.16g	2000
15	4.2.2/4	Amintaio 43+718	20.50+40.00+20.50	81.00	7.25	sv[2]	6.99	7.01	0.16g	2001
16	4.2.4	KO6 32+556.71	14.40+29.32+14.40	58.12	9.50	sv[2]	5.16	5.87	0.16g	1999
17	4.2.4	KO8 38+614.47	14.40+29.32+14.40	58.12	9.50	sv[2]	4.68	6.03	0.16g	1999
18	14.22	TE311 10+394	15.88+35.59+15.88	67.35	8.50	psv[3]	7.27	7.31	0.16g	2001
19	14.22	TE315 11+388	16.07+35.98+16.07	68.15	12.00	psv[3]	5.37	5.98	0.16g	2001
20	14.32/15.11	T425+544	29.50+33.50+29.50	92.50	9.50	psv[3]	7.80	8.10	0.16g	2000
21	15.56	KO8 8+827	34.07	34.07	10.50	psv[3]	6.30[5]	6.30[5]	0.12g	2001
22	15.56	Alex/poli 10+221	35.70	35.70	17.00	psv[3]	6.30[5]	6.30[5]	0.12g	2001
23	15.56	DO3 11+151	22.50+35.00+22.50	80.00	10.60	psv[3]	6.47	7.00	0.12g	2001
24	15.56	DO412+101	22.00+35.00+22.00	79.00	10.60	psv[3]	6.44	6.97	0.12g	2001
25	15.56	DO10 15+869	35.00	35.00	13.50	psv[3]	5.85[5]	6.73[5]	0.12g	2001
26	15.56	Alex/poli 18+552	19.00+38.00+19.00	76.00	17.00	psv[3]	7.78	8.37	0.12g	2001
27	15.56	DO15 19+750	22.00+35.00+22.00	79.00	10.60	psv[3]	6.97	6.97	0.12g	2001
28	15.7	Nipsa 3+911	21.40+21.40	42.80	10.00	psv[3]	7.30	7.30	0.12g	1999
29	15.7	KO2 5+689	20.00+20.00	40.00	10.10	psv[3]	8.10	8.10	0.12g	1999
30	15.8	Ardanio 3 7+943	32.25+32.25	64.50	11.40	psv[3]	9.30	9.30	0.12g	1999
31	15.8	Ardanio 4 8+152	22.75+22.75	45.50	15.15	psv[3]	8.00	8.00	0.12g	1999
32	15.8	Peplo 10+585	27.90+27.90	55.80	11.50	psv3	6.70	6.70	0.12g	1999
33	15.7	TE1 15+156	19.60+40.44+19.60	79.64	10.50	psv3	6.71	7.94	0.12g	2001
34	15.8	TE2 0+406	17.50+35.00+17.50	70.00	8.50	psv3	6.00	6.00	0.12g	2001
35	11.3	T4 14+735	15.00+29.70+15.00	59.70	6.50	psv3	8.40	9.00	0.16g	2003
36	11.3	T5 15+447	15.00+30.28+15.00	60.28	6.50	psv3	8.23	10.35	0.16g	2003
37	11.3	T7 17+746	14.30+28.10+14.30	56.70	6.50	psv3	8.43	9.69	0.16g	2003
38	11.3	T9 18+399	15.00+29.29+15.00	59.29	6.50	psv3	10.06	11.08	0.16g	2003
39	11.3	T10 19+700	15.00+29.70+15.00	59.70	6.50	psv3	8.50	9.50	0.16g	2003
40	2.1	-- 15+460	19.60+32.00+19.60	71.20	11.00	psv3	6.40	6.50	0.16g	2002
41	8.1/2/3	TE-2 12+727.36	24.70+24.30	49.00	23.50	psv3	5.45	6.62	0.16g	2002
42	45.2/3	T1 0+870	18.40+30.60+18.40	67.40	18.60	psbg4	6.10	6.90	0.12g	2001
43	45.2/3	T8 8+778	19.70+32.85+19.70	72.25	13.00	psbg4	5.00	7.25	0.12g	2001
44	45.2/3	T9 9+210	24.00+40.14+24.00	88.14	10.00	psbg4	6.40	9.00	0.12g	2001
45	15.56	Kirki 9+927	27.00+53.00+27.00	107.00	10.60	psbg4	9.00	9.00	0.12g	2002
46	11.2	KO18 3+195	35.00	35.00	6.50	psbg4	7.585	7.585	0.16g	2000
47	11.2	KOK21 6+231	35.00	35.00	6.50	psbg4	7.175	7.175	0.16g	2000
48	14.11	T3 2+246	34.00	34.00	10.50	psbg4	5.855	5.855	0.16g	2000
49	14.11	T5 4+172	19.40+37.30+19.40	76.10	10.50	psbg4	8.00	8.00	0.16g	2001
50	14.11	T6 5+389	19.40+37.30+19.40	76.10	10.50	psbg4	6.40	6.40	0.16g	2001
51	14.11	T8 6+525	19.40+37.30+19.40	76.10	10.50	psbg4	6.34	8.38	0.16g	2001
52	1.1.6	Γ11 33+062	17.20+41.60+17.20	76.00	9.50	psbg4	4.10	6.10	0.24g	2001
53	2.4	T3 1+300	22.70+37.60+22.70	83.00	9.00	psbg4	11.20	12.90	0.16g	2003
54	14.32/15.11	TE525 24+483	33.00+49.00+33.00	115.00	28.00	psbg4	7.92	7.92	0.16g	2001
55	45.2/3	T10 10+757	21.30+35.55+21.30	78.15	9.00	psbg4	6.05	7.15	0.12g	2001
56	45.2/3	T11 13+010	17.50+29.20+17.50	64.20	9.00	psbg4	6.00	7.25	0.12g	2001
57	45.2/3	T13 14+350	17.50+29.20+17.50	64.20	9.00	psbg4	6.00	8.10	0.12g	2001

ss[1]: solid slab; sv[2]: slab with voids; psv[3]: prestressed slab with voids; psbg[4]: prestressed single box girder; [5]: abutment height; pga[6]: peak ground acceleration

girder deck. The piers of the overpasses in the majority of the cases had cyclic cross-section with diameter ranging between 1.60 m to 2.30 m and in few cases twin cyclic of 1.20 m diameter each. Out of fifty seven bridges, seven were one span, sixteen two spans and thirty four three spans.

The compiled database apart from technical characteristics of each structure has been updated to include *on-site* input such as, surveyed material quantities, the contractual unit rates and final cost per work item. As the bridges were constructed in different periods between 1996 to 2003, the cost records have been revalued to prices of the second quarter of 2015 using the annual average rate of change in the harmonized indices of consumer prices reported by the (EUROSTAT, 2015).

The total construction cost of each bridge comprises of the cost of foundations, substructure, superstructure and accessories. Foundation costs include the construction of the foundations of abutments and piers, temporary works including slope stabilisation/protection and soil improvement works, as well as earthworks and all works necessary to provide safe access to the construction site. Substructure costs include the construction of abutments and piers whereas superstructure costs refer to the cost of construction of the deck. Finally, under the term accessories, the cost of bearings, expansion joints, drainage system, guardrails, bridge waterproofing and asphalt layer, is considered.

RESULTS AND DISCUSSION

Figure 1, depicts the total cost per deck surface area for each overpass, with an average cost of 810 €/m^2. As shown in Fig. 2, due to the structural system, which allows shallower superstructure, the most economical overpasses are those with three-spans 708 €/m^2 (average of 34 bridges), followed by those having solid slab deck 788 €/m^2 (average of 11 bridges). As expected, the most expensive were the one-span overpasses with 1246 €/m^2 (average of 7 bridges). For the remaining three classifications the average costs were similar.

The average costs per cost category were calculated and the results are presented in Fig. 3, which, it is envisaged, will assist contractors and awarding authorities in determining the expected project cash flow. Analysis of this data reveals that for all types of superstructure and span arrangement, the cost of construction of the deck represents the highest proportion of the total cost, ranging from 37% for those having solid slab to 49% for those with a three span arrangement. This variation in deck costs is justified by the fact that heavier decks and longer construction periods are required for three span bridges, while solid slabs usually do not require any particular equipment. The greater cross-section size of single box girder decks resulted in 46% average cost for the superstructure. The next significant cost category was foundation costs, which ranged from 23% of the total cost of construction for one span bridges to 35% for two span bridges. Similar proportions (26 to 30%) were observed for the rest, with variations attributed to pile foundations instead of the less expensive spread foundations. As the examined overpasses had similar pier cross-section, usually circular, the variation of substructure costs was narrow between 13 to 18% for the different types of deck. The highest percentile of substructure cost was observed in one span overpasses, which actually

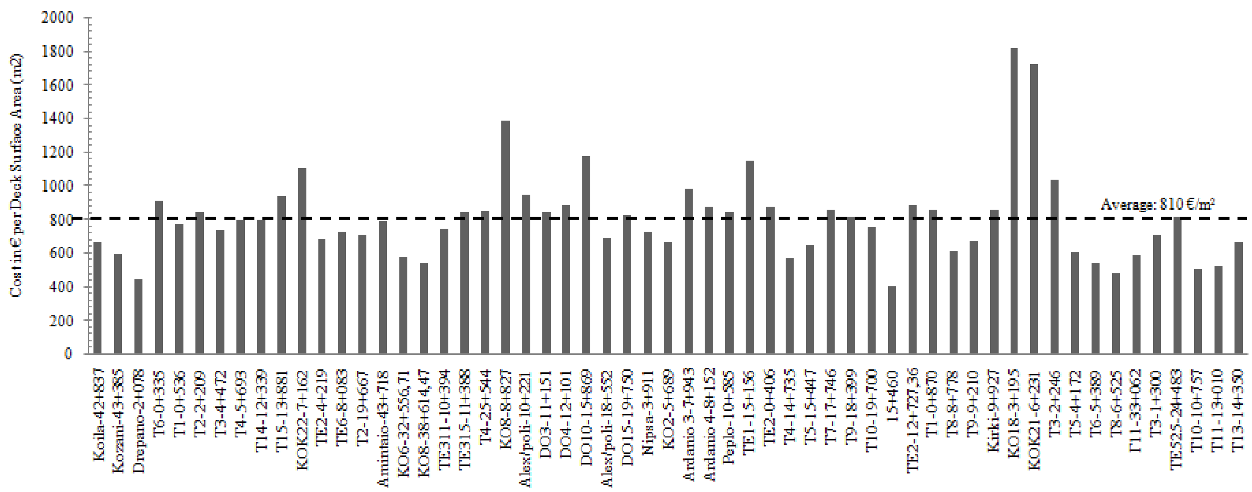


Fig. 1: Total cost per area of structure for all overpasses

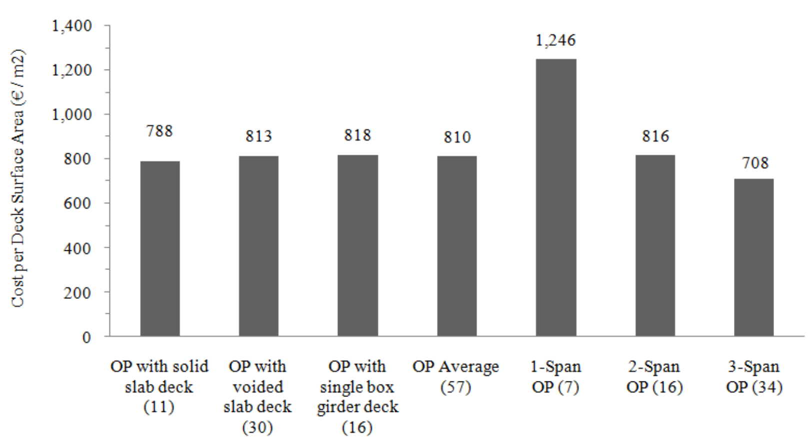


Fig. 2: Average cost per area of structure for overpasses

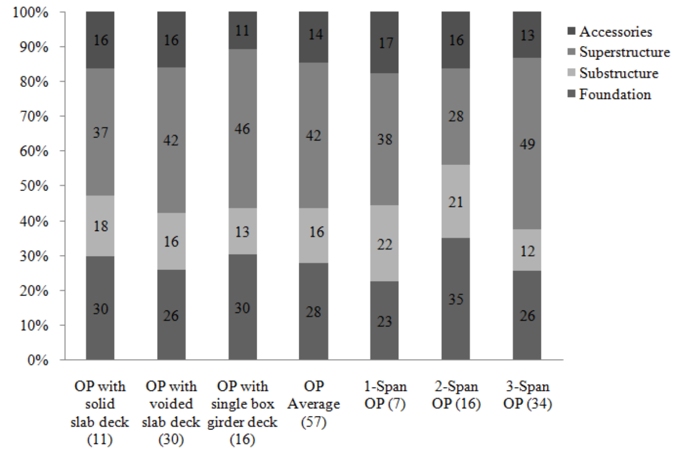


Fig. 3: Distribution of average costs for overpasses

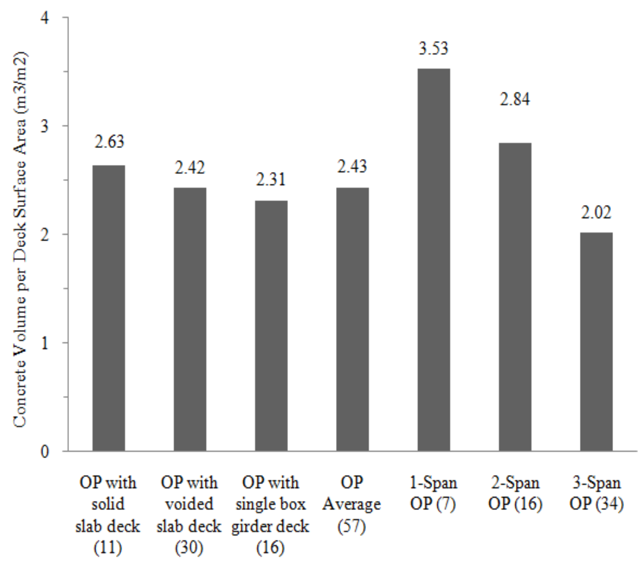


Fig. 4: Total amount of concrete (including prestressed concrete) consumed per area of structure

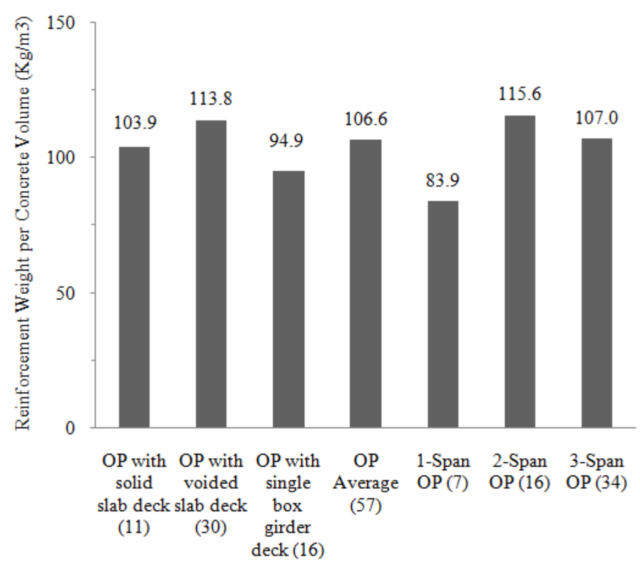


Fig. 5: Total amount of reinforcing steel consumed per cubic meter of concrete (including prestressed concrete)

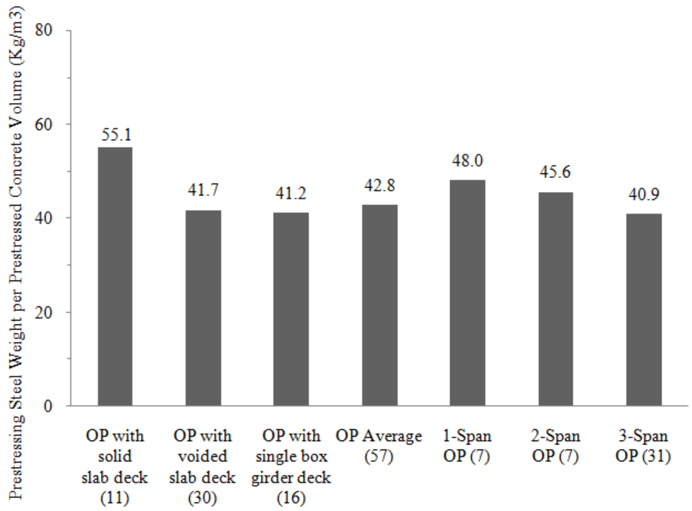


Fig. 6: Total amount of prestressing steel consumed per cubic meter of prestressed concrete

represents the cost for the construction the abutments. As none of the bridges were integral, the use of bearings and expansion joints resulted in the highest cost percentage for accessories in bridges with one span (16%), while the lowest were found in overpasses with single box girder deck (11%) and three span arrangement (13%), in which the piers are monolithically connected with the deck, hence, no bearings and expansion joints were necessary.

Figure 4 to 6 depict the average values of material consumption as far as concrete, reinforcing steel and prestressing steel in concerned, which actually are those contributing the most to the bridge cost. The numbers of sample bridges yielding the average values are also denoted on the Figures. As it is seen, for the construction of an overpass the average required amount of concrete per deck surface area was 2.43 m^3/m^2, the average required amount of reinforcing steel per concrete volume was 106.6 kg/m^3 and the average required amount of prestressing steel in the deck per prestressed concrete volume in the deck was 42.8 kg/m^3. It is understood that these figures are code of practice dependent, but it is interesting to note that the lowest rates of material consumption were observed for single box girder deck overpasses.

PROPOSED ANALYTICAL FORMULATIONS

The processing of data from fifty seven overpasses revealed that there is a strong relationship between cost and deck surface area. The total cost in euro denoted as COST can be predicted by applying the following Eq. (1) to Eq. (4), derived from a linear regression analysis, with coefficient of determination (R^2) ranging between 71 to 96% (Fig. 7), indicating a good fit to the data:

For all overpasses in general:

$$COST = 495A+35000 \quad (1)$$

For overpass with solid slab deck:

$$COST = 430A+15100 \quad (2)$$

For overpass with voided slab deck:

$$COST = 518A+45500 \quad (3)$$

For overpass with prestressed single box girder deck:

$$COST = 567A-28000 \quad (4)$$

where, A is the deck surface area in m^2, defined as the product of LxW of Table 1.

An alternative equation may be used based on theoretical volume of the structure proposed by Antoniou *et al*. (2015), which is a handy figure known even at the preliminary stage of design. By processing the data for all fifty seven bridges, the average cost in euro for overpasses can be estimated by using the following equation:

$$COST = 81\times Th\ V \quad (5)$$

Th V is the theoretical volume defined as the product of L×W×H in Table 1. In order to derive Eq. (5), H was the average value of minimum and maximum height of piers or abutments for bridges with one span.

The same trend was observed as cost between the consumption of materials and deck surface area, depicted in Fig. 8 and 9, while Eq. (6) to Eq. (9) present the proposed characteristic rates of material consumption with coefficient of determination (R^2) ranging between 68 to 92 %:

For reinforced concrete consumption (RCC) in m^3 is given by:

$$RCC = 0.97\ A+360 \quad (6)$$

For Prestressed Concrete Consumption (PCC) in m^3 is given by:

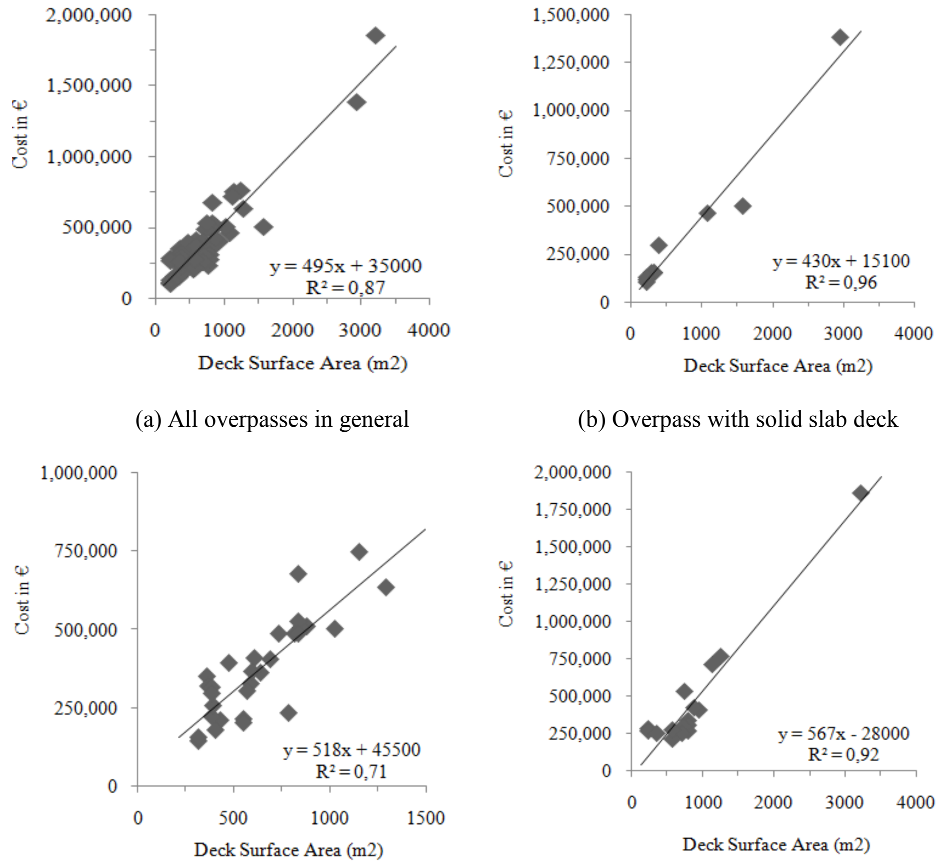
$$PCC = 0.72\ A+82 \tag{7}$$

For Reinforcing Steel Consumption (RSC) in Kg is given by:

$$RSC = 172\ A+41700 \tag{8}$$

For Prestressing Steel Consumption (PSC) in Kg is given by:

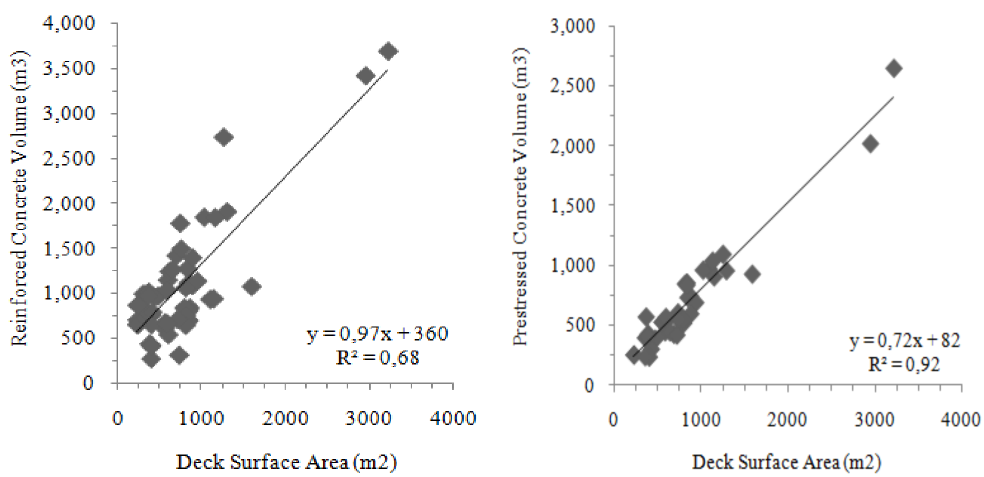
$$PSC = 39\ A\text{-}2400 \tag{9}$$



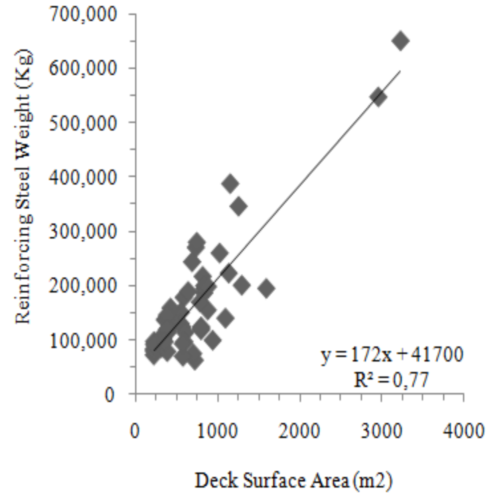
(a) All overpasses in general (b) Overpass with solid slab deck

(c) Overpass with voided slab deck (d) Overpass with prestressed single box girder deck

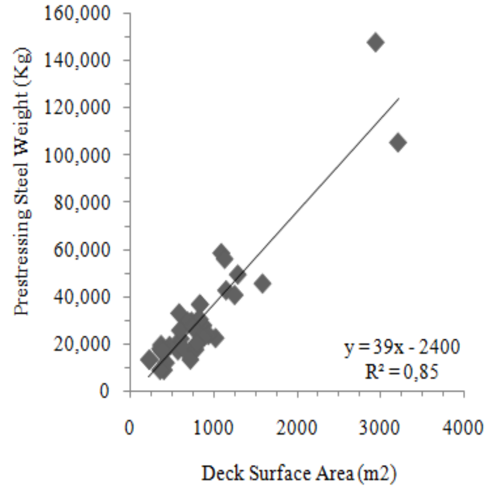
Fig. 7: Proposed relationships between cost and deck surface area in overpass bridges



(a) Reinforced concrete (b) Prestressed concrete

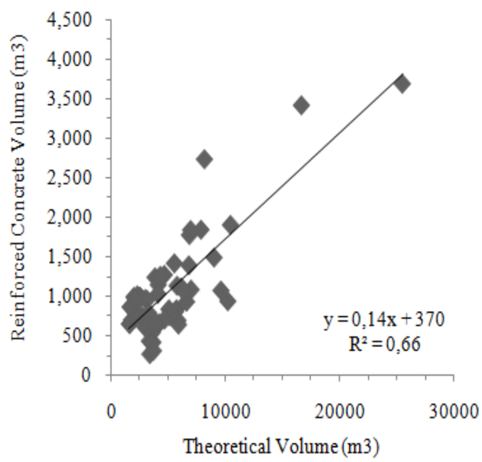


(c) Reinforcing steel

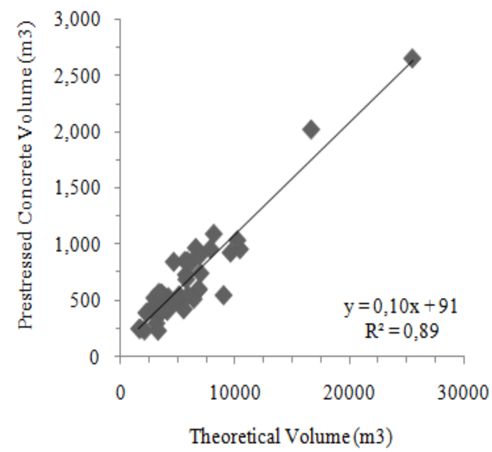


(d) Prestressing steel

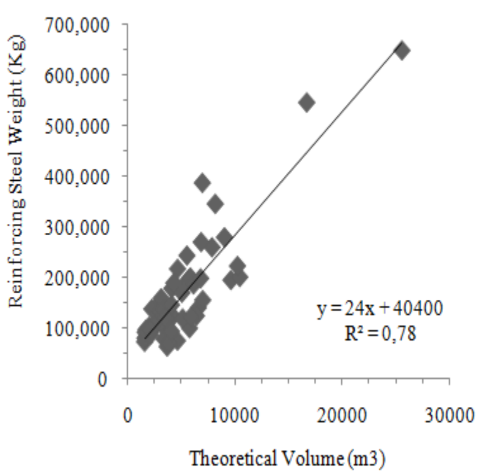
Fig. 8: Proposed relationships between material consumption and deck surface area in overpass bridges



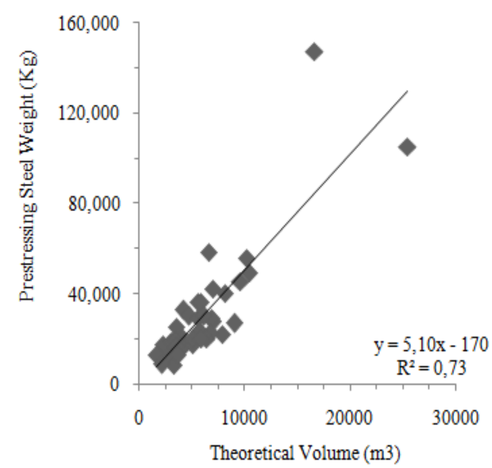
(a) Reinforced concrete



(b) Prestressed concrete



(c) Reinforcing steel



(d) Prestressing steel

Fig. 9: Proposed relationships between material consumption and theoretical volume in overpass bridges

Table 2: Statistics of the ratio of real to predicted values of cost

	Proposed equation in relation to deck surface area	
	Equation 1(57)	Equations 2-4(57)
Mean	1.02	1.05
St. Dev.	0.30	0.40
COV (%)	29.90	38.16
	Proposed equation in relation to theoretical volume	
	Equation 5(57)	
Mean	1.00	
St. Dev.	0.33	
COV (%)	33.14	

St. Dev.: Standard Deviation; COV: Coefficient of Variation

Table 3: Statistics of the ratio of real to predicted values of material consumption

	Proposed equations in relation to deck surface area			
	RCC(57)	PCC(45)	RSC(57)	PSC(45)
Mean	1.02	1.01	1.01	1.06
St. Dev.	0.35	0.19	0.29	0.35
COV (%)	34.44	19.30	28.47	33.41
	Proposed equations in relation to theoretical volume			
	RCC (57)	PCC (45)	RSC (57)	PSC (45)
Mean	0.99	1.01	1.02	1.02
St. Dev.	0.34	0.22	0.28	0.33
COV (%)	34.75	22.32	27.22	31.90

In the case that theoretical volume is adopted for the purpose of pre-estimation of materials then the following Eq. (10) to Eq. (13) are proposed with coefficient of determination (R^2) ranging between 66 to 89%:

For Reinforced Concrete Consumption (RCC) in m^3 is given by:

$$RCC = 0.14Th\ V+370 \tag{10}$$

For Prestressed Concrete Consumption (PCC) in m^3 is given by:

$$PCC = 0.10ThV+91 \tag{11}$$

For reinforcing steel consumption (RSC) in Kg is given by:

$$RSC = 24ThV+40400 \tag{12}$$

For Prestressing Steel Consumption (PSC) in Kg is given by:

$$PSC = 5.10\ ThV-170 \tag{13}$$

EVALUATION OF ANALYTICAL FORMULATIONS

The reliability evaluation of the proposed analytical formulations Eq. (1) to Eq. (13) was based on the computation of the statistics of the ratio of real to predicted values for both cost and material consumption. Table 2 and 3 illustrate the statistics for each analytical formulation alongside the number of bridges considered each time. It can be seen that the consumption of material PCC and PSC were evaluated on the basis of fewer bridges (45), as twelve bridges did not incorporate any prestressed concrete element.

The proposed formulation using theoretical volume Eq. (5) resulted in a mean value of unity (i.e., neither overestimation nor underestimation) with a relatively low uncertainty of 33%. The other two proposed formulations (i.e., Eq. 1 and Eq. 2-4) overestimate slightly the prediction of cost of an overpass by 2 and 5% respectively.

The mean values of all proposed analytical formulations for the prediction of material consumption was close to unity with scatter ranging between 19 and 35%.

CONCLUSION

Based on actual cost data and surveyed material quantities from fifty seven overpass bridges, the cost rates and distribution of cost, along with the rates of material consumption for overpasses with different superstructure types and different number of spans are presented. Then, using this data, analytical formulations were proposed for obtaining early cost and material quantity pre-estimates. The following conclusions can be drawn from this study:

- The range of cost of an overpass per surface area was found to be very close for the types of deck examined. The rate of cost per deck surface of an overpass with one span was the highest and that with three spans the lowest.
- The highest percentage of cost was allocated for the construction of the superstructure, followed by the foundation, the substructure and accessories.
- The proposed analytical formulations expressed either as a function of deck surface or theoretical volume of the structure resulted in good fit to the data, with relatively low uncertainties and can be used in similar projects.

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