Comparison between Highway Codes for Traffic Loads on Bridges

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Abstract: A comparison between the highway live loads specified by major international codes is presented. The straining actions obtained as a result of solving a typical bridge deck under the effect of live loads specified by the different codes are presented. Design aids that correlate the design values based on the different codes to the Egyptian code, EC45-1993, are presented to introduce a normalization procedure between these codes and to enable the designers to determine the design values required for the preliminary design of the deck according to any of the chosen codes. Major observations on the differences between the major codes are illustrated.

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1. Introduction

One of the most important steps in the process of designing a bridge is to determine the most appropriate live load representing, to a high certainty, the expected normal traffic loads that might go over the bridge. These expected live loads vary from a country to another country and may vary from a location to another location inside the same country depending on many parameters such as the degree of civilization, the location of the bridge inside the country, the volume of traffic, the nature of the expected major traffic passing over the bridge, i.e. military, commercial…etc.

The main code for live loads on the bridges in Egypt is The Egyptian Code for Loads and Forces on Structural and Masonry works (EC45-1993), [1]. Most of the other countries of the Middle East adopt both the British standard (BD 37/01 Loads for Highway Bridges), [2], and The American specifications AASHTO, [3, 4].

The need to have a unified live load system to be used in the Middle East is essential due to the wide range of foreign consultants working in this area. Moreover, many of the bridges are reviewed overseas by different companies who may not be familiar with the codes of each country.

Another important reason for the need to have unified live loads is to evaluate the performance of the bridges designed by different codes. For example, it was noticed that live loads of the American standards AASHTO, are not less than other codes, [5].

In order to facilitate the choice of the live loads among the designers in different countries, a comparative study is introduced to compare the results of the different codes when used to design a typical bridge. Six codes are chosen for this study as being mostly used in Egypt and all of the Arab countries: (1) The Egyptian, ECP 45-1993 [1]; (2) The New Egyptian Code, EC 201-2012,[6]; (3) The British standards, BD 37/01, [2]; (4) The European standard, Eurocode 1: EN-1991-2: 2003)[7] ; (5) The American specifications AASHTO Standard for Highway Bridges –17th edition – 2002, [3]; (6) The American specifications AASHTO LRFD Bridge Design – 4th edition – 2007[4].

The details of each code are shown in the references indicated above. The live loads specified in these codes are applied on a typical bridge deck, which has been used many times with almost the same configurations in many huge highway projects, to compare the effect of the imposed load on the structural straining actions of this bridge. The results are introduced in simple charts to be used among bridges designers. The grillage analysis method is adopted to model the case study bridge, [8].

In 1996, Mourad M. Bakhoum, has introduced a comparative study between five different codes with respect to the traffic loads, [9]. This study does not include AASHTO LRFD or EC201 and all of the other codes in this study have been updated. Moreover, it compared between the codes using equivalent uniformly distributed load which results in the same bending moment on the bridge deck as one piece.

Description of the bridge deck used in this study

The bridge under consideration is part of a series of bridges that have been built in Egypt in many big projects. Some of these major projects are: Al Maryoteia new link connecting both the eastern and western parts of Cairo ring road, Saft Al Laban, Al Meadia Bridge across Edko Lake, and other bridges all over Egypt. The same bridge configuration is very common worldwide. Pictures 1 to 4 illustrate some of these bridges.

Picture 1

Picture

Picture 3

Picture 4

Pictures 1 to 4: Some major highway projects using the same

The bridge deck of this study is composed of simple spans, 30-meter long. Each span is composed of reinforced concrete slab, 250mm thick over 4 post-tensioned girders spacing at 3.2 m. There is a 350 x 1750 mm reinforced concrete cross girder at mid-span of each bay. The main girders are connected together at each end by a 850x1750 mm cross girder. The main components of this bridge deck are shown in figure 1. The characteristic strength of the concrete after 28 days (f_{cu}) is 450 kg/cm^2.

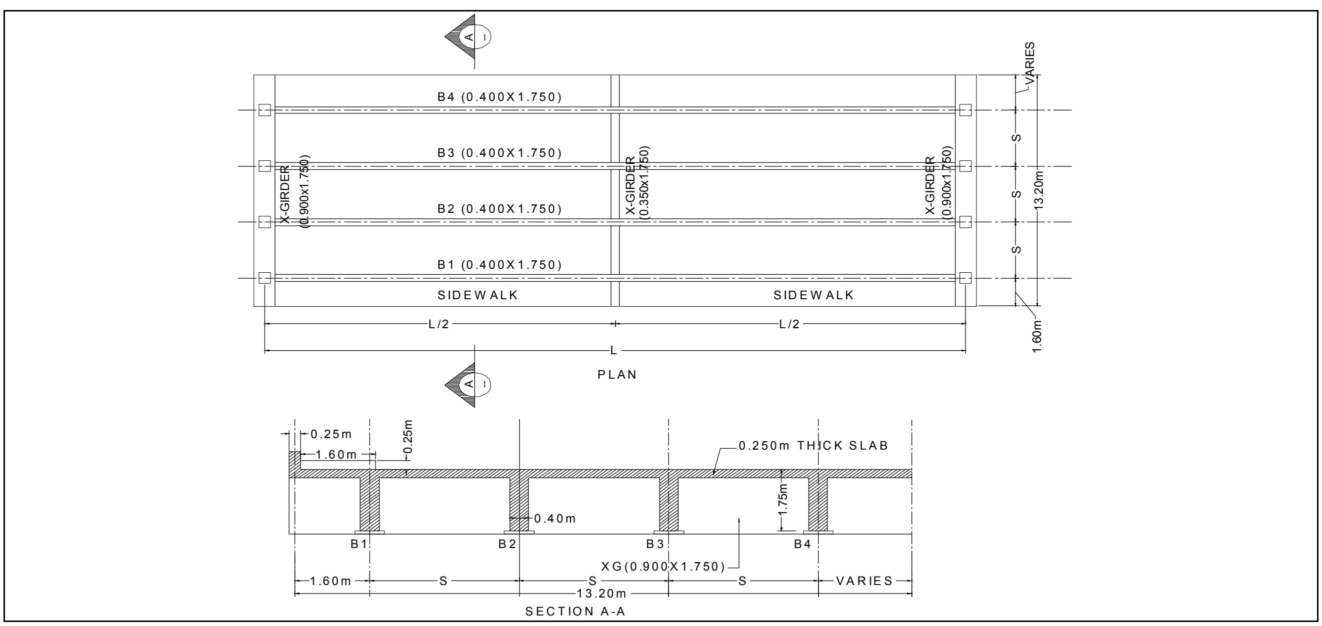

Figure 1: Details of the main components of the bridge deck considered in this study

Analysis of the Bridge Deck

The grillage modeling technique is used in this research. Both the longitudinal main girders are modeled with the properties of a T-section and the slab was modeled as lumped transversal beams at appropriate spacing. Figure 2 illustrates the grillage modeling technique; the details of this technique are illustrated in reference [9]

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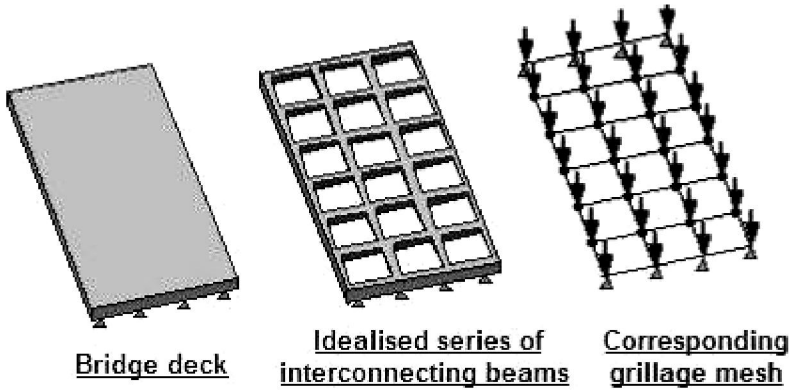

Figure 2: Grillage Modeling Technique

The live loads specified by the code are applied on the bridge deck described before using the grillage method.

In order to make this study more general, the straining actions due to the highway loads specified by each code are determined for different spans of the deck, (L=20, 25, 30,35,40,45 & 50 meters) and for different spacing between the girders (S=2.00, 2.50, 3.20 & 4.00 meters).

Comparison between the different codes

The following part describes a comparative analysis for the results obtained by applying the different codes to the typical bridge deck. The comparison is made to the Egyptian code EC45:1993. The values are shown for three different cases:

(a) UF= Unfactored values ; (b) SLS= Service limit state = γ_{SLS} x UF; and (c) ULS= Ultimate limit state= γ_{ULS} x UF

The loading factors, γ_{SLS} and $\gamma_{ULS,}$ change according to the code as shown in Table 1.

The comparisons are shown for the edge girder B1, as a sample for the results.

Table 1: Live load factors in different codes.

CODE	γ_{ULS}		γ_{ULS}	
EC-45:1993	1.00		1.60	
EC-201:2012	1.00		1.35	
EN-1992-2:2003	0.75 TS+0.40 UDL		1.35	
BD 37/01	1.20 HA	1.10 (HA+HB)	1.50 HA	1.30 (HA+HB)
AASHTO Standard 17th Ed, 2002	1.00		2.17	
AASHTO LRFD 2007	1.00		1.75	

A detailed comparison between the Egyptian Code EC45:1993 and AASHTO LRFD is shown in the following part. The same comparison is made between the Egyptian code and the other codes. The results of this comparative study are summarized in simple tables and curves to enable the design engineers in the preliminary design of the girders of the bridge deck.

Comparison between the Egyptian Code 45:1993 and AASHTO LRFD:

Tables 2 and 3 show the values of the maximum bending moment, BM, and the maximum shearing forces, SF, due to Egyptian Code EC45:1993 and AASHTO LRFD, and Table 4 shows the ratios of these values for AASHTO LRFD compared to EC45:1993, for different spans when the spacing S is 2 m, for the three cases; UF, SLS and ULS respectively.

Table 2: BM due to live load according to EC45:1993 and AASHTO LRFD (Ton, m)

Span (m)	UF		SLS		ULS	
	EC45-93	LRFD	EC45-93	LRFD	EC45-93	LRFD
20	171.35	110.00	171.35	110.00	274.16	192.50
25	221.6	145.00	221.6	145.00	354.56	253.75
30	271.56	179.00	271.56	179.00	434.49	313.25
35	321.00	213.00	321.00	213.00	513.6	372.75
40	370.61	248.00	370.61	248.00	592.97	434.00
45	421.24	284.00	421.24	284.00	673.98	497.00
50	474.54	319.00	474.54	319.00	759.26	558.25

Table 3: SF due to live load according to EC45:1993 and AASHTO LRFD (Ton)

Span (m)	UF		SLS		ULS	
	EC45-93	LRFD	EC45-93	LRFD	EC45-93	LRFD
20	37.00	27.50	37.00	27.50	59.20	48.12
25	40.00	30.50	40.00	30.50	64.00	53.37
30	42.00	33.10	42.00	33.10	67.20	57.92
35	44.00	35.60	44.00	35.60	70.40	62.30
40	46.00	38.00	46.00	38.00	73.60	66.50
45	47.00	40.00	47.00	40.00	75.20	70.00
50	49.00	42.00	49.00	42.00	78.40	73.50

Table 4: The ratios R_{BM}=BM $_{(AASHTO\ LRFD)}$/BM $_{(EC45:1993)}$ and R_{SF}= SF $_{(AASHTO\ LRFD)}$/SF $_{(EC45:1993)}$ {S=2.00m}

Span (m)	R_{BM}			R_{SF}		
	UF	SLS	ULS	UF	SLS	ULS
20	0.64	0.64	0.70	0.74	0.74	0.81
25	0.65	0.65	0.71	0.76	0.76	0.83
30	0.66	0.66	0.72	0.79	0.79	0.86
35	0.66	0.66	0.73	0.81	0.81	0.88
40	0.67	0.67	0.73	0.83	0.83	0.90
45	0.67	0.67	0.74	0.85	0.85	0.93
50	0.67	0.67	0.73	0.86	0.86	0.94

Table 5 shows the average ratios obtained by repeating the above mentioned comparisons for different spacing between the girders, S from 2 to 4 m.

Similar comparisons were done for all of the codes mentioned in this study. Tables 6 to 9 are similar to table 5 but for the other codes.

Table 5: The average ratios for R_{BM}=BM $_{(AASHTO\ LRFD)}$/BM $_{(EC45:1993)}$ and for R_{SF}= SF $_{(AASHTO\ LRFD)}$/SF $_{(EC45:1993)}$, {S=2, 2.5, 3.2 and 4m}

Span (m)	$R_{BM.\ Avrg}$			$R_{SF.\ Avrg}$		
	UF	SLS	ULS	UF	SLS	ULS
20	0.63	0.63	0.68	0.73	0.73	0.80
25	0.64	0.64	0.70	0.75	0.75	0.82
30	0.65	0.65	0.71	0.77	0.77	0.84
35	0.65	0.65	0.71	0.80	0.80	0.87
40	0.65	0.65	0.72	0.82	0.82	0.89
45	0.66	0.66	0.72	0.84	0.84	0.92
50	0.66	0.66	0.72	0.85	0.85	0.93

Table 6: The average ratios for R_{BM}=BM $_{(EC201:2012)}$/BM $_{(EC45:1993)}$ and for R_{SF}= SF $_{(EC201:2012)}$/SF $_{(EC45:1993)}$, {S=2, 2.5, 3.2 and 4m}

Span (m)	$R_{BM. Avrg}$			$R_{SF. Avrg}$		
	UF	SLS	ULS	UF	SLS	ULS
20	1.23	1.23	1.04	1.20	1.20	1.01
25	1.27	1.27	1.07	1.24	1.24	1.05
30	1.31	1.31	1.11	1.29	1.29	1.08
35	1.35	1.35	1.14	1.33	1.33	1.12
40	1.38	1.38	1.16	1.38	1.38	1.17
45	1.42	1.42	1.20	1.42	1.42	1.20
50	1.45	1.45	1.22	1.47	1.47	1.24

Table 7: The average ratios for R_{BM}=BM $_{(BD\ 37/01)}$/BM $_{(EC45:1993)}$ and for R_{SF}= SF $_{(BD\ 37/01)}$/SF $_{(EC45:1993)}$, {S=2, 2.5, 3.2 and 4m}

Span (m)	$R_{BM. Avrg}$			$R_{SF. Avrg}$		
	UF	SLS	ULS	UF	SLS	ULS
20	1.18	1.30	0.96	1.17	1.29	0.95
25	1.26	1.38	1.02	1.21	1.33	0.98
30	1.32	1.45	1.07	1.22	1.34	0.99
35	1.32	1.46	1.08	1.23	1.36	1.00
40	1.46	1.47	1.10	1.24	1.36	1.01
45	1.35	1.48	1.12	1.24	1.36	1.00
50	1.35	1.48	1.12	1.23	1.35	1.00

Table 8: The average ratios for R_{BM}=BM $_{(EN-1991-2:\ 2003)}$/BM $_{(EC45:1993)}$ and for R_{SF}= SF $_{(EN-1991-2:\ 2003)}$/SF $_{(EC45:1993)}$, {S=2, 2.5, 3.2 and 4m}

Span (m)	$R_{BM. Avrg}$			$R_{SF. Avrg}$		
	UF	SLS	ULS	UF	SLS	ULS
20	1.23	0.77	1.04	1.20	0.74	1.01
25	1.27	0.78	1.07	1.24	0.74	1.05
30	1.31	0.79	1.11	1.29	0.76	1.08
35	1.35	0.80	1.14	1.33	0.77	1.12
40	1.38	0.80	1.16	1.38	0.79	1.17
45	1.42	0.81	1.20	1.42	0.80	1.20
50	1.45	0.81	1.22	1.47	0.81	1.24

Table 9: The average ratios for R_{BM}=BM $_{(AASHTO\ Standard)}$/BM $_{(EC45:1993)}$ and for R_{SF}= SF $_{(AASHTO\ Standard)}$/SF $_{(EC45:1993)}$, {S=2, 2.5, 3.2 and 4m}

Span (m)	$R_{BM. Avrg}$			$R_{SF. Avrg}$		
	UF	SLS	ULS	UF	SLS	ULS
20	0.36	0.36	0.49	0.59	0.59	0.81
25	0.36	0.36	0.49	0.60	0.60	0.81
30	0.37	0.37	0.50	0.61	0.61	0.83
35	0.38	0.38	0.51	0.62	0.62	0.84
40	0.39	0.39	0.52	0.64	0.64	0.86
45	0.39	0.39	0.53	0.65	0.65	0.88
50	0.40	0.40	0.54	0.66	0.66	0.90

Discussions:

From the above mentioned results, it is observed that:

- The results obtained by the new Egyptian code, EC201:2012, is usually higher than the old code, EC45:1993. The average ratio is 1.45 for BM in case of UF and SLS. This ratio decreases in the case of ULS to be 1.22.
- Similarly, for the shear force, these ratios are 1.47, 1.47 and 1.24 for UF, SLS and ULS respectively.
- These ratios increase by increasing the span due to the decrease in the impact factor used in EC45:1993, while the impact factor in EC201:2012 is included in the values of live loads.

- The results obtained by BD 37/01 are higher than the results of EC45-93 in most of the cases. The ratio R_{BM} ranges between 1.18 to 1.35, 1.30 to 1.48 and 0.96 to 1.12 for the UF, SLS and ULS bending moments respectively. On the other hand, the ratio R_{SF} for the shear forces ranges between 1.17 to 1.23, 1.29 to 1.35 and 0.95 to 1.00 for the UF, SLS and ULS shear forces respectively.
- In general, the British Standard, BD37/01, develops larger service straining actions than the Egyptian code due to live loads, while they are almost equal for ultimate straining actions. (N.B: the comparison is made using 45 units of HB loading specified in the BD37/01)
- The results obtained by applying the European Standard (EN 1991-2:2003) are usually higher than the Egyptian code: EC45:1993 for the cases UF and ULS load cases. On the other hand, these results are lower for the case of SLS.

The ratio R_{BM} ranges between 1.23 to 1.45, 0.77 to 0.81 and 1.04 to 1.22 for the UF, SLS and ULS bending moments respectively. On the other hand, the ratio R_{SF} for the shear forces ranges between 1.2 to 1.47, 0.74 to 0.81 and 1.01 to 1.24 for the UF, SLS and ULS shear forces respectively. It is worthy to be mentioned that The results obtained by both the Egyptian Code EC-201:2012 and the European Code EN-1991-2:2003 are identical and they are higher than EC45:1993.

- The results obtained by AASHTO Standard (17th edition: 2002) are usually lower than the Egyptian code: EC45:1993. The ratios range between 0.36 to 0.40 for both UF and SLS bending moment and between 0.49 to 0.54 for the ULS bending moment. For shear forces, the ratios range between 0.59 to 0.66 for UF and SLS, and between 0.81 to 0.60 for ULS shear force.
- The results obtained by AASHTO LRFD (4th Edition: 2007) are usually lower than the Egyptian code: EC45:1993. The average ratio ranges between 0.63 to 0.66 for the UF and SLS bending moment; and 0.68 to 0.72 for the ULS bending moment. For the shear forces, the ratio ranges between 0.73 to 0.85. For UF and SLS shear force; and 0.80 to 0.93 for the ULS shear force. The ratio increases by increasing the span due to the decrease in the impact factor used in EC45:1993, while in AASHTO LRFD, the impact factor is constant.

The maximum average ratio R_f which relates the results of the different codes to the Egyptian code EC45:93 is shown in table 10 for both the bending moment and the shear force considering spans from 20m to 50 m and spacings from 2m to 4m. The numbers shown may be used for approximate conversion between the different codes.

Table 10 Maximum ratio R_f=f(code$_i$)/f(EC45:93)

Code	UF **R_{BM}**	SLS **R_{BM}**	ULS **R_{BM}**	UF **R_{SF}**	SLS **R_{SF}**	ULS **R_{SF}**
EC201:2012	1.45	1.45	1.22	1.47	1.47	1.24
BD 37/01	1.35	1.48	1.12	1.24	1.36	1.01
EN 1991-2:2003	1.45	0.81	1.22	1.47	0.81	1.24
AASHTO Standard:2002	0.40	0.40	0.54	0.66	0.66	0.90
AASHTO LRFD:2007	0.66	0.66	0.72	0.85	0.85	0.93

The results shown in tables 5 to 9 are illustrated in figures 3 to 6 for the UF and ULS values. These charts are extremely useful for designers who are used to work in different countries with different codes.

Conclusions:

A comparative study between the highway live loads specified by major international codes is presented. The main conclusions of this study may be summarized as follows:

1- The live loads specified by both the new Egyptian Code EC201-2012 and the European Code EN-1991 are identical and they give higher values than the old Egyptian code EC45 which still be used in the design of the bridges in Egypt.

2- The British Standard, BD37/01, develops larger service straining actions than EC45-1993, while they give almost the same results for ultimate straining actions.

3- The straining actions caused by the live loads of both AASHTO STANDARD and AASHTO LRFD are much lower than those obtained by the other codes. This remarkable difference may be attributed to the weight of the trucks specified by the AASHTO codes. In many countries these codes are adopted after increasing the value of the truck by a certain multiplier. In some projects, this multiplier reaches a value of 2.

4- It is not appropriate to use different bridge design codes in the same country. A unified design code is required to be developed and used in our area.

5- Conversion factors and charts are developed in this research to be used to convert between different codes in the stage of preliminary design.

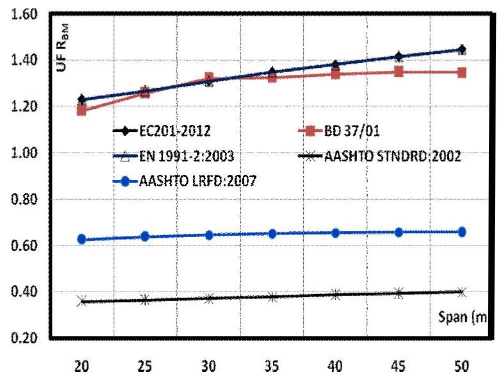

Figure 3: The average Ratio UF R_{BM}= UF BM $_{(CODE\ i)}$ / UF BM $_{(EC45:1993)}$

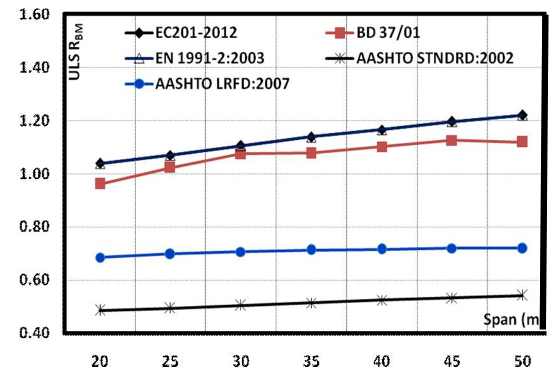

Figure 4: The average Ratio ULS R_{BM}= ULS BM $_{(CODE\ i)}$ / ULS BM $_{(EC45:1993)}$

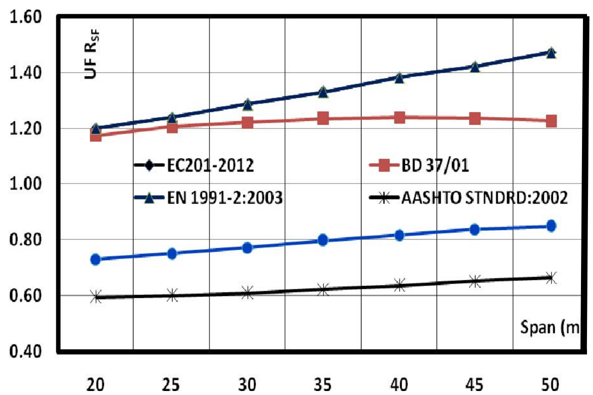

Figure 5: The average Ratio UF R_{SF}= UF SF $_{(CODE\ i)}$ / ULS SF $_{(EC45:1993)}$

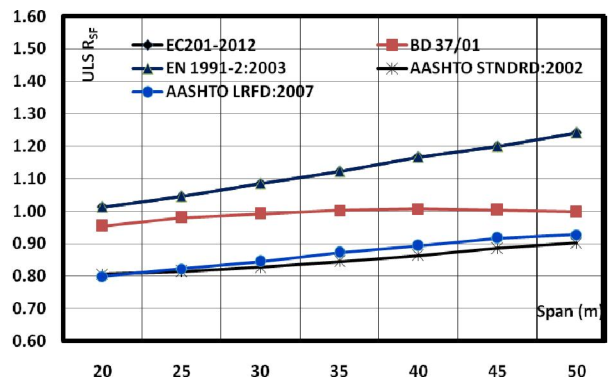

Figure 6: The average Ratio ULS R_{SF}=ULS SF $_{(CODE\ i)}$ / ULS SF $_{(EC45:1993)}$

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