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Artikel: Traffic actions for the design of long and medium span road bridges: a comparison of international codes

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Traffic Actions for the Design of Long and Medium Span Road Bridges. A Comparison of International Codes.

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Summary

Highway Bridge Design Codes & Suggested Provisions from USA, UK, Japan, Egypt, and Eurocode are considered. Comparisons of Action effects due to Traffic actions only, & Traffic actions combined with Permanent actions are carried out. ULS & SLS are considered. It is noted that comparing Traffic actions alone, a large difference is observed between codes (about 60%). When combined with Permanent actions (assuming concrete bridges), this difference reduces considerably (to about 15%). A brief comparison of Resistance of R.C. sections at ULS is also carried out.

1. Introduction

Traffic Actions (Live loads) given in Bridge Design Codes are models of actual traffic running on the bridges. It is recognized that traffic patterns in different countries are different to some extent, however, this does not justify the huge differences between traffic action models (LL) specified in the codes. Several studies have been carried out to compare LL in different bridge codes for short/medium span bridges [1,5] & few studies for long span bridges [3]. These studies give useful information, however, more studies are needed because: *i)*Introduction of new codes and new traffic action models such as Eurocode, *ii)* Previous studies focused on comparing Live Loads only. This is not sufficient, and might even be misleading. *iii)* New comparison between codes should include different load types (Live load, Dead Loads, other loads) and their load combinations, moreover, *iv)* not only loads, but also Resistance of sections should also be considered. An attempt to make such a study is given in this paper.

2. Selection of Parameters

The parameters considered in the study, are presented in the following:
--*Bridge Codes:* Five Codes from different countries are considered to investigate practices in different parts of the world. i) AASHTO & ASCE [USA], ii) BD 37/88 & BS5400:Part4 (UK), iii) EGCPL & EGCPC (Egypt), iv) JRA (Japan), and v) EC1:Part3 & EC2 (Eurocodes).
--*Actions Considered & Combination of Actions:* Actions considered in the study are: Traffic actions, Impact or Dynamic allowance for traffic actions (where applicable), Permanent actions due to self-weight of Structural elements & Non-Structural elements. The following terms & abbreviations are used interchangeably with the above mentioned actions: Live loads (*LL*), Impact (*IM*), Dead Loads (*DL*), Superimposed Dead Loads (*SDI*). Concerning combination

of actions, it is noted that for the design of bridge superstructures, the combination including above mentioned actions is --in many instances-- the most critical load combination. Hence, it is the only load combination considered in this study.

--Load factors: taken from AASHTO (both for ASCE & AASHTO loads), BD 37/88, EC1. Concerning EGCPL, no values for load factors are given in this code. Hence, load factors of EGCPC are assumed, for the sake of this comparative study, to be applicable to bridges at ULS. Load factors at ULS are given in Fig. 5 (top three rows). JRA is not considered in this study at ULS. Load factors for SLS or ASM are taken equal to 1 for all codes, except for BD 37/88 which uses 1.2 for HA loading, and 1.2 for SDL(deck surfacing).

--Live Loads: Figures 4a, 4b show a brief description of the LL considered in this study, & the application of the LL to a 4-lane bridge. It is noted that the AASHTO code is applicable only to spans up to 150 m. Hence, the LL suggested by ASCE for long span bridges are used in this study instead of AASHTO for spans >=125m. Also, EC1:Part3 is applicable up to 200m only. But, it is extended up to 1000m in this study. Pedestrian loads (sidewalk) not considered.

--Live Load Classes: Live loads considered here are heaviest loads specified in the codes for First class (Federal, Interstate) highways, e.g. for AASHTO use HS20-44.

--Live Load Levels: Some codes (e.g. JRA, ASCE) specify different LL intensities depending on percentage of heavy or large vehicles on bridge. LL levels considered are shown in Fig. 4.

--Live Load Models: Some codes (EGCPC/DIN & ASCE) specify one live load model only. In other codes, several LL models are given. For example BD 37/88 specifies: HA load, HB, & combination of HA,HB. Also, AASHTO specifies(HS20 truck, HS20 lane load, Military load). In this study, the live load models believed to produce largest load effects (in the longitudinal direction) in main girders of medium & long span bridges are considered.(see Fig. 4).

--Traffic Lanes, Bridge Deck Width, and Geometrical Design Issues: Bridges with 2-lanes, 4-lanes, and 6-lanes are considered in the study. Total bridge deck widths (*B*) are 12.30m, 19.80m, 28.40m, respectively (Fig. 4 shows a drawing of 4-lane bridge). These are derived as follows: Lane width assumed to be 3.65m. Values for Median, Median clearance, Shoulder (side clearance), Side walk (for maintenance purposes) and space for Handrail are given in the table below. Most of these values conform to AASHTO Geometric Design requirements.

	Total Width	LaneWidth	Side Clr.	Side Walk	Handrail	Median	Median Clr.
2-lanes	12.30m	3.65m	1.25m	0.75m	0.50m	---	---
4-Lanes	19.80m	3.65m	0.60m	0.75m	0.50m	1.0m	0.25m
6-Lanes	28.40m	3.65m	1.25m	0.75m	0.50m	1.0m	0.25m

--Bridge Spans: Medium & long span bridges are considered. Medium span bridges are defined as 30m, 60m, 90m, 120m. Long span bridges are defined as 125m, 250m, 500m, 1000m. It is noted that bridges with span of about 125m could be considered as Medium/Long bridges.

--Bridge Systems: For spans 30m to 120m, structural system assumed to be Concrete "Box Girder Beam" Bridges (*BGB*). For spans 125m to 1000m, structural system assumed to be Concrete "Cable-Stayed" Bridges (*CSB*). It is noted that 1000m is probably too long for a Concrete CSB, however, it is considered here just for comparison purposes.

--Estimation of Dead Load Intensity of Structural elements: DL=(25kN/m3)*(B)*(tav.) kN/m. where B is the bridge width as described above, tav is the average or equivalent thickness of bridge in transversal direction. tav. could be estimated as follows: for spans 30m to 120m, following formulas (for BGB) could be useful: tav.=0.35+0.0045L [6], or tav.=0.4+0.0035L. For spans 125m to1000m (Concrete CSB), use tav=0.50m. Walther (Ref. 7,Table 3.30)

observed that for CSB road bridges, with spans ranging from 97m to 440m, including both One-plane & Two-plane CSB, tav. is about 0.50m. Values of tav. considered in the study are:

Span	30m	60m	90m	120m	125m	250m	500m	1000m
tav.	0.512m	0.64m	0.745m	0.85m	0.50m	0.50m	0.50m	0.50m

-- *SDL, Weight of Non-Structural elements:* Deck surfacing (22 kN/m3)*(B*0.08m), Handrails (2*5kN/m), Traffic Barriers (n*3kN/m/barrier, n=2 for 2-lanes, n=4 otherwise).

--*Resistance of Sections at Ultimate:* Figure 5 gives some of the relevant data.

3. Presentation and Discussions of Results

Figure 1 shows four different comparisons between the loads of the bridge codes considered in this study, for a 2-lane bridge. In Fig. 1a, only traffic actions and impact are considered. All loads are multiplied by 1. In Fig.1b, above values are multiplied by load factors for ULS (see Fig.5). Fig. 1c shows combination of Traffic actions (LL, IM) with permanent actions (DL, SDL) at SLS. Finally, Fig. 1d shows loads at ULS. The vertical axis in the figures gives EUDL. For a given bridge code & span, *EUDL* is a uniformly distributed load, which produces the same maximum moment in a simply supported beam subjected to the live loads given in the bridge code considered. The horizontal axis in the figures comprises two parts. Left part for spans 30m to120m (considered as med. span bridges in this study). Right part for spans 125m to 1000m (long span). Refer to Section 2, for discussions on Bridge systems. *Tables next to the Figs. 1a to 1d,* give relative values of EUDL for a certain code, with respect to EUDL for Eurocode. For example,for Fig. 1a, EUDL(AASHTO) / EUDL (EC1)=0.40. (considering unfactored LL only). Also, for Fig. 1d, considering all loads factored for ULS, EUDL(AASHTO) / EUDL (EC1)=0.89. Discussions above apply to Fig. 2,3 as well.

Figure 4 gives some information concerning the Road traffic actions considered in this study. Note large differences in the Topology of the load models.

Figure 5: Safety requirements in all codes requires that action effects at a section must be ≤ Resistance (Strength,Capacity) of the section. Parameters on both sides of this design equation are selected & calibrated so as to lead to safe structures. Work reported up till now focused on left side of the design equation (action side). In order to complement this comparative study, it would be useful to consider also Resistance considerations in the different codes. In Fig. 5, rows 1,4,5,7 give some of the code provisions for resistance & actions. Rows 6,8 present some calculations concerning resistance. Rows 2, 3 give values related to action effects as previously reported in Fig. 2. Now, a comparison is made between Actions (row 3) & Resistance (row 6) for flexure design. It could be said that EC, BS5400, EGCP would give similar dimensions (EGCP slightly bigger), while AASHTO would be less conservative than EC. Now, another comparison is made between Resistance of Sections in Flexure (row 6), & in Axial Load (row 8). It could be observed that i)there are larger differences between codes in row 8 than in row 6, ii) AASHTO is the least conservative in flexural resistance, & one of the most conservative in axial resistance. It is noted that axial strength of Columns in EC2 (given in row 8) is based on the following equation: Nud = 0.57 .fck .Ac + 0.87. fyk. As [Ref. 2].

From results reported in the study, an observation is made relating live loads levels specified in AASHTO (Fig. 1 to 3), and the performance of bridges in USA. It is well known that LL in AASHTO are lower than other codes, even lower than actual loads on bridges in USA[8].

Based on the results reported in this paper, and comparing AASHTO to other bridge codes (take Eurocode for example), Tables 1c, 1d show relative values of EUDL for a 2-lane bridges (both permanent actions and traffic actions are considered at SLS and ULS). The ratio of EUDL in AASHTO with respect to Eurocode is 0.86(SLS), and 0.89 (ULS). i.e. the difference between codes is smaller at ULS than at SLS. This might be one of the explanations why many bridges in the USA suffer serviceability problems (more than in other countries, partly due to low values of live loads in AASHTO), but bridges do not suffer from complete failure (high value of live load factor at ULS, =2.17, contribute to a large value of ultimate action effect).

4. Conclusions

For the cases considered in this paper, some conclusions are given: (1) Concerning traffic actions on bridges, large differences are observed between actions intensities given in the codes (Fig. 1a,2a,3a). (2) Same applies to load factors (Fig.5). (3)When variable actions are combined with permanent actions, the difference is still observed. However, it decreases, especially at ULS (Fig. 1d,2d,3d). (4) Differences between Action effects are more than differences between Resistance of sections in Flexure. (5) Considering both Action effects and Resistance at ULS, AASHTO is less conservative than EC in flexure, and much more conservative in Axial Loads.

5. Bibliography

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6. Acknowledgment

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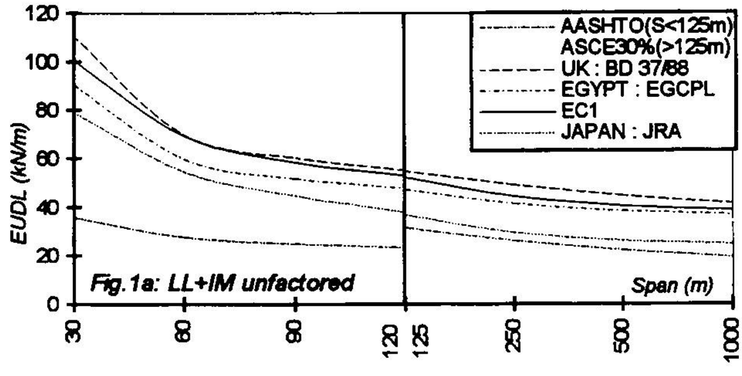
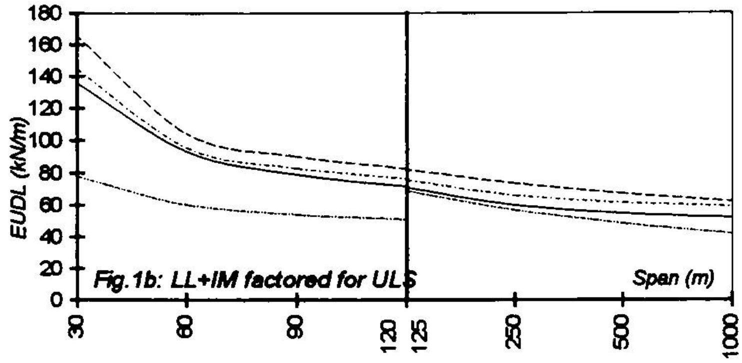
7. Selected Notation

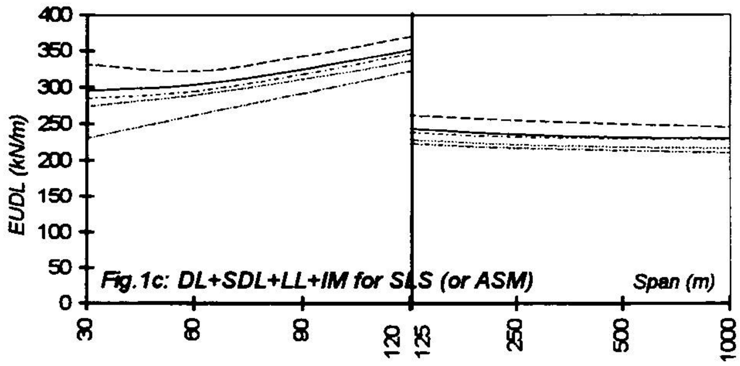
AASHTO:	Standard Specifications for Highway Bridges, USA, 15th Edition, 1992.
ASCE:	American Soc. of Civil Eng., USA, Recommendations for Bridge Loading, 1981
BD 37/88:	Ministry of Transport, UK. Departmental Standard: Loads for Highway Bridges.
BS5400:	Code of Practice & Specs. for Design of Brides (Part 4: Concrete), BSI,UK.
EC1, EC2:	Eurocode 1-Part3:Traffic loads on bridges & EC2: Design of Concrete Structures.
EGCPL:	Egyptian Code of Practice for Loads, 1993. Highway Loads same as DIN.
EGCPC:	Egyptian Code of Practice for Design and Execution of Concrete Struc., 1989.
SLS, ASM:	Serviceability Limit State, Allowable Stress Method or Working Stress Method
ULS:	Ultimate Limit State for EC, UK, Egypt. In this paper, ULS is used also to denote also factored loads at Ultimate in the AASHTO code.
JRA:	Japan Road Association, Japan



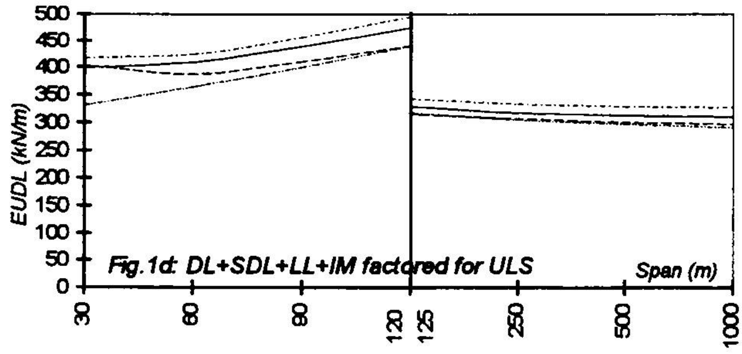
Rel.load w.r.t.(EC1)		
Code	Span (m)	
	60m	250m
AASHTO	0.40	0.59
BD 37/88	1.01	1.11
EGCPL	0.87	0.93
EC1	*1.*	*1.*
JAPAN	0.79	0.67



Rel.load w.r.t.(EC1)		
Code	Span (m)	
	60m	250m
AASHTO	0.64	0.95
BD 37/88	1.12	1.23
EGCPL	1.03	1.10
EC1	*1.*	*1.*
JAPAN	-	-



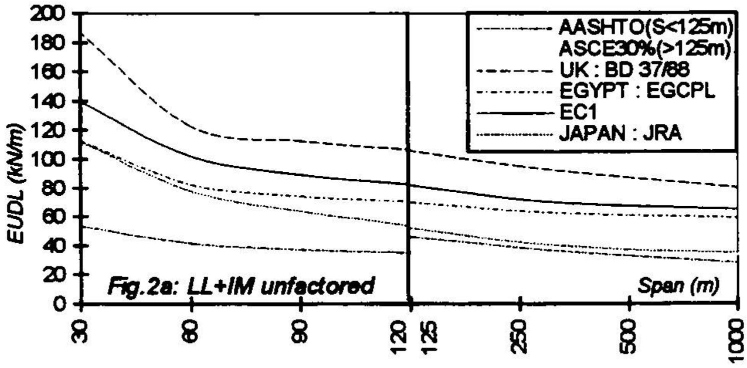
Rel.load w.r.t.(EC1)		
Code	Span (m)	
	60m	250m
AASHTO	0.86	0.92
BD 37/88	1.06	1.08
EGCPL	0.97	0.99
EC1	*1.*	*1.*
JAPAN	0.95	0.94



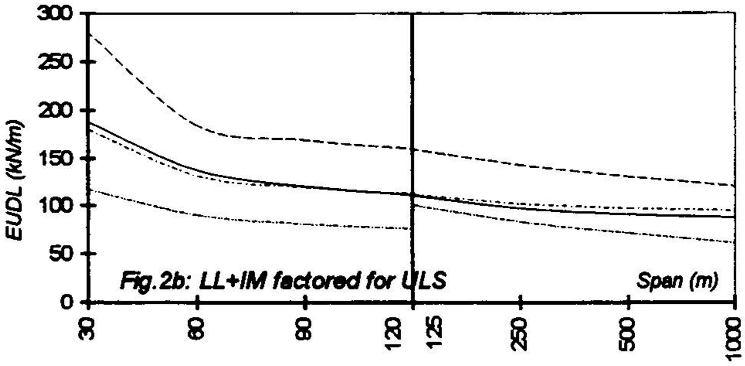
Rel.load w.r.t.(EC1)		
Code	Span (m)	
	60m	250m
AASHTO	0.89	0.96
BD 37/88	0.95	0.97
EGCPL	1.03	1.05
EC1	*1.*	*1.*
JAPAN	-	-

Notes: 1)EUDL:Equivalent Unif. Dist. Load,gives same max. moment as in simply supported bridge
2) Fig.1a,b: Traffic Actions only (LL,IM) — Fig.1c,d: combined with Permanent Actions (DL,SDL)
3) DL Intesity:Assume Conc.Br., B=12.3m, $t_{av.}$=0.51m to 0.85m & 0.50m(span <125m & >=125m)

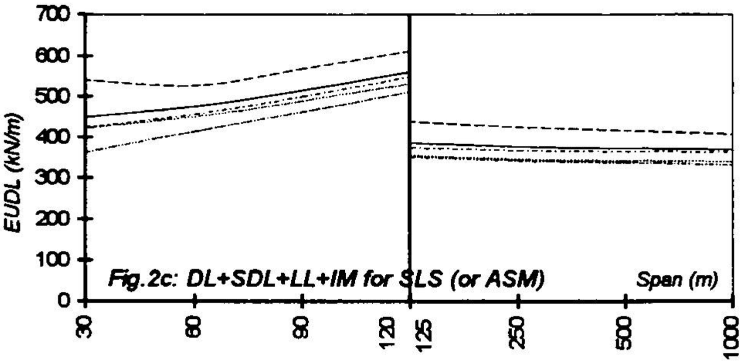
Fig.1: Comparison of Traffic Actions (Live Loads) on 2-Lane Bridges



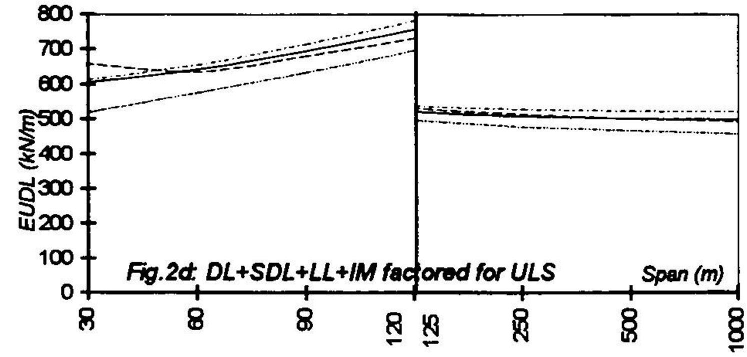
Rel.load w.r.t.(EC1)		
Code	Span (m)	
	60m	250m
AASHTO	0.41	0.53
BD 37/88	1.20	1.32
EGCPL	0.81	0.88
EC1	*1.*	*1.*
JAPAN	0.76	0.59



Rel.load w.r.t.(EC1)		
Code	Span (m)	
	60m	250m
AASHTO	0.66	0.86
BD 37/88	1.34	1.46
EGCPL	0.96	1.05
EC1	*1.*	*1.*
JAPAN	-	-



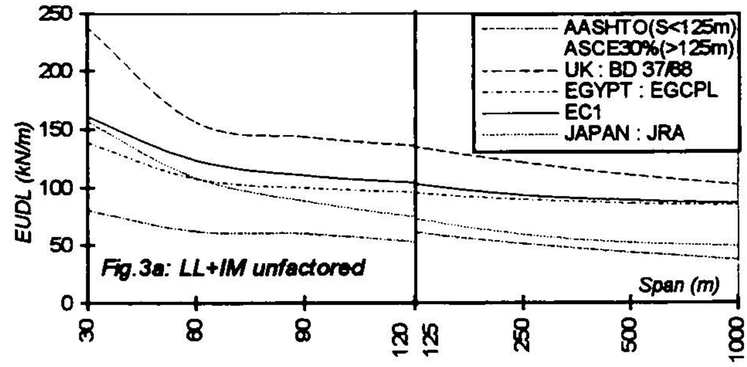
Rel.load w.r.t.(EC1)		
Code	Span (m)	
	60m	250m
AASHTO	0.87	0.91
BD 37/88	1.11	1.13
EGCPL	0.96	0.98
EC1	*1.*	*1.*
JAPAN	0.95	0.92



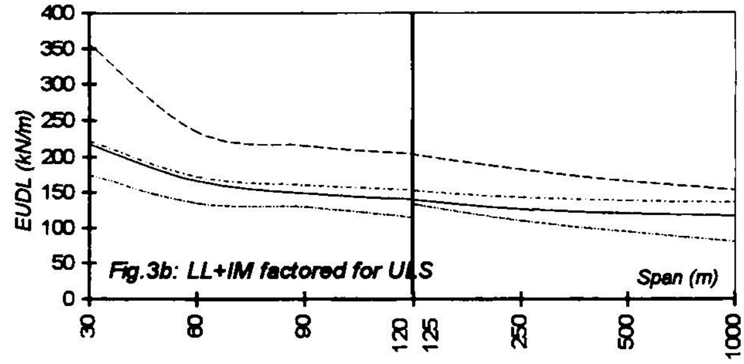
Rel.load w.r.t.(EC1)		
Code	Span (m)	
	60m	250m
AASHTO	0.90	0.94
BD 37/88	0.99	1.01
EGCPL	1.02	1.04
EC1	*1.*	*1.*
JAPAN	-	-

Notes: 1) EUDL: Equivalent Unif. Dist. Load, gives same max. moment as in simply supported bridge
2) Fig.2a,b: Traffic Actions only (LL,IM) — Fig.2c,d: combined with Permanent Actions (DL,SDL)
3) DL Intesity: Assume Conc.Br., B=19.8m, $t_{av.}$=0.51m to 0.85m & 0.50m(span <125m & >=125m)

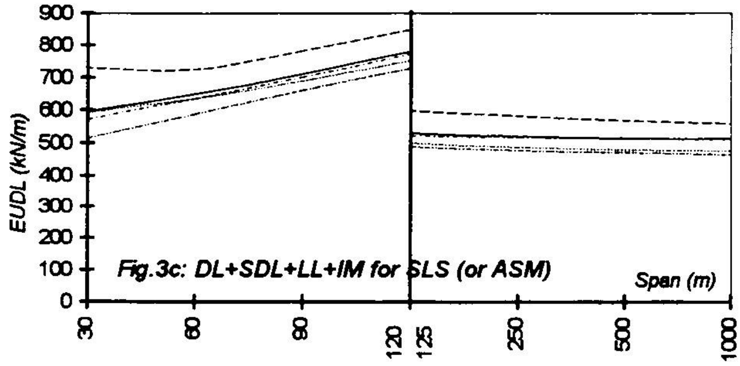
Fig.2: Comparison of Traffic Actions (Live Loads) on 4-Lane Bridges



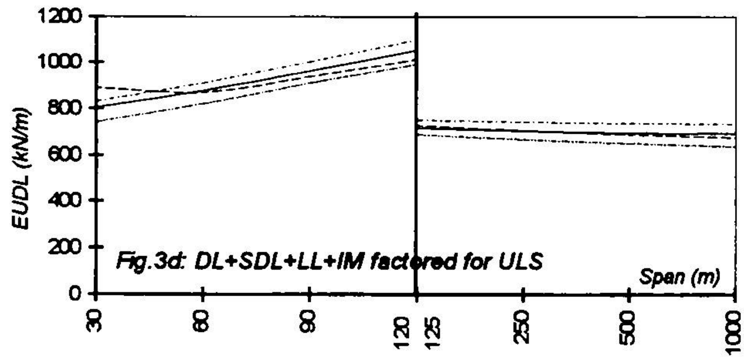
Rel.load w.r.t.(EC1)		
Code	Span (m)	
	60m	250m
AASHTO	0.51	0.54
BD 37/88	1.27	1.29
EGCPL	0.88	0.96
EC1	1.	1.
JAPAN	0.88	0.63



Rel.load w.r.t.(EC1)		
Code	Span (m)	
	60m	250m
AASHTO	0.81	0.87
BD 37/88	1.41	1.44
EGCPL	1.04	1.13
EC1	1.	1.
JAPAN	-	-



Rel.load w.r.t.(EC1)		
Code	Span (m)	
	60m	250m
AASHTO	0.91	0.92
BD 37/88	1.11	1.12
EGCPL	0.98	0.99
EC1	1.	1.
JAPAN	0.98	0.93



Rel.load w.r.t.(EC1)		
Code	Span (m)	
	60m	250m
AASHTO	0.93	0.95
BD 37/88	0.99	1.00
EGCPL	1.04	1.05
EC1	1.	1.
JAPAN	-	-

Notes: 1)EUDL:Equivalent Unif. Dist. Load,gives same max. moment as in simply supported bridge
2) Fig.3a,b: Traffic Actions only (LL,IM) — Fig.3c,d: combined with Permanent Actions (DL,SDL)
3) DL Intesity:Assume Conc.Br., B=28.4m, $t_{av.}$=0.51m to 0.85m & 0.50m(span <125m & >=125m)

Fig.3: Comparison of Traffic Actions (Live Loads) on 6-Lane Bridges

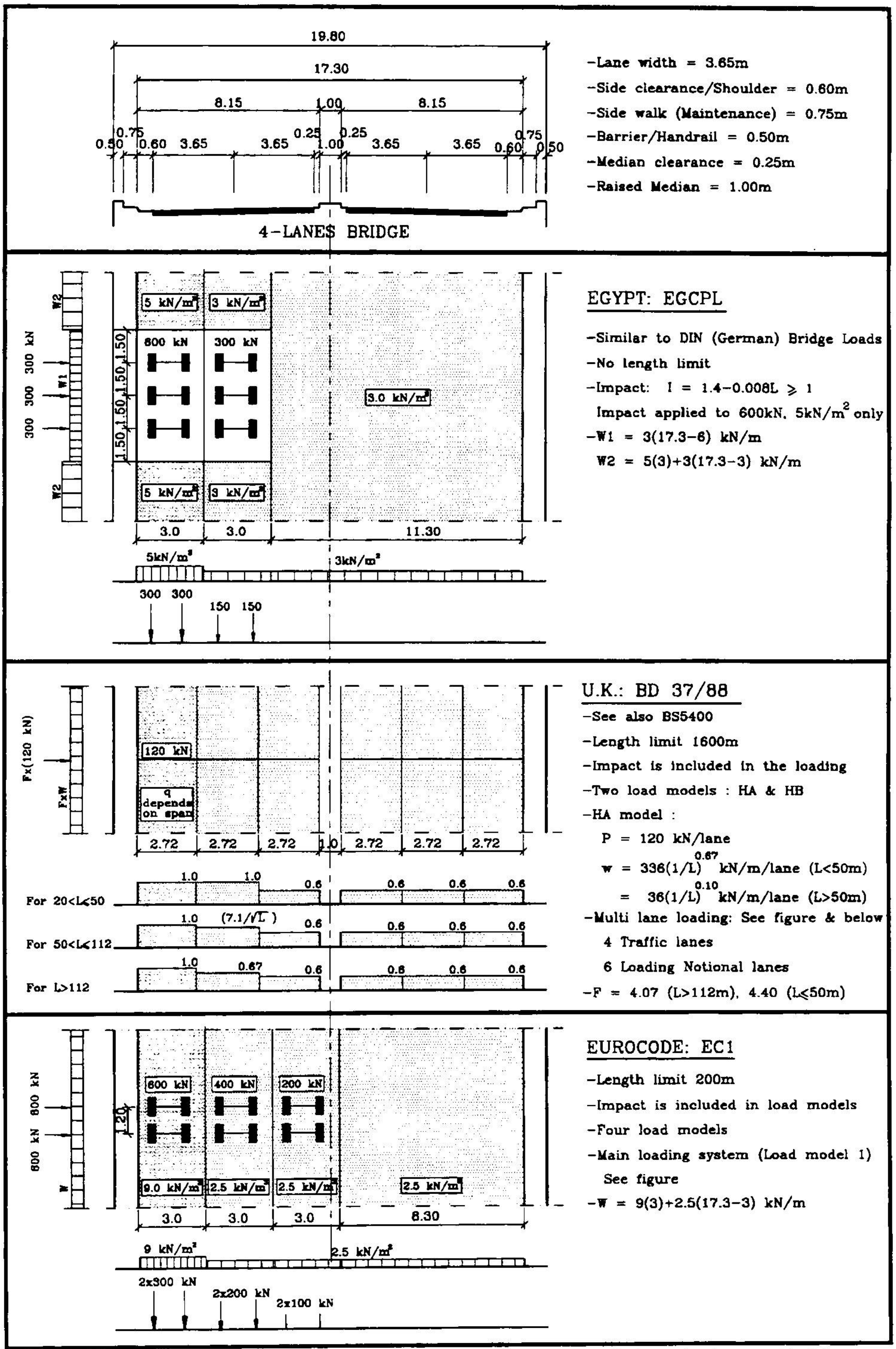
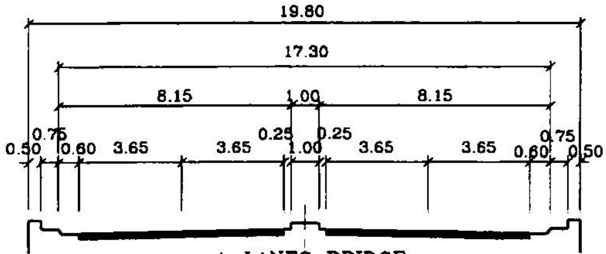
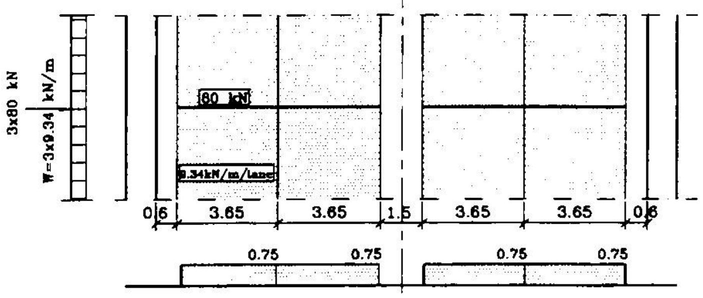


Fig.4a: Traffic Actions (Live Loads) Applied to 4-lane Bridge



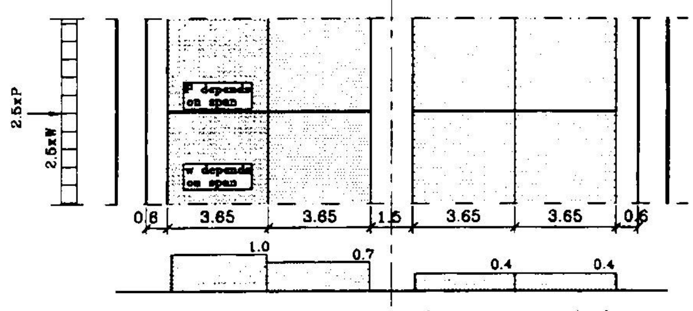
4-LANES BRIDGE

-Lane width = 3.65m
-Side clearance/Shoulder = 0.60m
-Side walk (Maintenance) = 0.75m
-Barrier/Handrail = 0.50m
-Median clearance = 0.25m
-Raised Median = 1.00m



U.S.A.: AASHTO

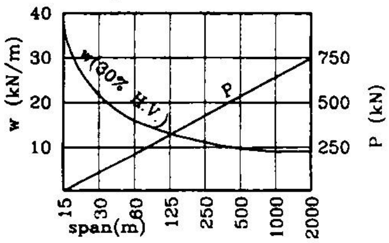
-Length limit 152m
-Impact: I=15.2/(L+38)
-Three load models:
HS20 Truck, HS20 Lane, Military
-HS20 Lane load: See figure
P = 80 kN/lane (for moment)
w = 9.34 kN/m/lane
-Multi lane loading: See figure



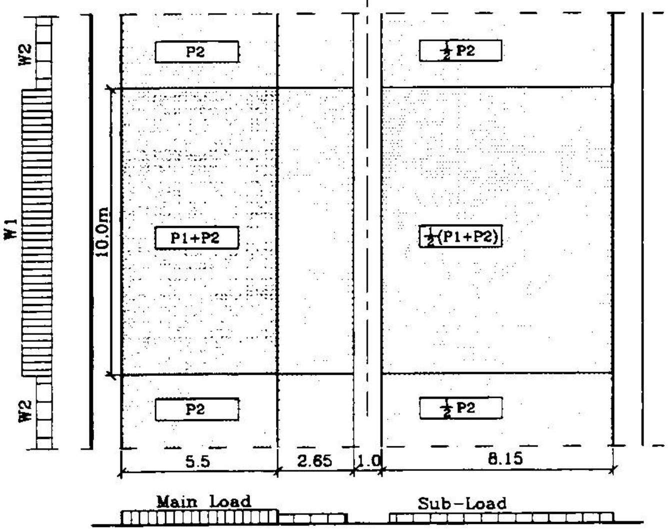
-For span 250m: P = 425 kN/lane, w=12 kN/m/lane

U.S.A.: ASCE(30% H.V.)

-Length limit 2000m !
-Impact not relevant here (Max.loading occures with stationary traffic)
-Three live load levels depending on Traffic volume (7.5%, 30%, 100% H.V.)
-30% Heavy Vehicles shown below:



-Multi lane loading: See figure



JAPAN: JRA

-No length limit
-Impact: I=7/(20+L) for R.C.Bridges
-Two live load levels depending on Traffic volume (ratio of large vehicles)
A_load:(low ratio), B_load:(high ratio)
-B_load:two load models(L_load,T_load)
Main girder(L_load), slab/floor(T_load)
-L_load:
Main load (5.5m wide)
P1=for shear (12 kN/m^2)
for moment (10kN/m^2)
P2=3.5 kN/m^2 (L≤80m)
=4.3-(L/100) kN/m^2 (80<L≤130)
=3.0 kN/m^2 (L>130m)
Sub load (Rest of carriageway width)

Fig.4b: Traffic Actions (Live Loads) Applied to 4-lane Bridge

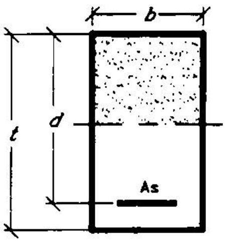
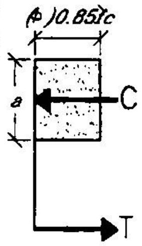
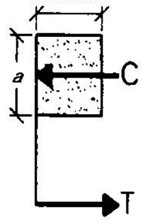
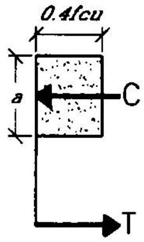
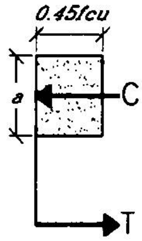
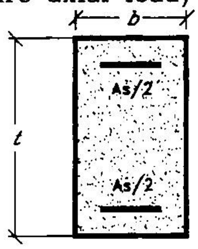
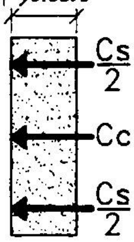
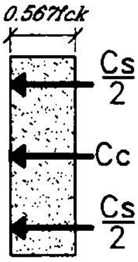
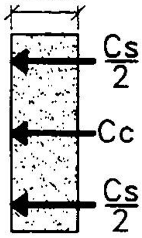
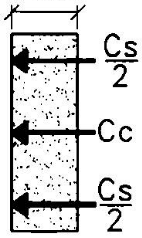
		AASHTO	EC	BS 5400	EGCP
Action Side	1- Load factors at ULS Dead load Super imposed Dead Load Live Load	 1.3 1.3 2.17	 1.35 1.35 1.35*	 1.15 1.75⊕ 1.5	 1.4 1.4 1.6
	2-Factored Action at ULS EUDL in kN/m,4 lanes Br., see fig. 2d •Span 60m •Span 250m	 575.9 479.2	 642.1 508.5	 635.8 515.0	 654.9 528.3
	3- Relative action values w.r.t. EC1: •Span 60m •Span 250m	 90% 94%	 100% 100%	 99% 101%	 102% 104%
Resistance Side in Flexure	4- Material factors for R.C. section in flexure Concrete Steel	ϕ=0.90	1/1.50** 1/1.15**	1/1.50 1/1.15	1/1.50 1/1.15
	5- Equilibrium of under reinforced sections in flexure at failure 	$C=0.85f'c \cdot a \cdot b$ $T=fy \cdot As$ ϕ)0.85f'c 	$C=0.567fck \cdot a \cdot b$ $T=\frac{fyk}{1.15} \cdot As$ 0.567fck 	$C=0.4fcu \cdot a \cdot b$ $T=\frac{fy}{1.15} \cdot As$ 0.4fcu 	$C=0.45fcu \cdot a \cdot b$ $T=\frac{fy}{1.15} \cdot As$ 0.45fcu 
	6- Ult. Moment of Resistance of under singly rft. section (fck=40N/mm², fy=500N/mm², ρ=1.0%)	106%	100%	98.7%	100%
Resistance Side in Axial Load	7- Resistance of Axially loaded sections at Ultimate Limit State (Theoretical case of pure axial load) 	$Cc=0.85f'c \cdot b \cdot t$ $\frac{Cs}{2}=fy \cdot As/2$ *** ϕ)0.85f'c 	$Cc=0.567fck \cdot b \cdot t$ $\frac{Cs}{2}=\frac{fyk}{1.15} \cdot \frac{As}{2}$ 0.567fck 	$Cc=0.4fcu \cdot b \cdot t$ $\frac{Cs}{2}=\frac{fy}{1.15} \cdot \frac{As}{2}$ 0.4fcu 	$Cc=0.45fcu \cdot b \cdot t$ $\frac{Cs}{2}=\frac{fy}{1.15} \cdot \frac{As}{2}$ 0.45fcu 
	8- Ult. capacity of short columns (fck=40N/mm², fy=500N/mm², ρ=1.0%)	80%***	100%	87%	77%
Notes	Assume: fcu(BS 5400)=fcu(EGCPC)=1.25fck(EC2)=1.25f'c(AASHTO) * Traffic action ** For fundemental combination only ⊕ 1.75 for deck surfacing, 1.2 for other SDL ***80% from 0.8[ϕ 0.85f'c] to account for accidental moments in tied columns				

Fig.5 Comparison of Action Effects & Resistances in Bridge Design Codes at ULS