

Supplementary Material

A Simplified Method for Estimating Bridge Frequency Effects Considering Train Mass

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1 Supplementary Figures and Tables

1.1 Supplementary Figures

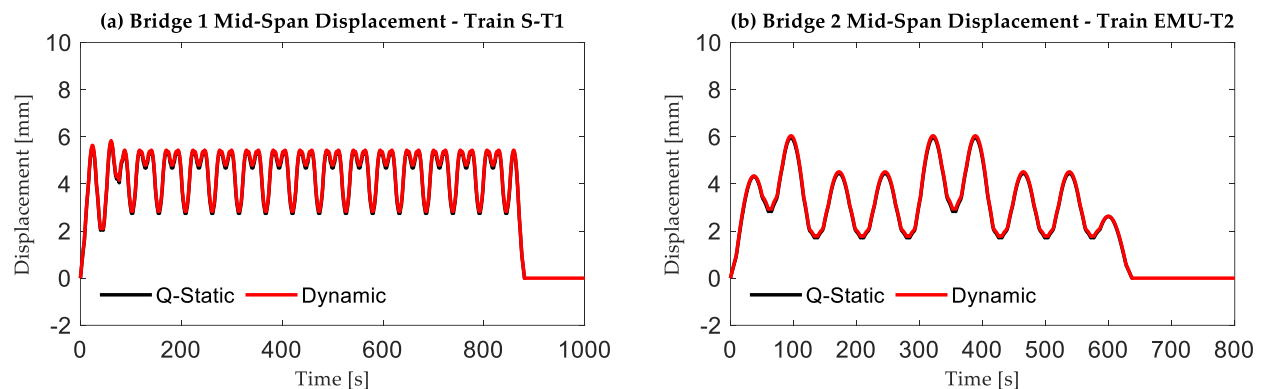


Figure S1. Comparison of displacement time histories between EBB Dynamic & Quasi-static model

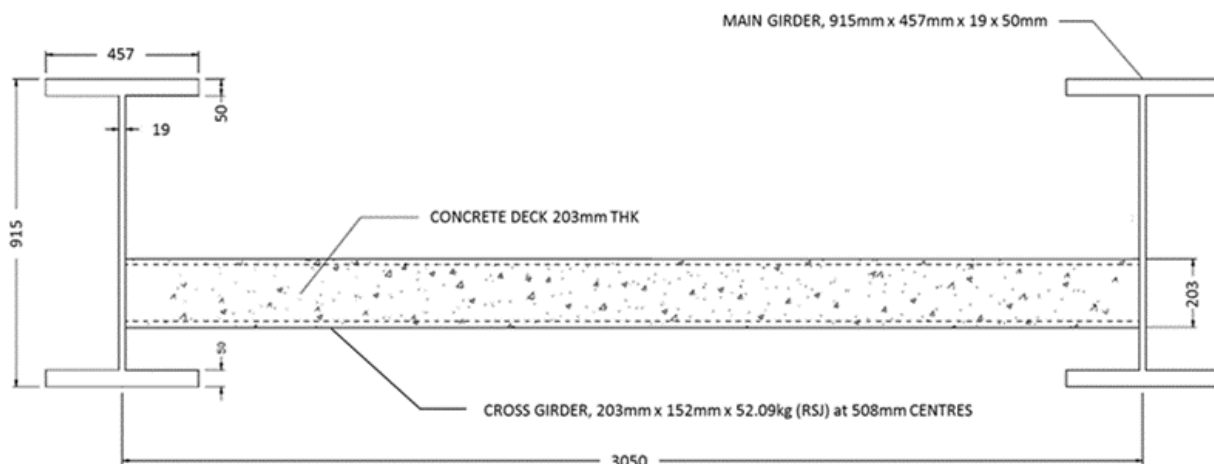


Figure S2. Half-through deck plate girder bridge - Bridge 2 (Gaillard, 2003)

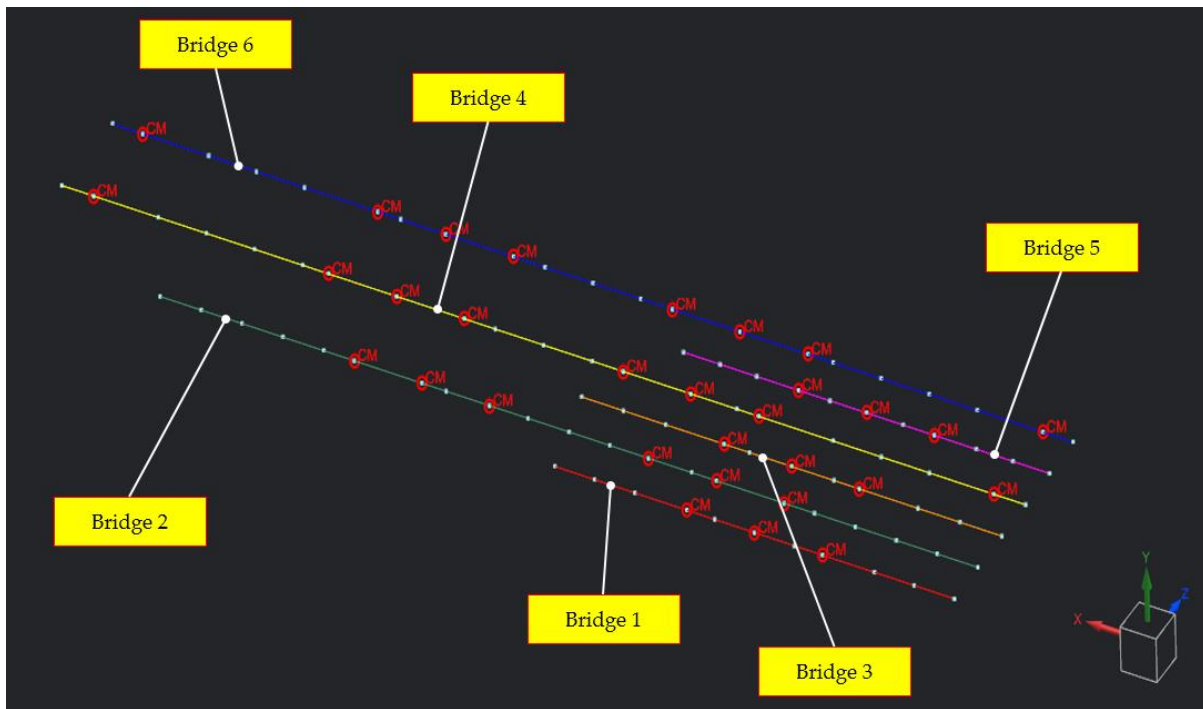
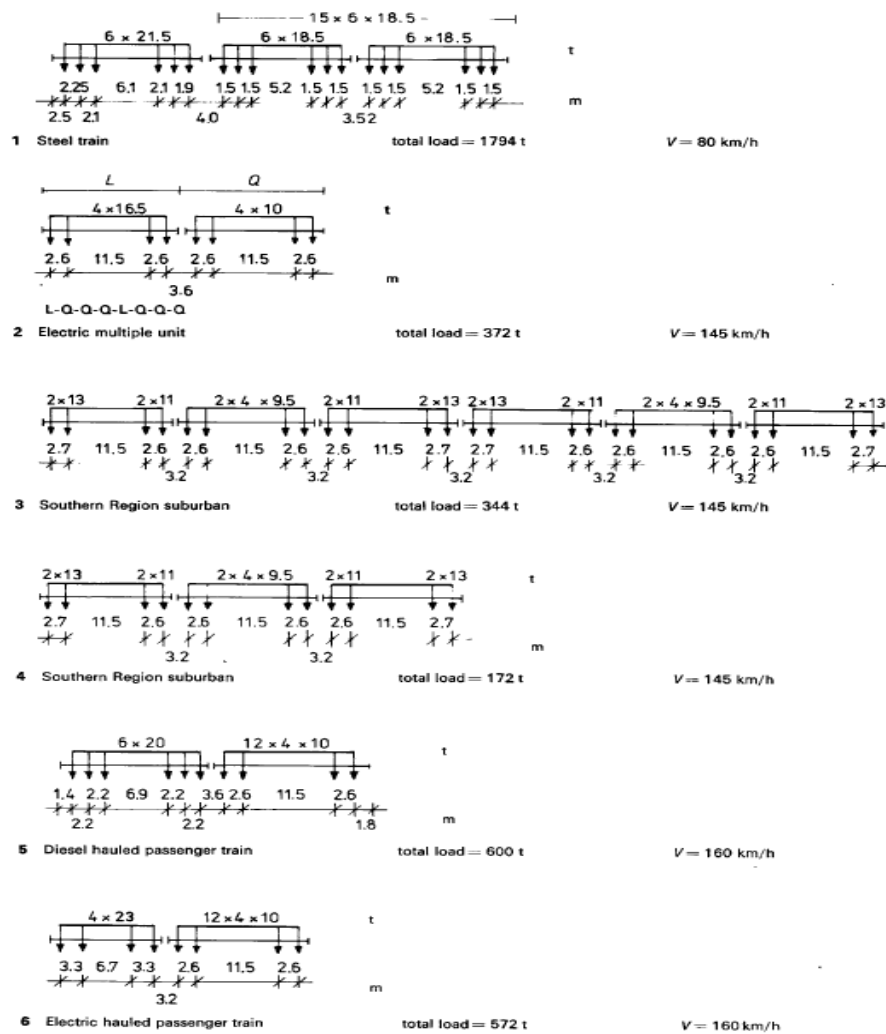
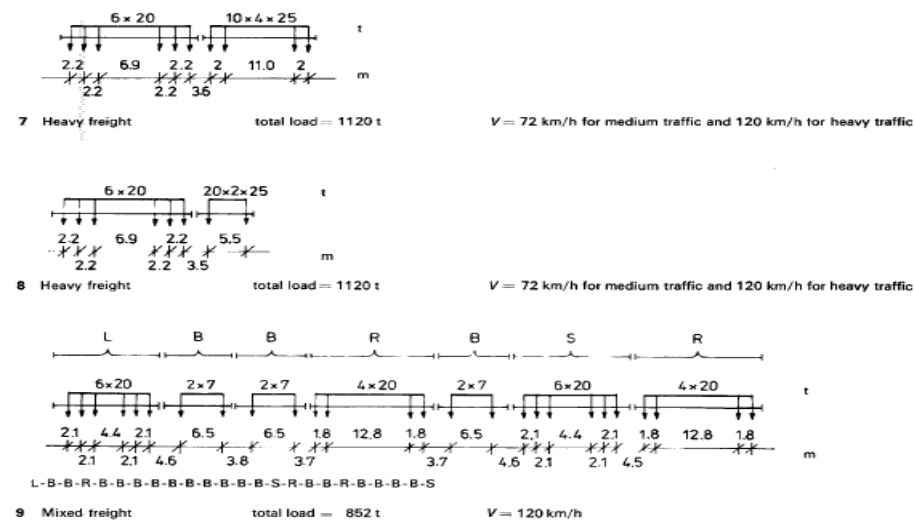


Figure S3. Finite Element Models of Bridges 1-6



(b) BS-5400 trains 1-6 – axle configurations [BS-5400 1980]



(c) BS-5400 trains 7-9 – axle configurations [BS-5400 1980]

Figure S4. Train dimensions & axle configurations

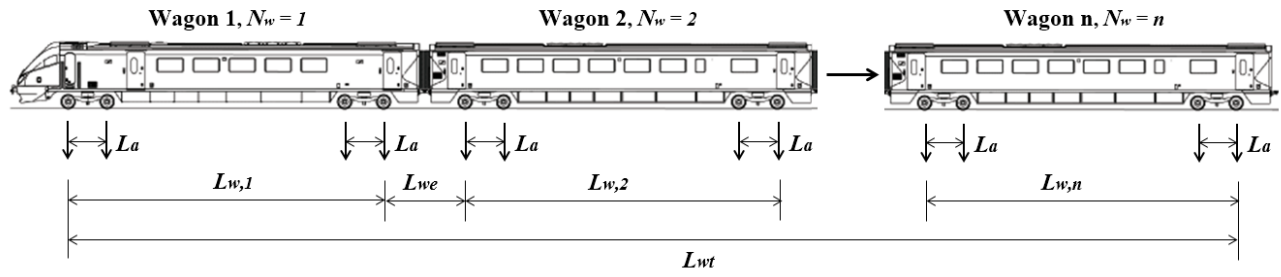


Figure S5. General train dimensions for model

1.2 Supplementary Tables

Table S1. BS-5400 standard train mixes (L: Locomotive; W: Wagon)

Train No.	BS-5400 Train Type		No. Axles & Weights [t]		No Wagons		Locomotive-Wagon (Train) Configuration
			Locomotive	Wagons			
1	Steel	S-T1	6×21.5t	6×18.5t	15	W	L - 15×W
2	Electric Multiple Unit	EMU-T2	4×16.5t	4×10t	3	W1	L - 3×W1 - L - 3×W2
				4×16.5t (Loc)	1	L	
				4×10t	3	W2	
3	Southern Regional Suburban	SRS-T3	2×13t + 2×11t	4×9.5t	2	W1	L - 2×W1 - W2 - W3 - 2×W1 - W2
				2×11t + 2×13t	1	W2	
				2×13t + 2×11t	1	W3	
				4×9.5t	2	W1	
				2×11t + 2×13t	1	W2	
4	Southern Regional Suburban	SRS-T4	2×13t + 2×11t	4×9.5t	2	W1	L - 2×W1 - W2
				2×11t + 2×13t	1	W2	
5	Diesel Hauled Passenger	DHP-T5	6×20t	4×10t	12	W	L - 12×W
6	Electric Hauled Passenger	EHP-T6	4×23t	4×10t	12	W	L - 12×W
7	Heavy Freight	HF-T7	6×20t	4×25t	10	W	L - 10×W
8	Heavy Freight	HF-T8	6×20t	2×25t	20	W	L - 20×W
9	Mixed Freight	MF-T9	6×20t	2×7t	18	W1	L - 2×W1 - W2 - 10×W1 - W3 - W2 - 2×W1 - W2 - 4×W1 - W3
				4×20t	3	W2	
				6×20t	2	W3	
10	Non-BS-5400 (Hypothetical Train) with equally spaced axles	ESA-10	10t	10t	10	W	L-10×W

Table S2. BS-5400 train/wagon dimensions (trains 1-9)

BS5400 Train	Wagon Length, L_w [m]	Wagon Coupling Distance, L_{wc} [m]	No. of Wagons, N_w
S-T1	11.2	3.5	15
EMU-T2	16.7	3.6	7
SRS-T3	16.7	3.2	7
SRS-T4	16.8	3.2	3
DHP-T5	16.7	3.6	12
EHP-T6	16.7	3.2	12
HF-T7	15	3.6	10
HF-T8	5.5	3.5	20
MF-T9	6.5	3.8	Mixed
ESA-T10	1	1	10

Table S3. Train-bridge mass ratio & frequency change for train types (bridges 1-3)

BS5400 Train	Bridge 1		Bridge 2		Bridge 3	
	M_w/M_b	$f_{b,w}$, [Hz]	M_w/M_b	$f_{b,w}$, [Hz]	M_w/M_b	$f_{b,w}$, [Hz]
S-T1	0.96	6.67	0.64	3.72	0.37	11.13
EMU-T2	0.29	8.85	0.18	4.69	0.11	12.94
SRS-T3	0.27	8.92	0.17	4.72	0.10	13.00
SRS-T4	0.26	8.96	0.15	4.76	0.10	13.01
DHP-T5	0.29	8.85	0.17	4.72	0.10	13.04
EHP-T6	0.29	8.86	0.17	4.70	0.10	13.04
HF-T7	0.69	7.62	0.45	4.05	0.27	11.86
HF-T8	0.71	7.23	0.47	4.00	0.28	11.63
MF-T9	0.17	9.29	0.12	4.87	0.07	13.30
ESA-T10	0.65	7.35	0.42	4.09	0.25	11.81
S-T1 (25t)*	1.33	5.98	0.87	3.43	0.52	10.39
S-T1 (30t)*	1.59	5.62	1.04	3.25	0.62	9.95
S-T1 (35t)*	1.86	5.31	1.21	3.09	0.72	9.57
S-T1 (40t)*	2.13	5.05	1.39	2.95	0.82	9.23
S-T1 (45t)*	2.39	4.83	1.56	2.84	0.93	8.92
S-T1 (50t)*	2.66	4.63	1.73	2.73	1.03	8.64

* Train configuration same as for train S-T1 except for axle load increase as shown

Table S4. Train-bridge mass ratio & frequency change for train types (bridges 4-6)

BS5400 Train	Bridge 4		Bridge 5		Bridge 6	
	M_w/M_b	$f_{b,w}$, [Hz]	M_w/M_b	$f_{b,w}$, [Hz]	M_w/M_b	$f_{b,w}$, [Hz]
S-T1	0.25	5.74	0.67	8.48	0.48	4.13
EMU-T2	0.07	6.46	0.20	10.64	0.13	5.00
SRS-T3	0.06	6.48	0.19	10.08	0.12	5.03
SRS-T4	0.06	6.50	0.18	10.74	0.11	5.07
DHP-T5	0.07	6.47	0.18	10.76	0.13	5.02
EHP-T6	0.07	6.46	0.18	10.77	0.13	5.01
HF-T7	0.18	6.00	0.49	9.42	0.34	4.43
HF-T8	0.18	5.97	0.51	9.02	0.36	4.39
MF-T9	0.05	6.56	0.12	11.08	0.09	5.15
ESA-T10	0.17	6.04	0.46	9.20	0.32	4.47
S-T1 (25t)*	0.34	5.47	0.93	7.74	0.48	4.13
S-T1 (30t)*	0.41	5.29	1.11	7.33	0.78	3.67
S-T1 (35t)*	0.47	5.13	1.30	6.97	0.91	3.51
S-T1 (40t)*	0.54	4.97	1.49	6.67	1.04	3.37
S-T1 (45t)*	0.61	4.84	1.67	6.40	1.17	3.24
S-T1 (50t)*	0.68	4.71	1.86	6.16	1.30	3.13

* Train configuration same as for train S-T1 except for axle load increase as shown

Table S5. BS5400 train speeds (BS5400, 1980)

BS5400 Train	Speed [km/h]
S-T1	80
EMU-T2	145
SRS-T3	145
SRS-T4	145
DHP-T5	160
EHP-T6	160
HF-T7	120
HF-T8	120