NCHRP 24-31

LRFD DESIGN SPECIFICATIONS FOR SHALLOW FOUNDATIONS

Final Report
September 2009

APPENDIX B
FINDINGS – STATE OF PRACTICE, SERVICEABILITY, AND DATABASES

Prepared for
National Cooperative Highway Research Program
Transportation Research Board
National Research Council

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FINDINGS – STATE OF PRACTICE, SERVICEABILITY CRITERIA AND DATABASES[1]

B.1 SUMMARY OF RESPONSE

The three surveys were sent to 164 contacts in 50 states and other agencies. Seventy-five (75) engineers responded to the questionnaires. Overall response was obtained from 32 states (64%), additional responses were provided by Alberta and Ontario in Canada, and the New Jersey Turnpike Authority. In total 30 responses were obtained for the superstructure questionnaire, 31 for the serviceability questionnaire and 32 for the geotechnical questionnaire. Details outlining the response per state and person are provided in section A-2 of Appendix A.

B.2 SUPERSTRUCTURE OF BRIDGES – MAJOR FINDINGS

B.2.1 Construction

1. During the year 2003, 1,486 new/replacement bridges were built in the US and 17 in Canada, averaging 57 bridges per responding state. At the same period 1,059 bridges were rehabilitated (including substructure only) in the US and 35 in Canada, averaging 42 bridges per responding state.
2. Over a five year period (1999-2003), a total of 8,281 new/replacement bridges were built in the US and 119 in Canada, averaging 319 bridges per responding state. At the same period 5,421 bridges were rehabilitated (including substructure only) in the US and 250 in Canada averaging 217 bridges per responding state.
3. Table C.1 presents the summary of all 30 completed superstructure surveys. Based on five year bridge construction (1999-2003), the following bridge types are being used:
   - Integral Abutment – 46.6% (simple span 10.7% and multispan 35.9%)
   - Multispan – 36.0% (simple supported 8.5% and continuous 27.5%)
   - Single Span Simple Supported – 14.4%
   - All other types 2.5% (e.g. Arch box culverts, Truss arch, etc.).
4. Following are the major structure types in bridge construction prioritized by frequency of use out of all constructed bridges over a five year period (1999-2003):
   - Integral abutment prestressed concrete girder multispan (13.5%) with bridge lengths ranging between 50 to 1,200ft (15 to 366m), typically between 145 to 360ft (44 to 110m), with average spans of 75ft (23m).
   - Integral abutment multiple steel beam/girders (13.1%) with bridge lengths ranging between 80 to 1,532ft (24 to 467m), typically between 165 to 435ft (50 to 133m), with average spans of 105ft (32m).
   - Multispan continuous steel beam/girders (11.9%) with bridge lengths ranging between 65 to 5,007ft (20 to 1,526m), typically between 330 to 1,570ft (101 to 479m), with average spans of 140ft (43m).

[1] Paikowsky, S., Honjo, Y., Faraji, S., Yoshida, I., and Lu, Y. (2004). Interim Progress Report to NCHRP for project NCHRP 12-66 "AASHTO LRFD Specifications for the Serviceability in the Design of Bridge Foundations.", January, GTR, Inc., MA.

- Multispan continuous prestressed concrete girders (10.6%) with bridge lengths ranging between 40 to 2,000ft (12 to 610m), typically between 240 to 940ft (73 to 287m), with average spans of 90ft (27m).
- Single span simple supported prestressed concrete girders (7.5%) with bridge lengths ranging between 27 to 230ft (8 to 70m), typically between 55 to 115ft (17 to 35m).
- Integral abutment multispan concrete slab (6.1%) with bridge lengths ranging between 20 to 699ft (6 to 213m), typically between 70 to 225ft (21 to 69m), with average spans of 35ft (11m).
- Integral abutment simple span prestressed concrete girders (6.0%) with lengths ranging between 61 to 109ft (19 to 33m), typically between 30 to 150ft (9 to 46m).

5. The abutments of the integral bridges are typically supported by piles and the piers are column bent or pile bent supported. Elastomeric bearings are commonly used either fixed, allowing rotation only, or expansion, allowing rotation and horizontal translation.
6. The abutments of the multispan continuous bridges are typically supported by a pile bent for steel bridges and cantilever for concrete bridges. The piers are supported by column bent, followed by a multi column hammerhead bent. Elastometric bearings are commonly used mostly accommodating expansion allowing rotation and horizontal translation.
7. Comparative bridge cost was provided by California as a general guideline for structure type selection. Based on the provided information, 80% of the bridges on California state highways are comprised of concrete section varying from Reinforced Concrete (RC) slab for common span ranges of 16 to 44ft (5 to 13m) at a cost of \$75 - \$115/ft^2 (\$807 - \$1,238/m^2) to Concrete In Place (CIP) post stress box for common span ranges of 100 to 250ft (30 to 76m) at a cost of \$75 - \$110/ft^2 (\$807 - \$1,184/m^2).

Table B.1 Summary of Bridge Construction (1999-2003) – Major Findings

Bridge Type	Superstructure Type		Frequency of use in New Design		Range of Bridge Length (ft)	Span Range (ft) Typical	Min	Max	Typical Abutment Configuration[A]	Typical Bearing Type[B]	Function[C]	Typical Pier Configuration[D]
1	2	3	4	5	6	7	8	9	10	11	12	13
Multispan Simple Supported	Steel Girders	Multiple Beam/Girders	8.5%	17.2	288 – 1205 100 / 6022	114	78	164	A3=1 A6=2 A4=1 A8=2	B1=5 B8=1	C1=2 C2=6	D1M=1 D2=5 D4=1
		Box Girders		0								
	Concrete	Prestressed Girders		55.5	98 – 1719 60 / 10,280	76	41	125	A3=1 A5=1 A4=1 A6=2 A8=4	B1=7 B9=1	C1=2 C2=7	D1S=1 D1M=2 D2=3 D3=4
		CIP Box Girders		0.4	102 – 218 102 / 218	53	34	73	A6=1	B1=1	C2=1	D2=1
		Concrete Slab		26.9	92 – 156 34 / 300	35	28	44	A5=1 A10=1 A8=4	B1=4 B9=1	C1=1 C2=3	D1 S/M=2 D3=3 D4=1
Multispan Continuous	Steel Girders	Multiple Beam/Girders	27.5%	43.3	329 – 1570 65 / 5007	142	80	272	A3=4 A6=4 A11=2 A4=1 A8=6 A12=1 A5=2 A10=2	B1=13 B3,B8=3 B5=2	C1=7 C2=15	D1M=6 D3=1 D1S=4 D4=3 D2=10 D5=1 D6=1
		Box Girders		1.9	368 – 2857 100 / 8628	158	93	274	A3=2 A6=2 A5=1 A8=1	B1=2 B6=1 B8=1	C2=4	D1S=2 D1M=1 D2=3
	Concrete	Prestressed Girders		38.7	240 – 937 40 / 2000	89	55	149	A1=1 A5=3 A10=2 A3=6 A6=3 A11=1 A4=1 A8=4	B1=16	C1=4 C2=14	All D1M=5 D1S=2 D2=7 D3=5 D4=2 D5=2 D6=1
		CIP Box Girders		7.4	1702 – 1927 100 / 4015	175	139	251	A3=2 A6=2 A5=1 A10=1	B1=4	C1=1 C2=5	All D1S/M=1 D2=2 D5=2 D6=1
		Concrete Slab		9.5	83 – 399 20 / 1506	34	22	50	A3=1 A6=1 A10=2 A5=3 A8=2 A11=2	B1=6 B9=2	C1=3 C2=6	ALL D1=1 D2=5 D3=1 D4=2 D5=1
Single Span* Simple Supported	Steel Girders	Multiple Beam/Girders	14.4%	27.5	61 – 177 18 / 400	116	82	176	A3=4 A5=2 A8=2 A4=3 A6=4 A10=1	B1=10 B3,B5, B9=1 B8=2	C1=5 C2=12	N/A
		Box Girders		0.6	100 60 / 140	145	135	200	A3=1 A6=2 A5=1	B1=2	C2=2	N/A
	Concrete	Prestressed Girders		51.9	53 – 114 27 / 230	90	53	127	A3=6 A5=3 A8=3 A4=2 A6=4 A10=2	B1=14 B3=1	C1=6 C2=12	N/A
		CIP Box Girders		12.7	89 – 139 34 / 200	107	75	164	A3=2 A6=2 A5=1 A8=1	B1=3	C2=3	N/A
		Concrete Slab		9.9	30 – 51 14 / 80	37	25	51	A3=2 A8=2 A11=2 A5=4 A10=1	B1=6 B9=1	C1=2 C2=6	N/A

Column 4: refer to % of the specific bridge type in relation to all new bridges designed
Column 5: refer to % of the specific structural configuration out of the relevant bridge type.
*Discrepancy between columns 6 and 7, 8, 9 is due to inconsistent and/or limited responses

Column 6: top is avg. min-avg. max; bottom is absolute min/absolute max
CIP = Cast In Place

Table B.1 (continued)

Bridge Type	Superstructure Type		Frequency of use in New Design		Range of Bridge Length	Span Range			Typical Abutment Configuration[A]	Typical Bearing		Typical Pier Configuration[D]
						Typical	Min	Max		Type[B]	Function[C]	
1	2	3	4	5	6	7	8	9	10	11	12	13
Integral Abutment Simple Span	Steel Girders	Multiple Beam/Girders	10.7%	27.0	57 – 148 33 / 225	110	74	152	A4=1 A10=1 A8=3 A11=6	B1=4 B3,B9=1	C1=3 C2=2	D1=1 D2=2
		Box Girders		0.5	60 – 60 60 / 60	75	65	100	A11=1	B1=1	C2=1	D2=1
	Concrete	Prestressed Girders		56.2	61 – 109 30 / 150	73	51	115	A3=2 A8=3 A11=9 A5=1 A10=3	B1=9 B9=1	C1=7 C2=3	D1=1 D1M=1 D2=1 D3=1
		CIP Box Girders		6.8	218 – 218 218 / 218	94	33	65	A11=1	B1=1	C2=1	D2=1
		Concrete Slab		5.4	39 – 41 20 / 54	30	25	36	A8=1 A11=5	B1=1 B9=1	C1=C2=1	D4=D5=1
Integral Abutment Multispan	Steel Girders	Multiple Beam/Girders	35.9%	36.5	163 – 436 80 / 1532	106	71	184	A8=4 A10=2 A11=8	B1=9 B5,B9=1 B3=2	C1=8 C2=7	D1=2 D1S=2 D1M=1 D2=7 D3=5 D4=2 D5=1 D6=2
		Box Girders		0.3	0	135	105	195	A8=1	B1=1	C1=1	D2=2 D3=1
	Concrete	Prestressed Girders		37.5	143 – 362 50 / 1200	73	43	116	A3=1 A10=2 A8=3 A11=8	B1=11 B5=1	C1=9 C2=5	D1=1 D1S=2 D1M=2 D2=6 D3=5 D4=2 D5=1 D6=2
		CIP Box Girders		4.9	0	103	63	125		B1=1	C2=1	D2=2
		Concrete Slab		16.9	69 – 226 20 / 699	34	22	50	A3=A8=1 A11=7	B1=4 B9=2	C1=5 C2=3	D2=3 D3=2 D4=2 D5=1 D6=2
Specify Others if Relevant to New Design	Concrete / Steel	CIP Girders Truss, Arch, box culverts, 3-sided culverts	2.5%		198 – 355 27 / 500	208	198	283	A2=A4=A8=1	B6=2 B9=1	C1=1 C2=2	D4=D3=1

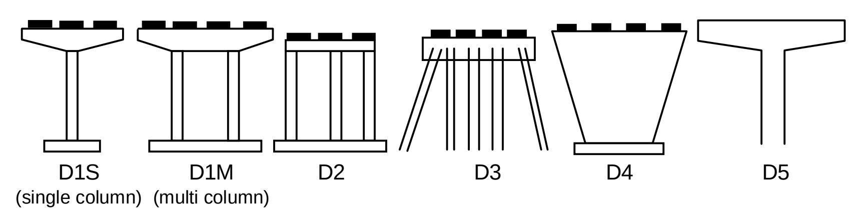
Notes:

A. Abutment Type	
A1	Gravity
A2	U
A3	Cantilever
A4	Full Height
A5	Stub
A6	Semi Stub
A7	Counter Fort
A8	Pile Bent
A9	Reinforced Earth System
A10	Spill-through
A11	Pile Supported Integral
A12	Others, please specify

B. Bearing Type	
B1	Elastomeric Bearings
B2	Seismic Isolaters
B3	Rocker Bearings
B4	Roller Bearings
B8	Siding Plate Bearing
B6	Pot Bearing
B7	Spherical Bearing
B8	Lead Rubber
B9	Others, please specify

C. Bearing Function	
C1	Fixed Allows Rotation only
C2	Expansion Allows Rotation and Horizontal Translation
C3	Expansion allows Rotation and Vertical + Horizontal Translation

D. Pier Type	
D1	Hammerhead S/M
D2	Column Bent
D3	Pile Bent
D4	Solid Wall
D5	Integral Pier
D6	Others, please specify



B.2.2 Design

1. Forces and moments in the superstructure under service loads are usually evaluated via single girder with a tributary slab width, (80% and 90% of the cases for skewed and non-skewed bridges, respectively). A 2-D and 3-D model are used for 3 to 7% of the cases depending on the structure and the loading. In 7% of the cases, a 3-D model of superstructure/substructure with non-linear soil-structure interaction is being used.
2. The entire superstructure modeling under service load is used by 33% and under seismic loads by 37%, mostly utilizing STAAD (27%), GTSTRUDL (23%), and SAP 2000 (17%). The substructure is modeled using the same tools.
3. Deep foundations response is evaluated via the p-y method using LPile (57%), COM 624P (43%) (COM 624P is the FHWA public domain software version of LPile) and 10% use FB Pier. One state uses the strain wedge model.
4. Pile head is assumed to be hinged by 27%, fixed by 37%, and partially restrained by 20%.
5. 80% do not consider the impact of the foundations' settlement in the superstructure design. Out of those, 67% believe it should not be done (54% of total).
6. The responders that consider the effect of settlement (20%) and differential settlement (30%) on the superstructure design, do so mostly in special cases of either large differential settlements (e.g. NY, CA), concerns expressed in geotechnical reports (MA), etc. It is being considered via force and moment redistribution (AZ), design for moments and shear due to settlement and differential settlement (WA, NM) and evaluating the limiting settlements (NH).
7. Vertical and horizontal movements of abutments and piers are considered by 20% and 13% of the responders, respectively. Some consider it for integral abutments (MA, Ontario) and some via design of bearings and expansion joints to accommodate the movement.
8. Only one state (WA) specified its consideration of differential settlement in the transverse direction via imposed settlement in the bridge model examining forces/movements in all members.
9. 77% of the responders evaluate the pile's structural acceptability under lateral loads, most of them use p-y analysis as described in number 3 above.

B.3 SUBSTRUCTURE OF BRIDGES – MAJOR FINDINGS

B.3.1 Construction

1. Foundation alternatives include 62% driven piles, 21% In Place Constructed Deep Foundations (IPCDF) and 17% shallow foundations.
2. Shallow foundations are founded on rock (55%), frictional soil (23%), IGM (19%), and cohesive soils (3%). About half of the shallow foundations built on clay are constructed with ground improvement measures, i.e. only about 0.25% of the total bridge foundations are built on clay with some states indicating they construct shallow foundations on rock only (AK, TN), don't use shallow foundations at all (LA, TX) but utilize the analyses for retaining walls, etc. (TX).

3. Lateral loads in piers and abutments, respectively are resolved by batter driven piles (42%, 50%), vertical driven piles (30%), drilled shafts (25%, 17%), and pile cap resistance (1%). Rock anchored pipe piles are used in Maine and shallow foundations in limited cases in MA and CA.
4. Most batter piles range in batter between 1H:5V to 1H:9V
5. Lateral loading and movements due to embankments are considered by 69% of the responders utilizing lateral earth pressure analysis and p-y lateral pile analysis (LPile).
6. Tension loads in piers and abutments are resolved by vertical driven piles (69%), drilled shafts in piers (35%) and in abutments (25%) with the remainder resolved by anchors.