Preliminary Bridge Design (AASHTO LRFD 2017)

Date: 23 February 2022
Session 37 – Bridges 01

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S-8A SEng PRP Training Program

BASIC CONCRETE BRIDGE TYPES

In several thousand years since we started building bridges, we have built only

FOUR TYPES OF BRIDGES

Girder bridges

Arch bridges

Suspension bridges

Cable-stayed bridges

BASIC BRIDGE TYPES

Cable-stayed Bridge

Girder Bridge

Suspension Bridge

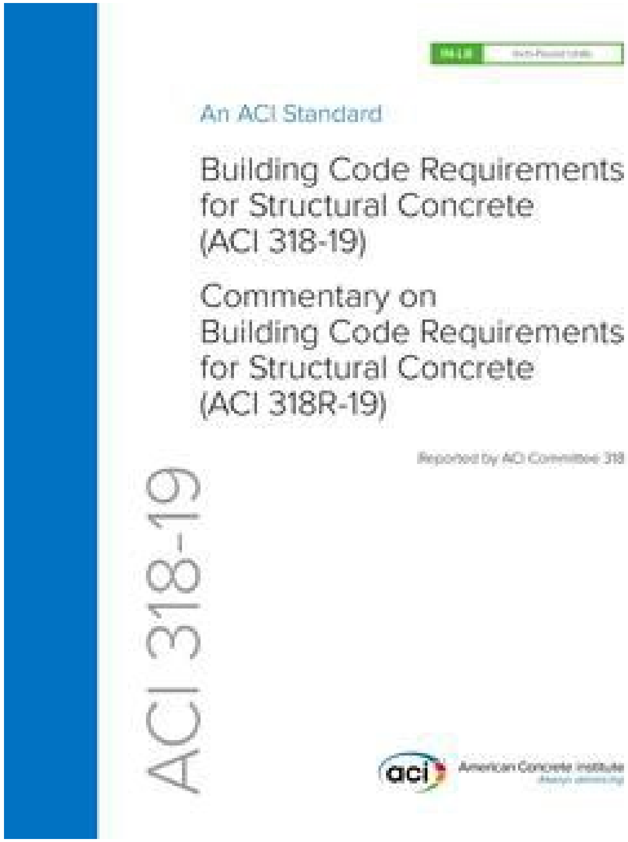
Arch Bridge

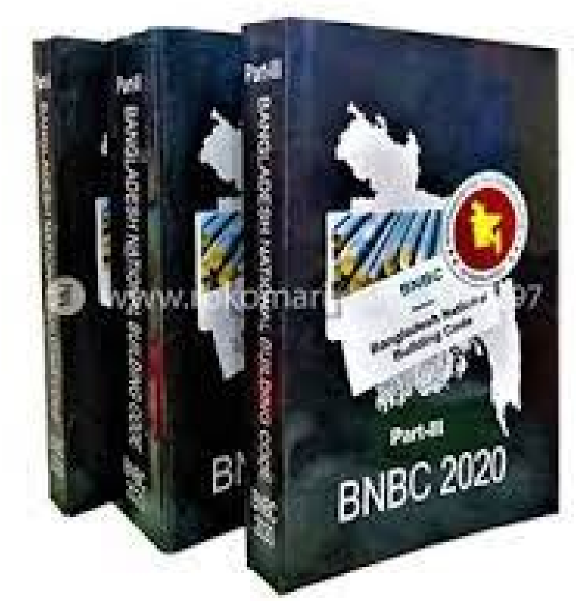
BASIC BRIDGE TYPES

Today's bridges

more sophisticated, bigger, stronger, and more durable

WHAT ENGINEERS MAY BE USED TO WORKING WITH

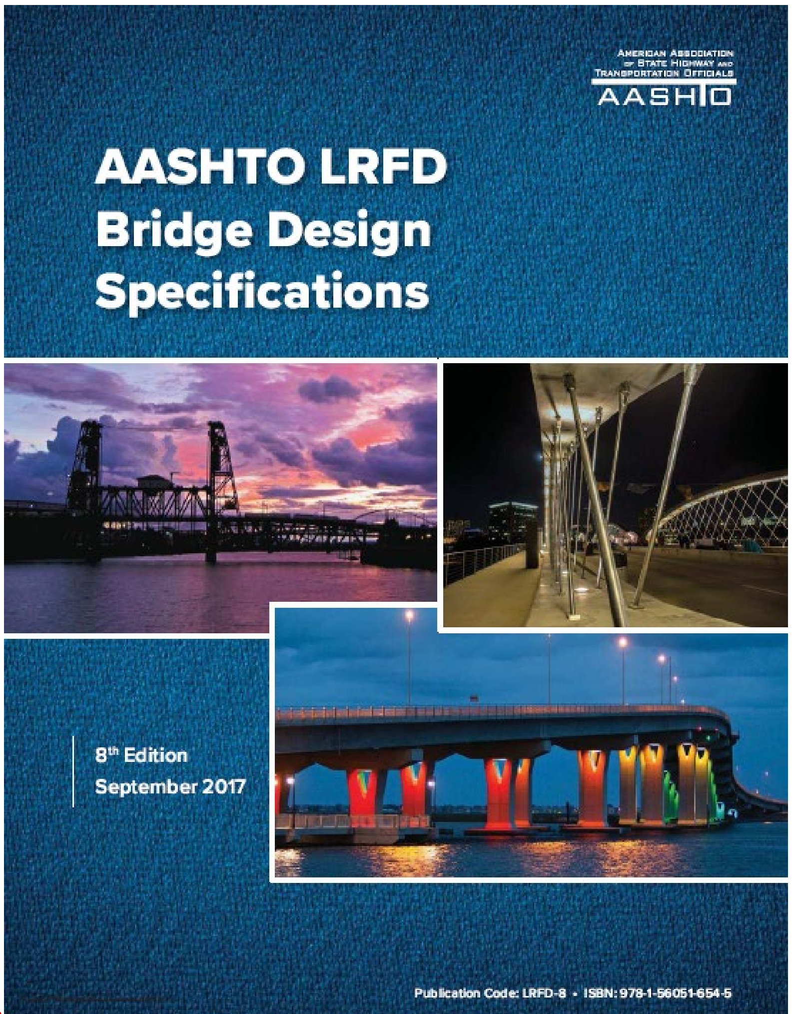


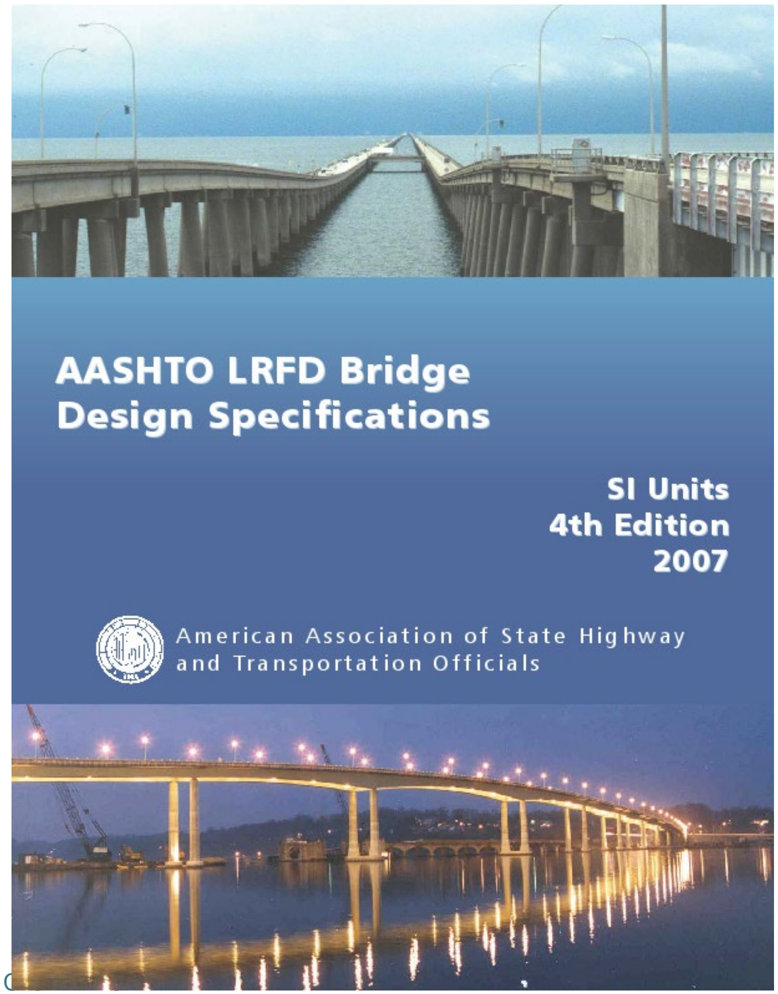


BRIDGE DESIGN CODES

- BNBC is only applicable to building design.
- ACI 318 Code is also applicable to building design.
- There is currently no dedicated bridge design, construction or evaluation code in Bangladesh.
- However, it is customary in Bangladesh to use the following codes:
  - AASHTO LRFD Specifications for Bridge Design (2017, U.S. units)
  - AASHRO LRFD Specifications for Bridge Design (2007, SI units)

AASHTO LRFD BRIDGE DESIGN Specifications

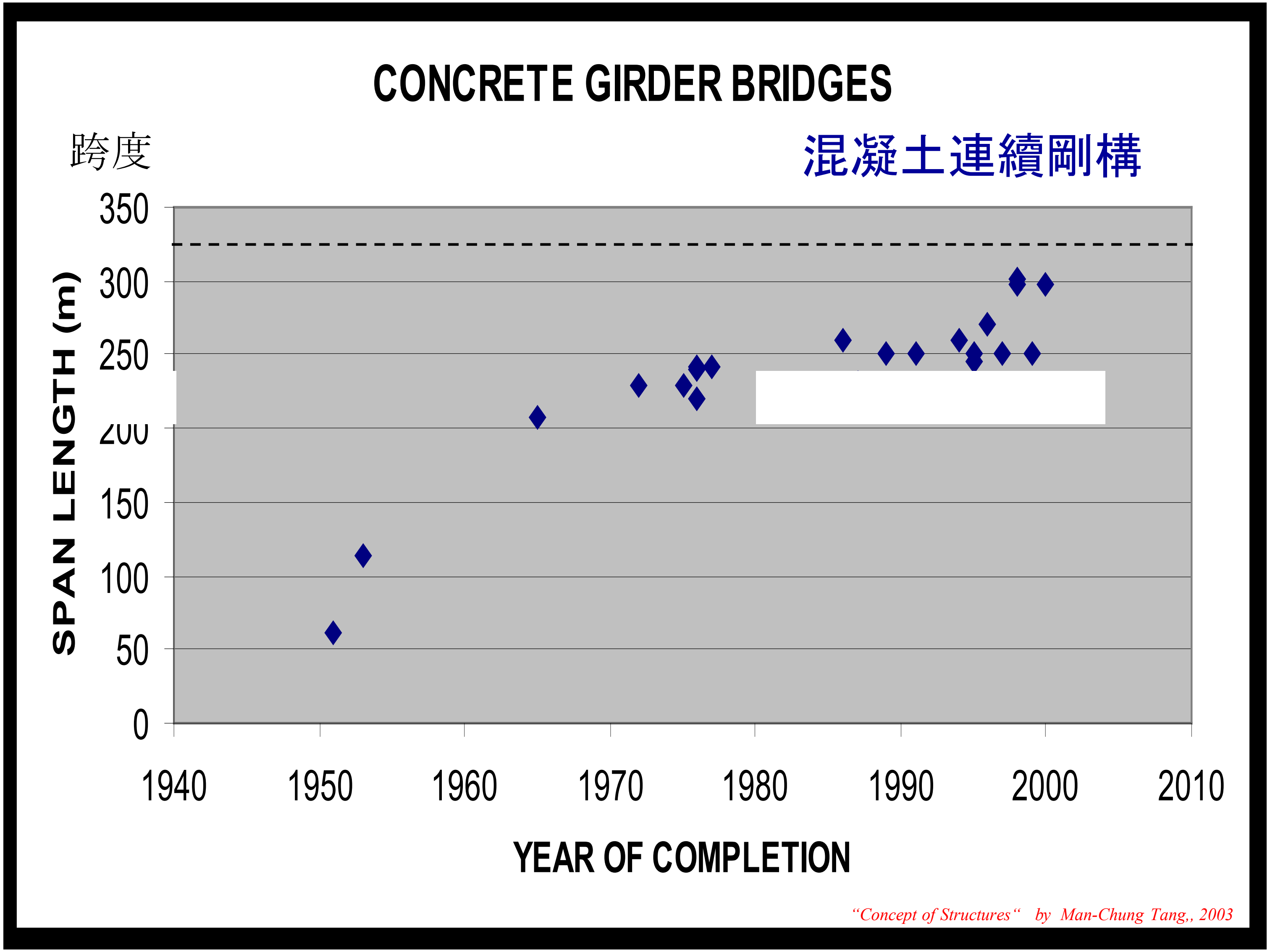




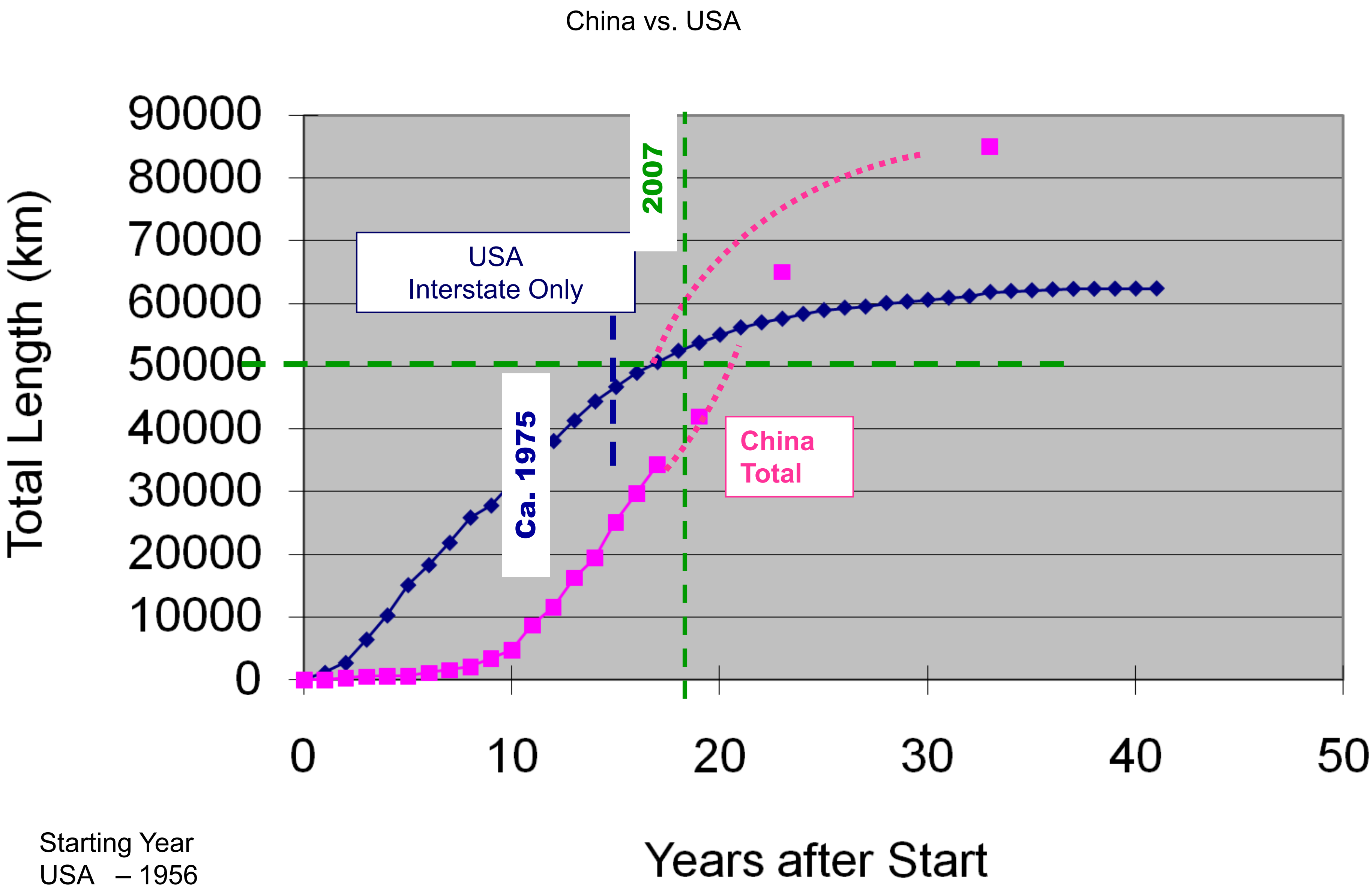
Preliminary Bridge Design

- Preliminary design is the first step in designing an economical bridge.
- AASHTO does not provide any such guidelines.

So, we shall look at other sources.

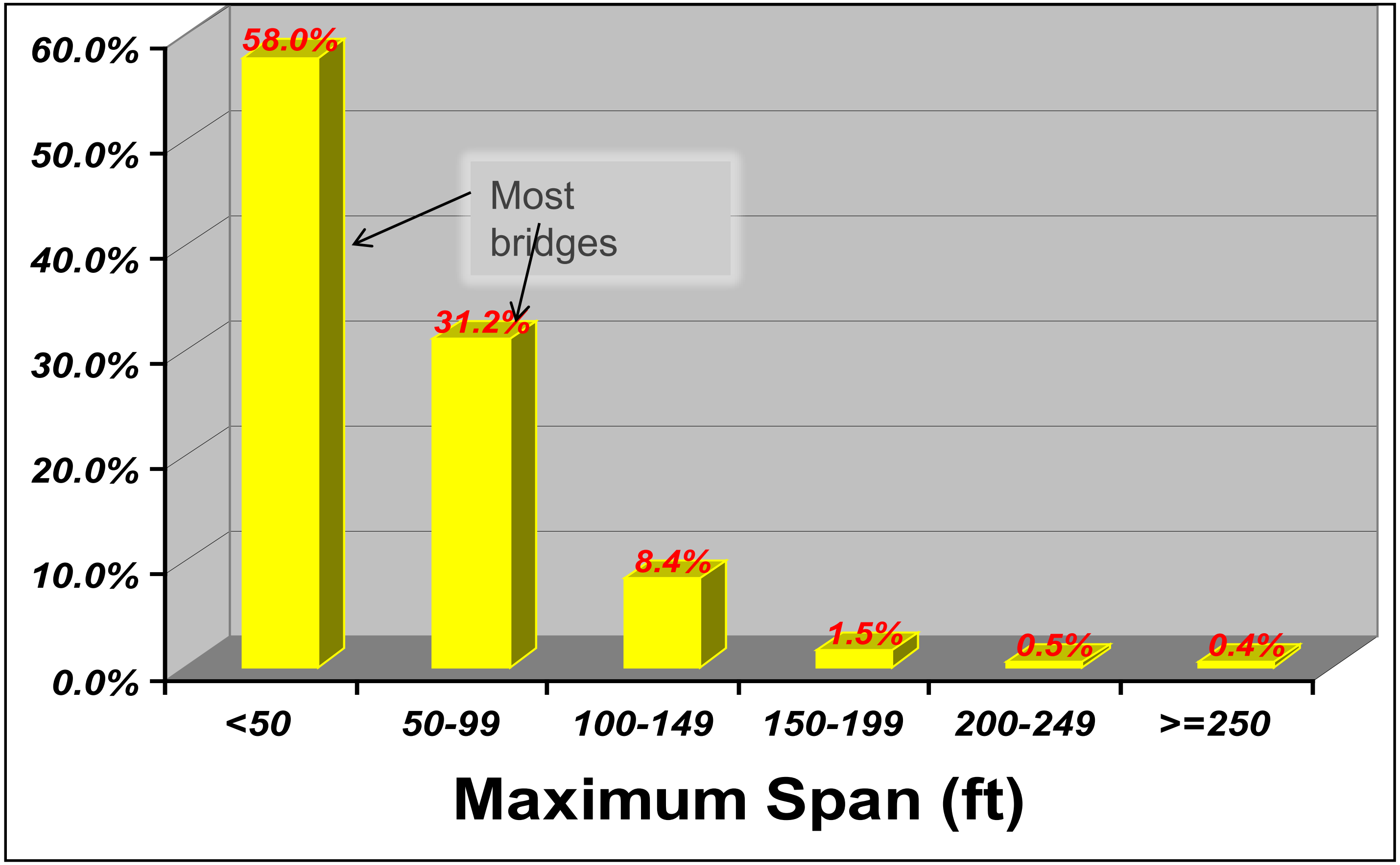

CONCRETE GIRDER BRIDGES
跨度
混凝土連續剛構
SPAN LENGTH (m)
350
300
250
200
150
100
50
0
1940
1950
1960
1970
1980
1990
2000
2010
YEAR OF COMPLETION
"Concept of Structures" by Man-Chung Tang,, 2003

FREEWAY CONSTRUCTION



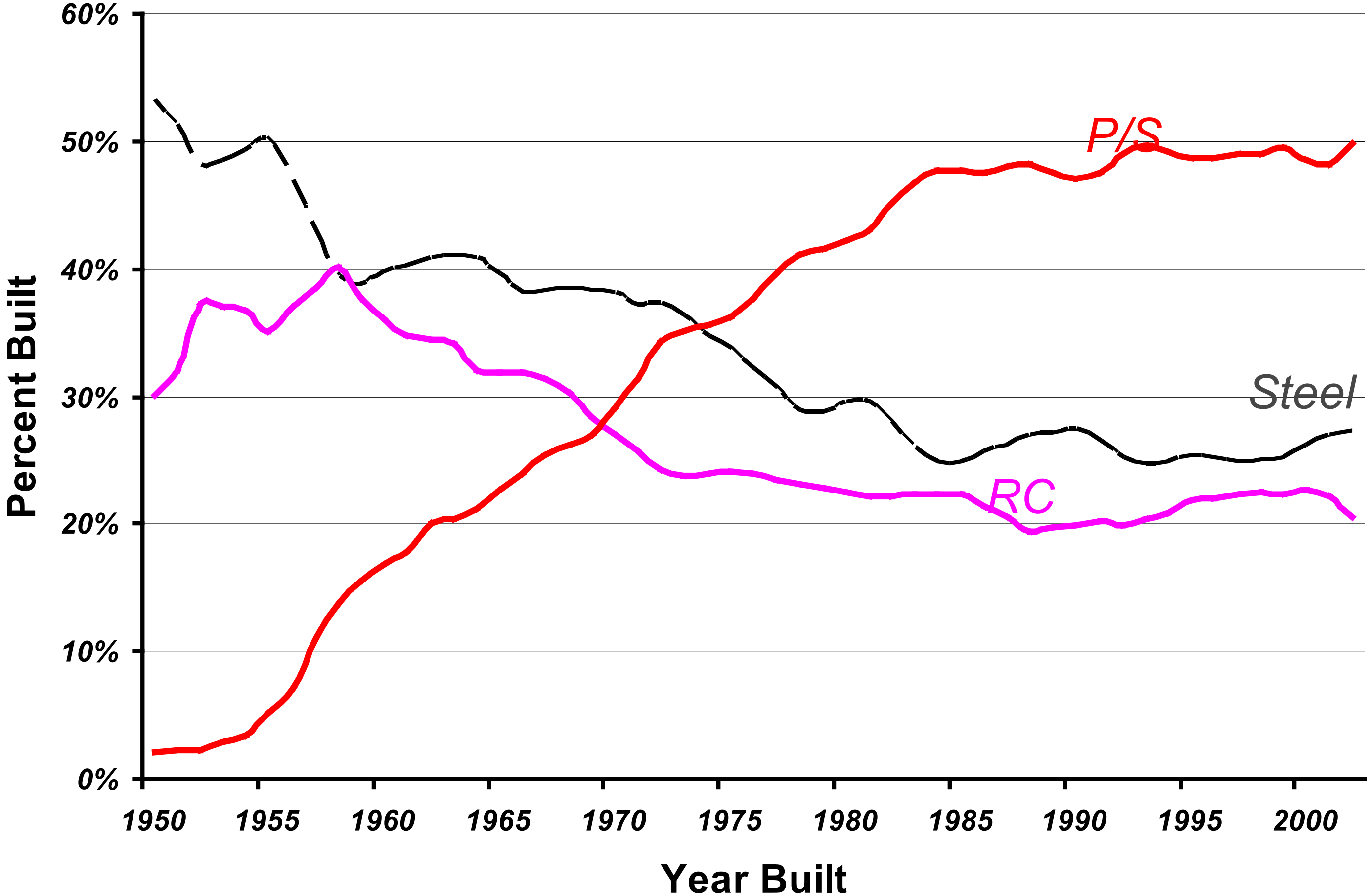
Starting Year
USA – 1956
China – 1987

All Existing U.S. Bridges
NBI Data, 2018



Total Built = 475,000 Bridges

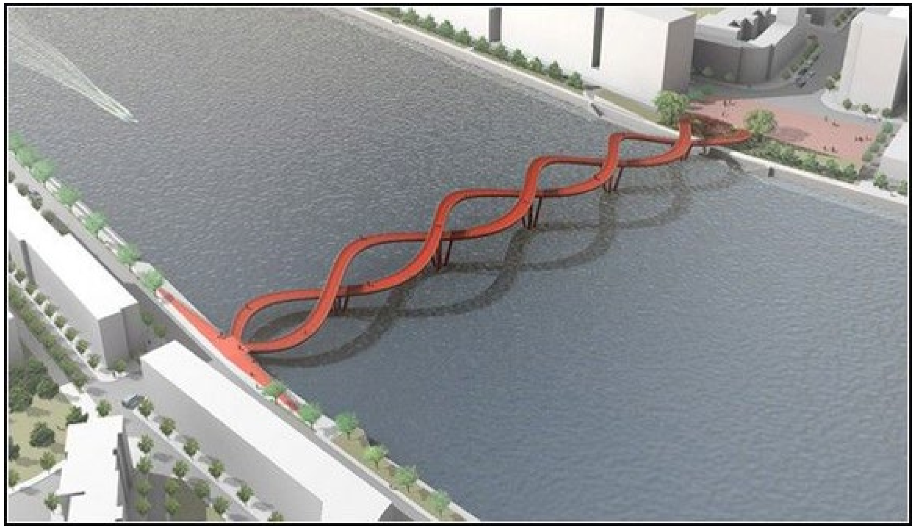
Bridges Built, 2018 NBI Data



Next Innovations in Bridges?

- Composite bridges
- Entirely modular bridges
- 3D printing – precast mold building
- BIM in general
- Laser and drones for bridge monitoring
- Jointless bridges

Unusual Bridges



Unusual Bridges

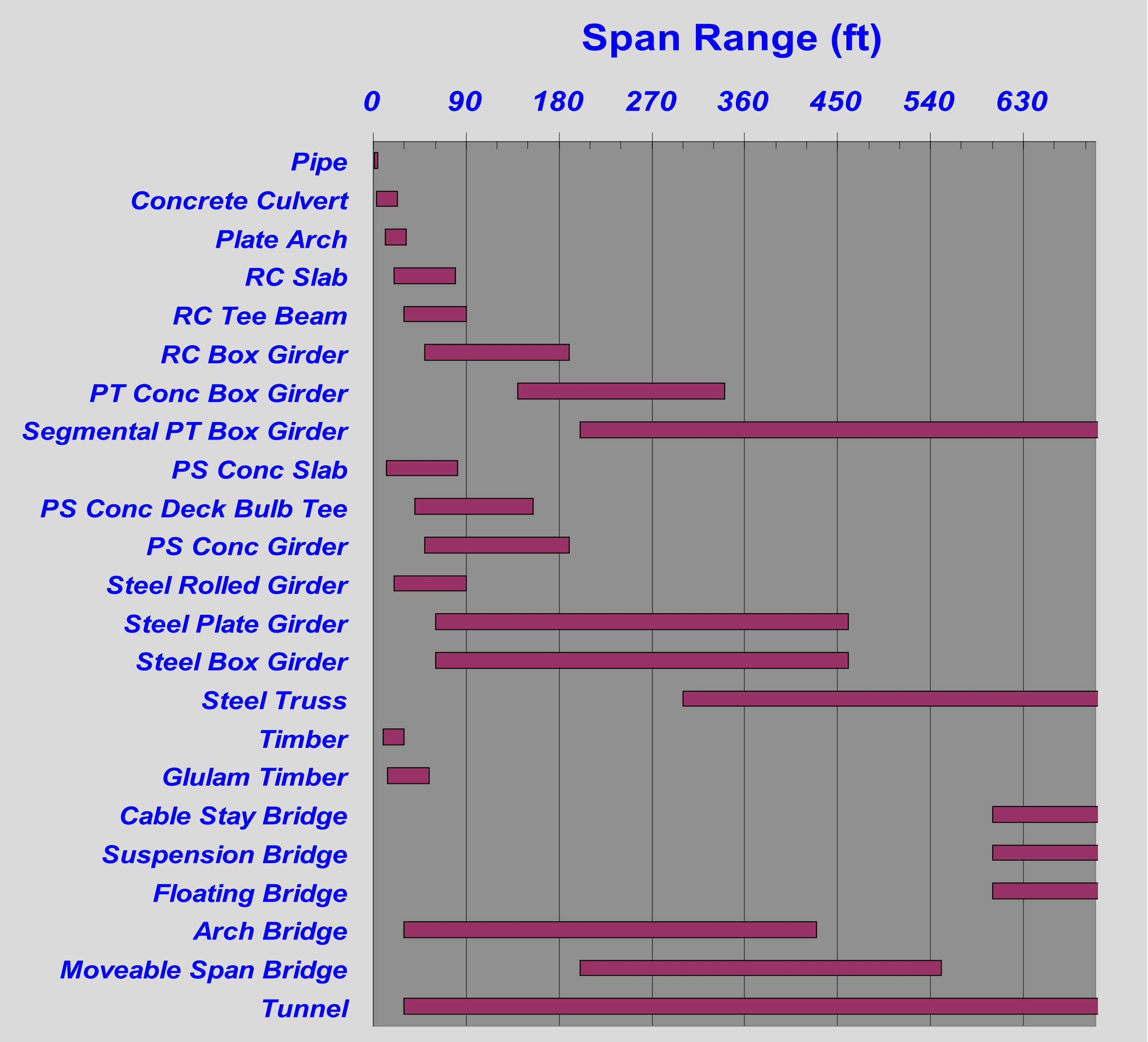
Common Concrete Bridge Types

- Slab
- I-Girder
- Box Girder
- Segmental
- U-Girder
- Spliced Girder
- Arch
- Cable-Stayed

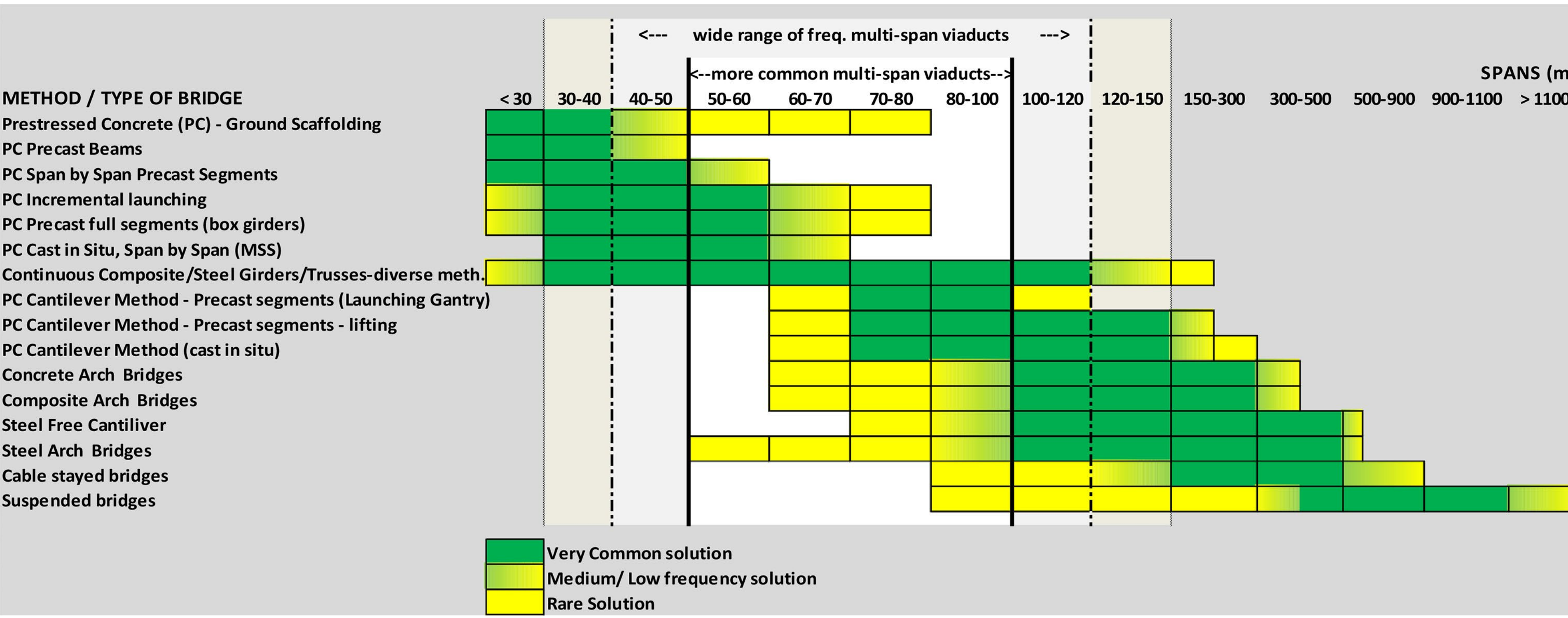
Preliminary Design (most common shapes)

- CIP Short Span Bridges
  - Slab
  - T-Beam
- Precast, Prestressed
  - Standard AASHTO/PCI/ Girders
    - I-Girders
    - Box Girders

Preliminary Selection Guide (WSDOT)



Preliminary Selection Guide (Portugal)



Slab Bridges

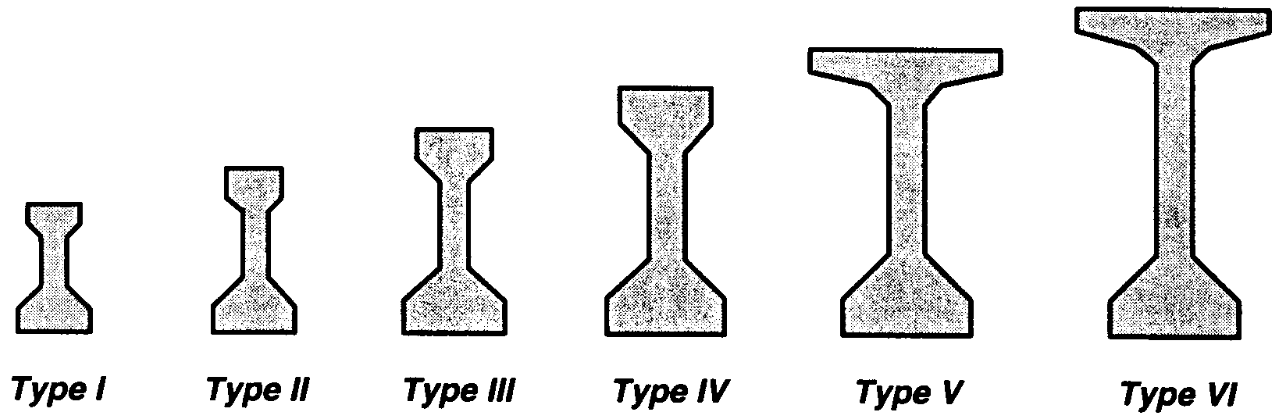
- Simple, easy to construct
- Well-suited for spans up to about 15 m.
- Cast-in-place or precast. Reinforced or prestressed.
- Can be made continuous with abutments and piers to mobilize frame action.

I-Girder Bridges

- Most popular bridge type in the USA, also used in Bangladesh.
- For spans up to about 55 m.
- Common sizes: AASHTO/PCI Type I-VI (710 mm to 1.8 m), Bulb-Tee (1.4 m, 1.6 m, and 1.8 m).

Walnut Lane Bridge, Philadelphia, PA

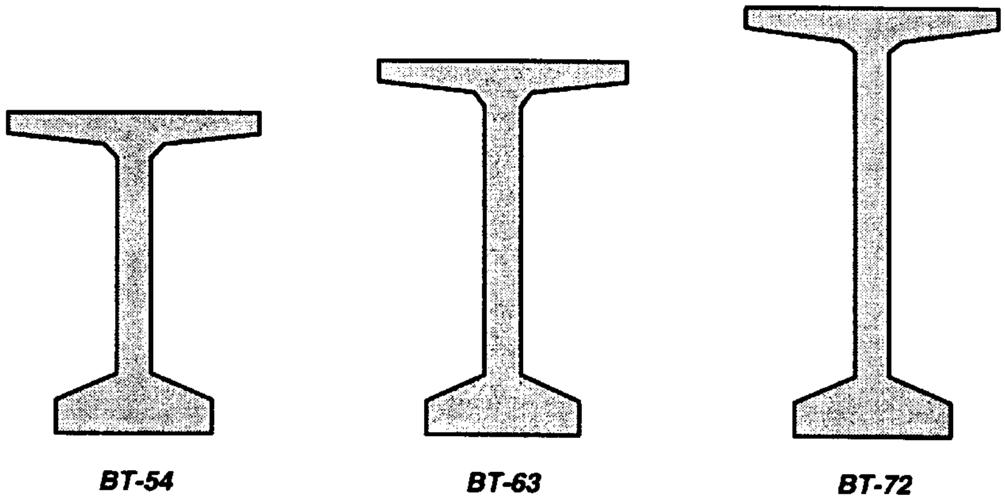
Properties, Dimensions and Maximum Spans for AASHTO-PCI I-Girders



Beam Properties and Basic Dimensions

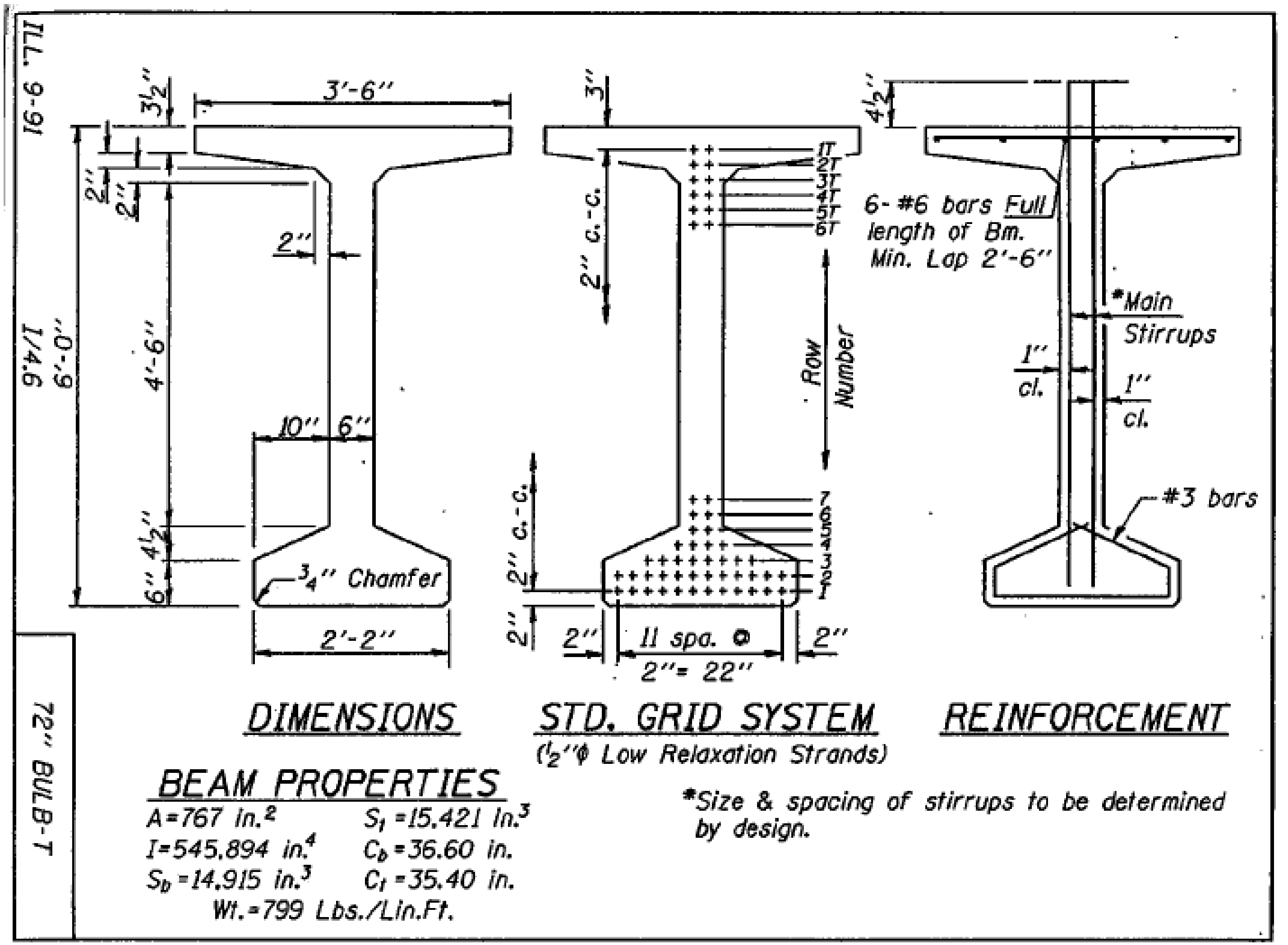
Type	Area	Centroid to Btm	Moment of Inertia	Height	Width: Top Flange	Width: Web	Width: Bottom Flange
	(in.^{2})	(in.)	(in.^{4})	(in.)	(in.)	(in.)	(in.)
I	276	12.59	22,750	28	12	6	16
II	369	15.83	50,980	36	12	6	18
III	560	20.27	125,390	45	16	7	22
IV	789	24.73	260,730	54	20	8	26
V	1,013	31.96	521,180	63	42	8	28
VI	1,085	36.38	733,320	72	42	8	28

Properties, Dimensions and Maximum Spans for PCI Bulb Tee Girders



Beam Properties and Basic Dimensions							
					Width		
Type	Area	Centroid to Btm	Moment of Inertia	Height	Top Flange	Web	Bottom Flange
	(in. ^{2})	(in.)	(in. ^{4})	(in.)	(in.)	(in.)	(in.)
BT-54	659	27.63	268,077	54	42	6	26
BT-63	713	32.12	392,638	63	42	6	26
BT-72	767	36.60	545,894	72	42	6	26

Properties, Dimensions and Maximum Spans for PCI Bulb Tee Girders

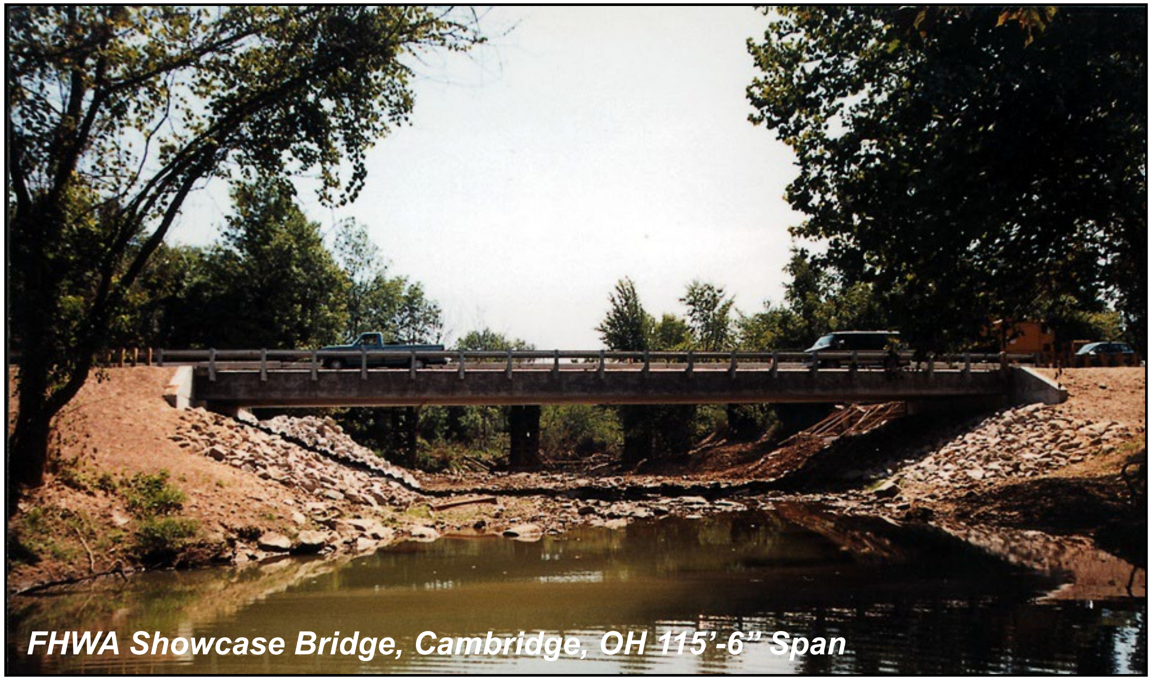


Bow River Bridge, Calgary, Alberta

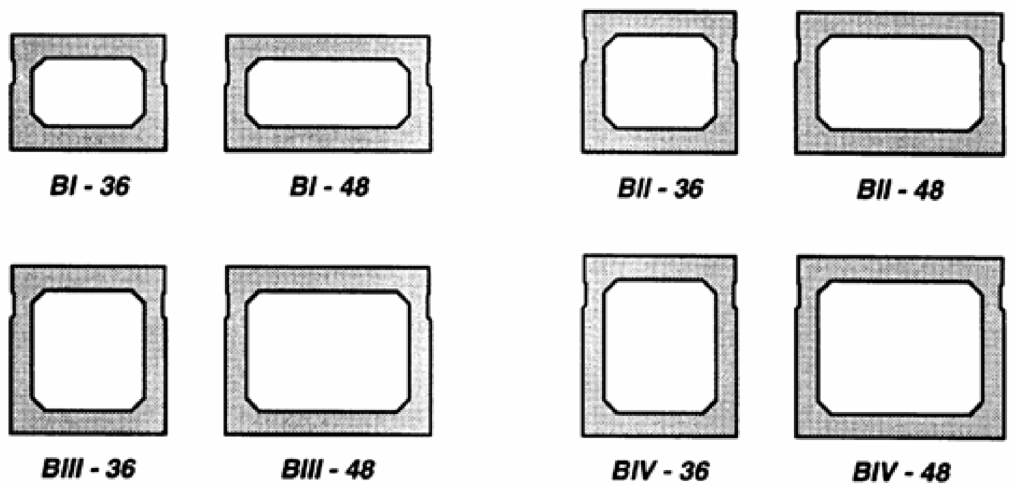
Bow River Bridge, Calgary, Alberta (transportation could be a challenge for very long girders)

Box Girder Bridges

- Second-most popular after the I-girder bridges
- Common sizes: AASHTO/PCI Type BI-BIV
- Span Range: 18 m – 32 m.
- Use of side-by-side boxes without a wearing course offers speedy construction


FHWA Showcase Bridge, Cambridge, OH 115'-6" Span

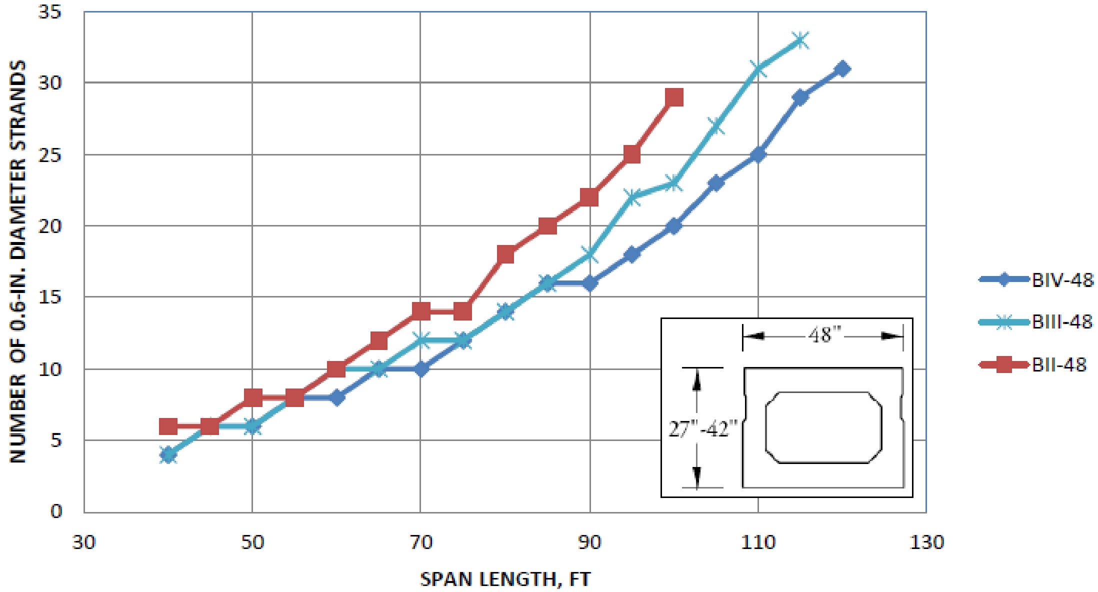
Properties, Dimensions and Maximum Spans for AASHTO - PCI Box Girders

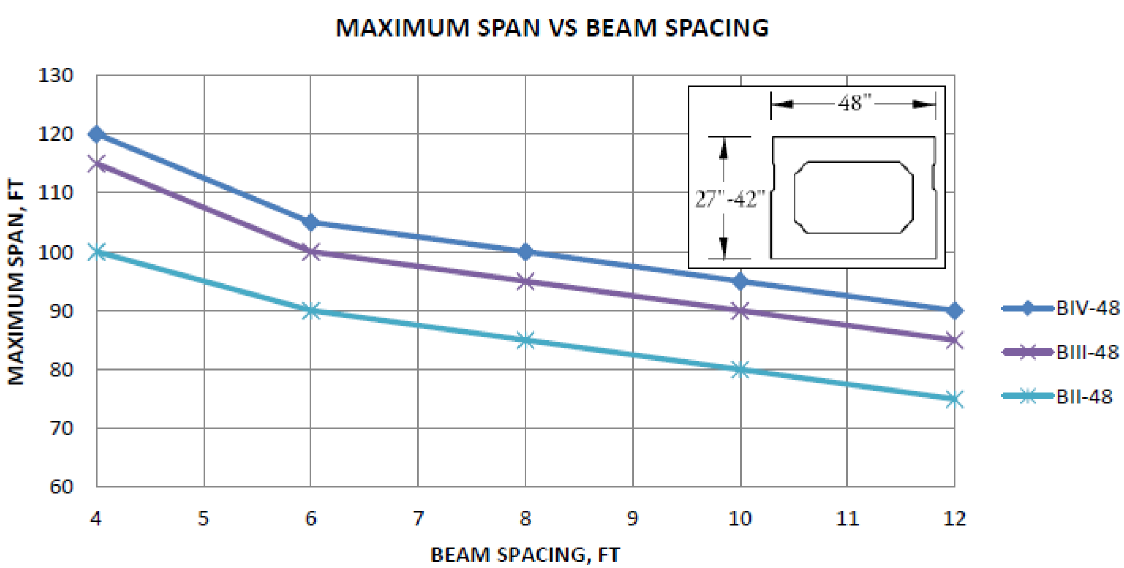


Beam Properties and Basic Dimensions

Type	Area	Centroid to Btm	Moment of Inertia	Height	Width: Top Flange	Width: Webs	Top & Bottom Flange
	$(in.^2)$	(in.)	$(in.^4)$	(in.)	(in.)	(in.)	(in.)
BI-36	560.5	13.35	50,334	27	36	5	5.5
BI-48	692.5	13.37	65,941	27	48	5	5.5
BII-36	620.5	16.29	85,153	33	36	5	5.5
BII-48	752.5	16.33	110,499	33	48	5	5.5
BIII-36	680.5	19.25	131,145	39	36	5	5.5
BIII-48	812.5	19.29	168,367	39	48	5	5.5
BIV-36	710.5	20.73	158,644	42	36	5	5.5
BIV-48	842.5	20.78	203,088	42	48	5	5.5

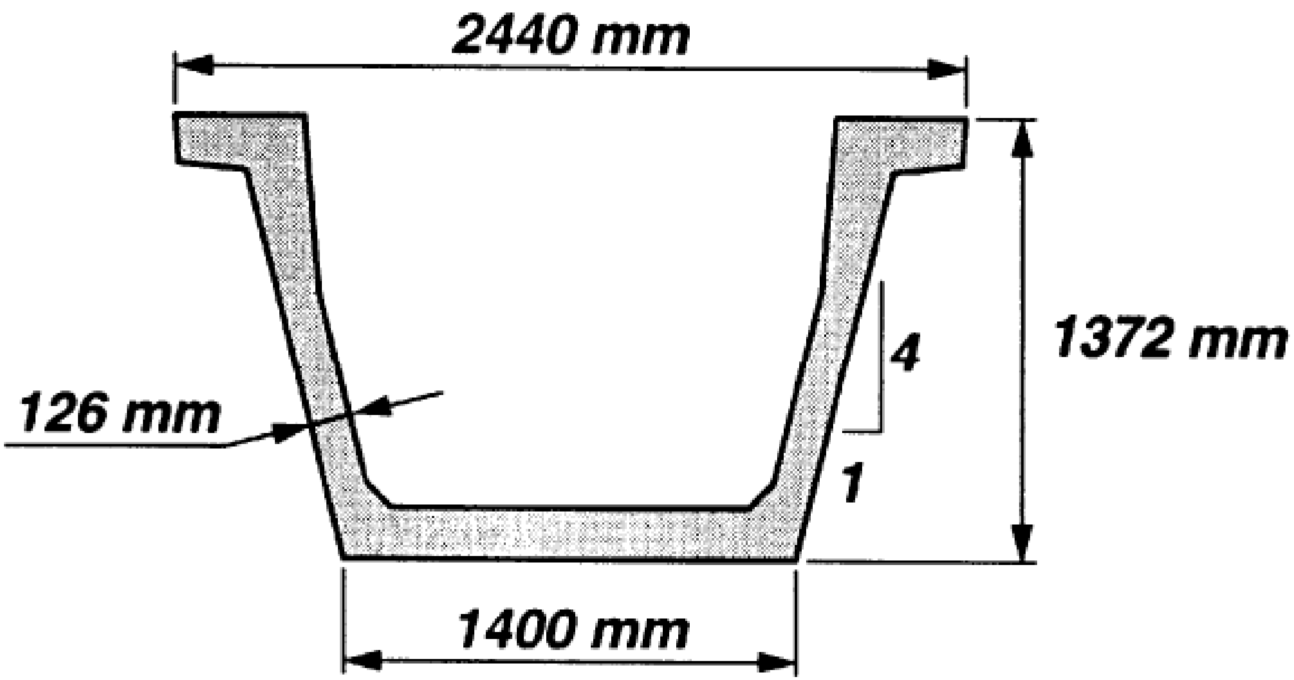
Chart BB-2
AASHTO Adjacent Box Beams 48 in. Wide





U-Girder Bridges

U-Girder Bridges



- Closed cellular section.
- Good strength-weight ratio.
- Combination of box-girder and double-tee beam.

U-Girder Bridges

Chart U-1
U-Beams

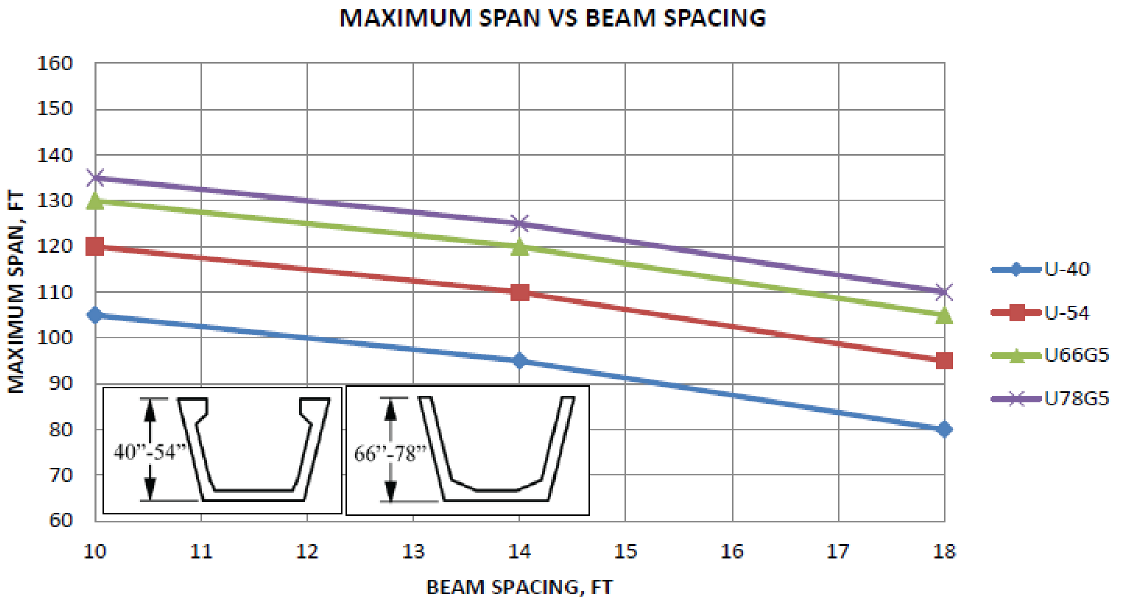
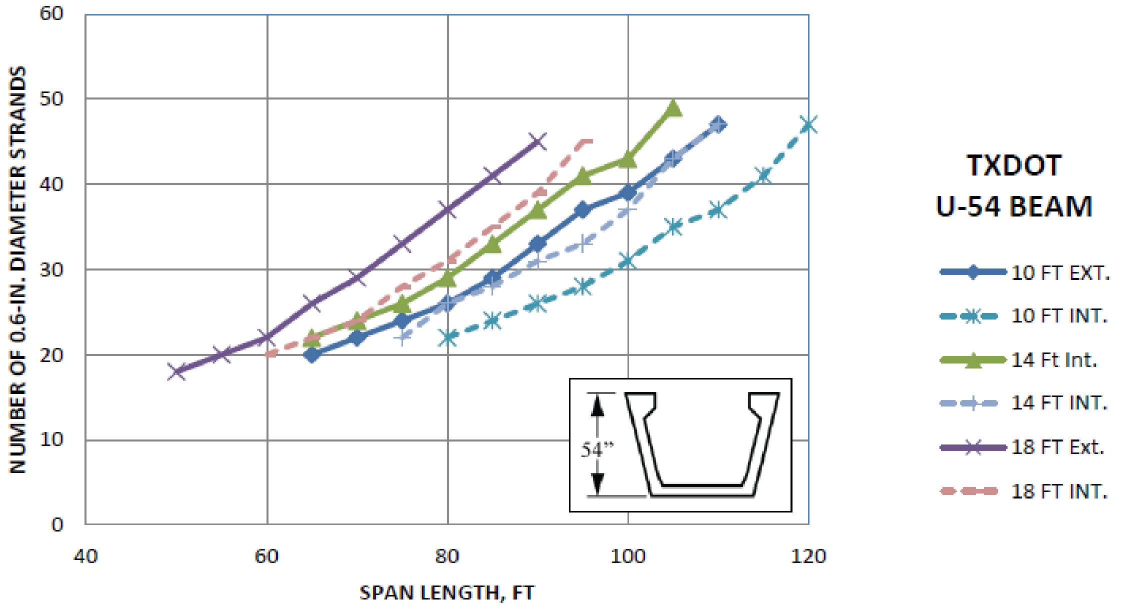


Chart U-3
Texas U-54 Beams



02/23/2022

Louetta Road Bridge Deck Panels

Louetta Road Bridge

Chart IB-1
AASHTO I-Beams

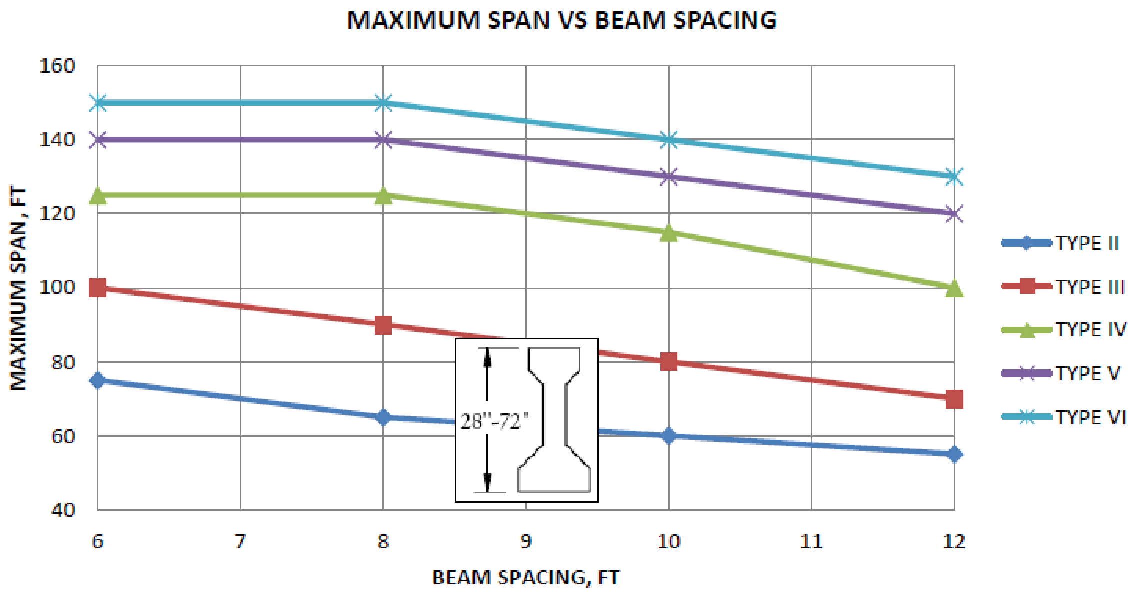
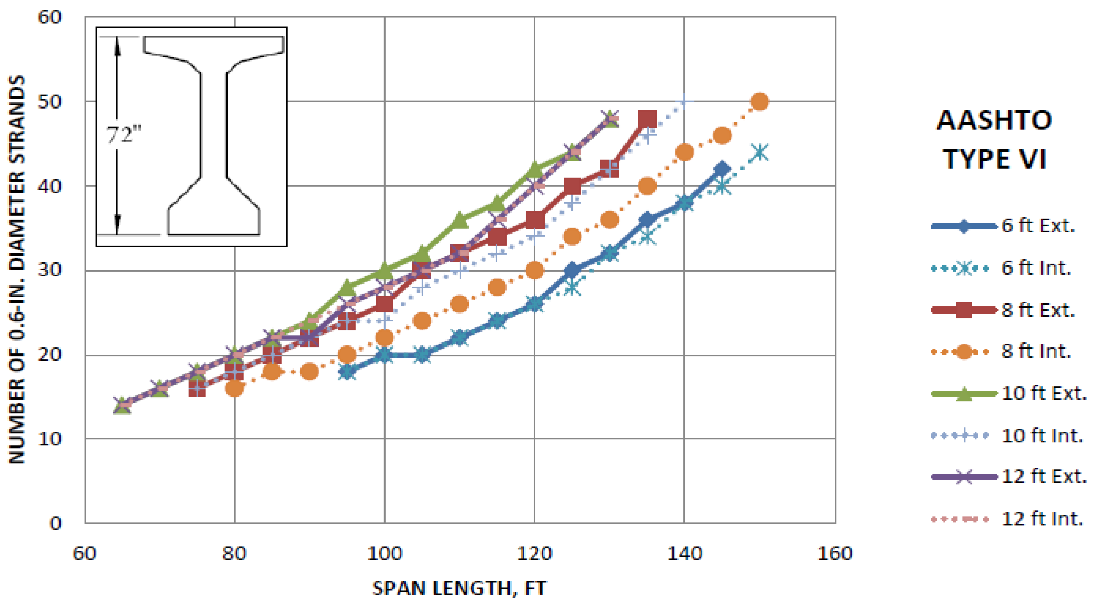


Chart IB-6
AASHTO I-Beams Type VI



02/23/2022

Design a simple span bridge for HL-93 loading with 120 ft. span. The width is 51 ft. with a 6 in. thick cast-in-place deck

Product Options for Example No. 2[1]

Products		Depth in.	Spacing ft	Deck Thickness in.	Number of Strands	Design Chart
AASHTO I-Beams	I V	54	8	8.0	42	IB-4
		54	6	8.0	36	IB-4
	V	63	12	9.0	46	IB-5
		63	10	8.0	48	IB-5
	VI	63	8	8.0	42	IB-5
		63	6	8.0	32	IB-5
		72	12	9.0	40	IB-6
		72	10	8.0	42	IB-6
		72	8	8.0	36	IB-6
		72	6	8.0	26	IB-6
AASHTO-PCI Bulb-Tees	BT-54	54	6	8.0	34	BT-2
	BT-63	63	6	8.0	28	BT-3
	BT-72	72	6	8.0	24	BT-4
		72	8	8.0	34	BT-4
		72	10	8.0	38	BT-4
		72	12	9.0	36	BT-4
Deck Bulb-Tees 6-ft-Wide Flange		53	6	None	30	DBT-2
		65	6	None	23	DBT-2
AASHTO Box Beams	BIV-36	39	3	6.0	27	BB-7
	BIV-48	42	4	6.0	31	BB-5
Washington U-Beams	U66G5	66	10	8.0	47	U-4
	U78G5	78	14	8.0	49	U-5
		78	10	8.0	43	U-5

Preliminary Design Hints

- Beneficial to use the widest possible spacing to minimize the number of girder lines.
- Clearance requirements may dictate the structure depth.
- If no depth limitations, the most economical will be the deepest. Minimize number of strands.

Girder Options	72 in. AASHTO Type VI	72 in. AASHTO-PCI Bulb-Tee	AASHTO Box BIV-48	U-Beam U78G5
Spacing (ft.)	8	8	4	10
Number of girders	7	7	13	5
Girder depth (in.)	72	72	42	66
Cross section area in^2)	1085	767	842	767
Number of strands	36	34	31	47

Segmental Bridges

- ✓ The first long-span segmental concrete bridge in the U.S. was built over the Gulf-Intracoastal Waterway in Texas in 1973.
- ✓ Over 460 segmental bridges have been built in the U.S.
- ✓ **M**aximum span length: 760 ft. for segmental box girder and 1300 ft. for cable-stayed bridges.
- ✓ Advantages**: r**epetitive & economical construction, durable structure, can be placed on small footprint**, can** be used on a small radius**,** aesthetically pleasing, concrete can be colored to blend into the environment.

Segmental Bridges

✓ Precast segments are usually erected using the span-by-span, balanced cantilever, or progressive placement methods.

Precast, Span-by-Span Method

Precast, balanced cantilever method

Segmental Bridges

Precast, progressive placement method

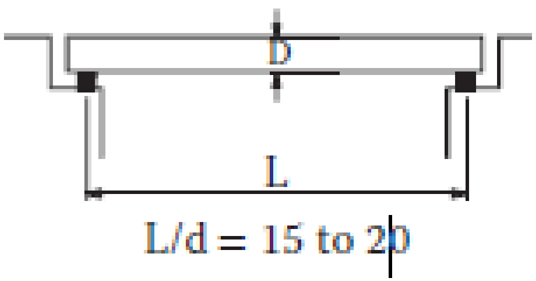
Cast-in-place, balanced cantilever method

Segmental Bridges

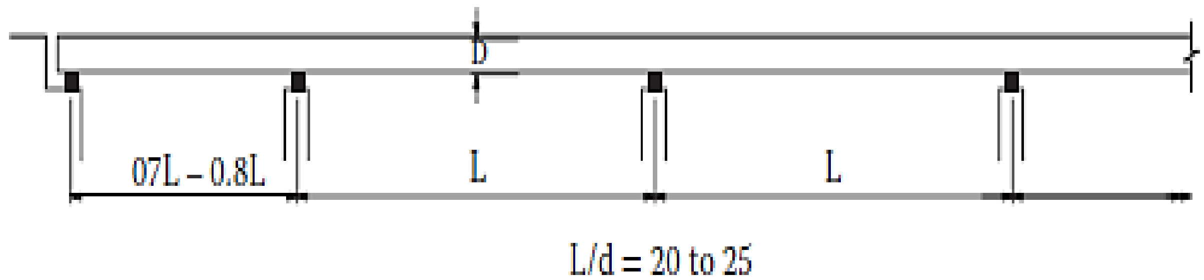
- ✓ AASHTO LRFD adopted segmental bridge design provisions from AASHTO Guide Specifications for Design and Construction of Segmental Bridges.
- ✓ ***Considerations during preliminary*** design stage:
  - Span arrangement and configuration should be closely studied by considering ***the*** location of the bridge.
  - A bridge crossing over a navigable waterway is very much dictated by the horizontal and vertical clearance requirements.
  - Uniformity of the span lengths is critical in order to maximize the benefit of precasting the segments. Uniform spans produce economical design.
  - For spans up to 250 ft. , constant depth section is typically utilized.
  - For span length greater than 250 ft., a variable depth section is more economical and efficient.
  - **Span length over depth ratio (L/D) plays an important role in preliminary design.**

Segmental Bridges

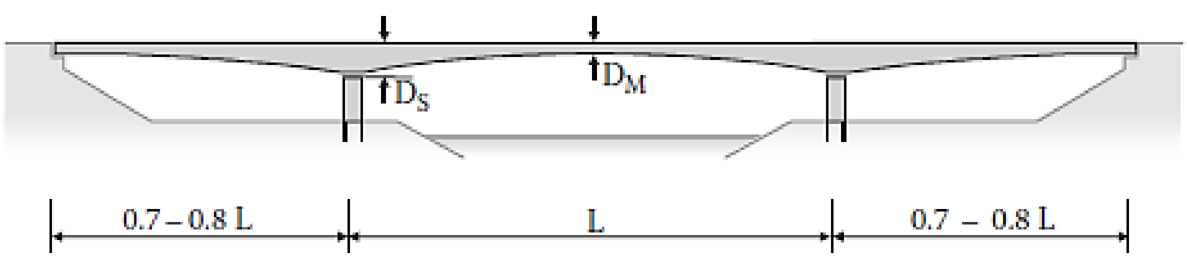
- The preliminary superstructure depth is selected on the basis of the *L/D* ratio.
- The initial depth selected is continuously refined in the preliminary and final design.



Simply supported girder



Continuous girder



Span/Depth ratio: $L/D_S = 15$ to 18
$L/D_M = 35$ to 45

Variable-depth bridge girder (for span ≥ 250 ft.)

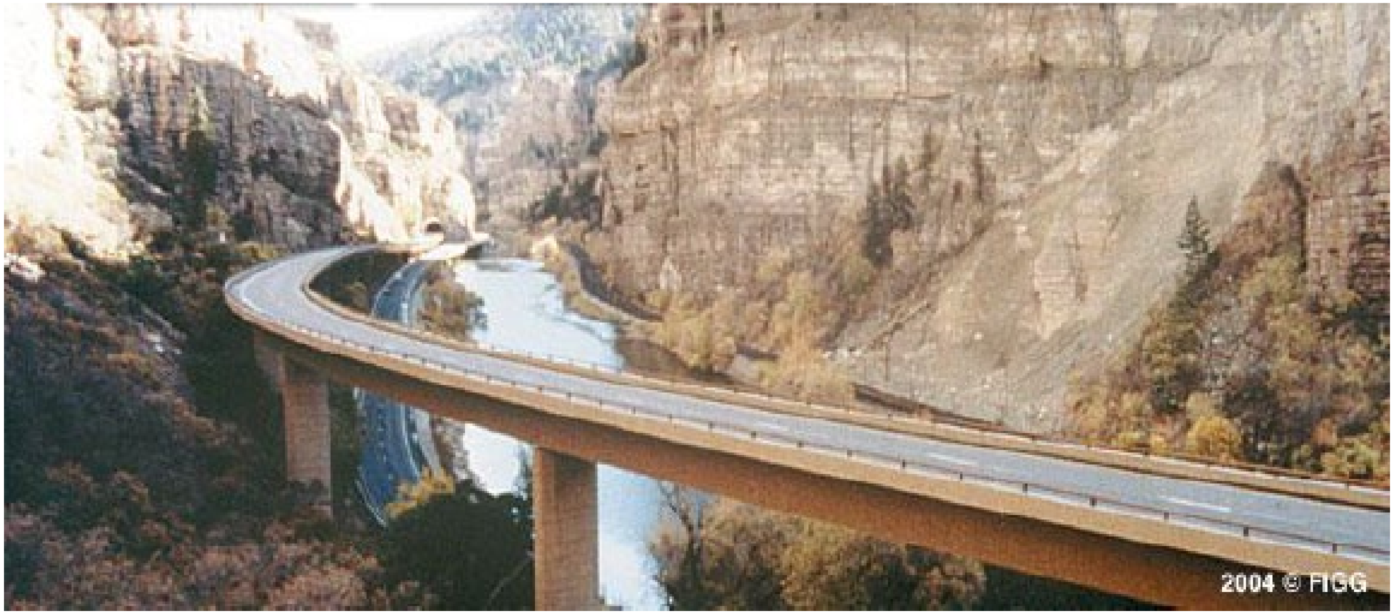
Segmental Bridges

- Economical, durable, aesthetically pleasing
- Post-tensioned or/and cable-stayed
- Typical segment type: Concrete box
- Cast-in-place (CIP) or precast
- Perfectly suited for gradual and sharply curved alignments


Sagadahoc Bridge, Bath-Woolwich, ME, Span 420'

Hanging Lake Viaduct

- I-70 Highway in Glenwood, Colorado
- Segmental precast concrete bridge
- Balanced Cantilever construction



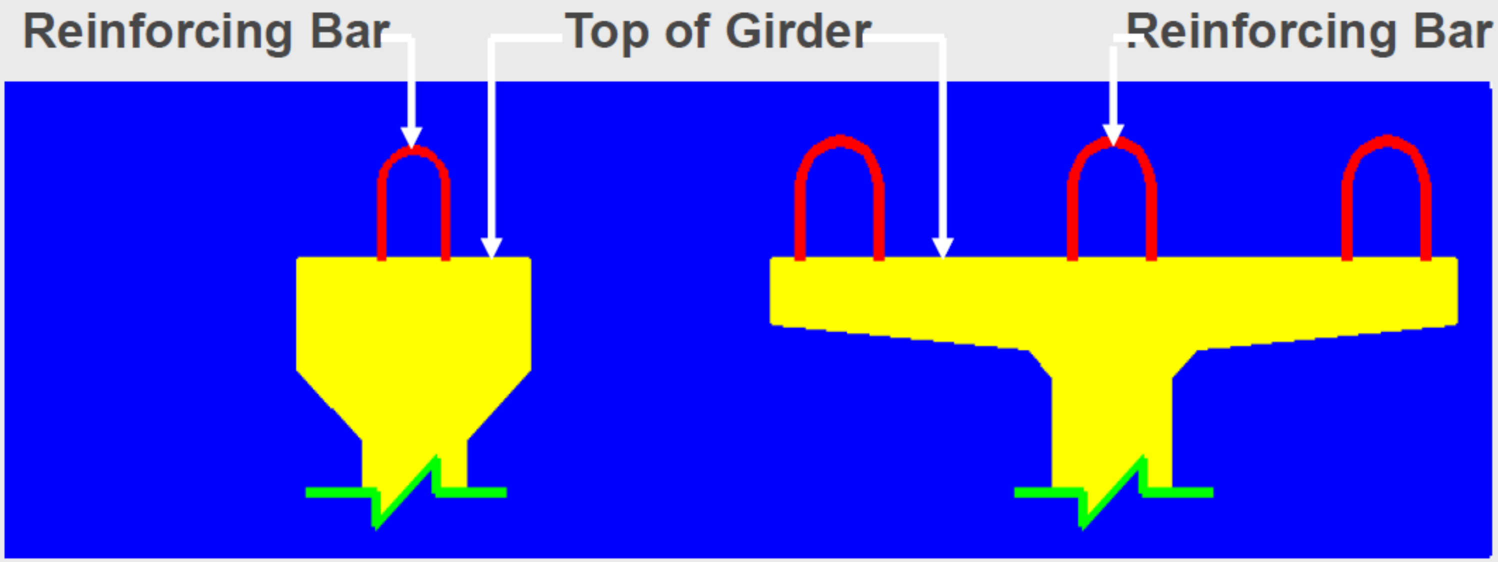
Spliced Girder Bridges

- Innovative technique for very long spans
- Long-segment precast prestressed girders spliced
- Spans of more than 91 m have been achieved


Shelby Creek Bridge, KY, Span 250 ft.

Spliced Girder Bridges

Example 2- Ease of Construction AASHTO Girders vs. PCEF Bulb Tee



Top of AASHTO IV Girder

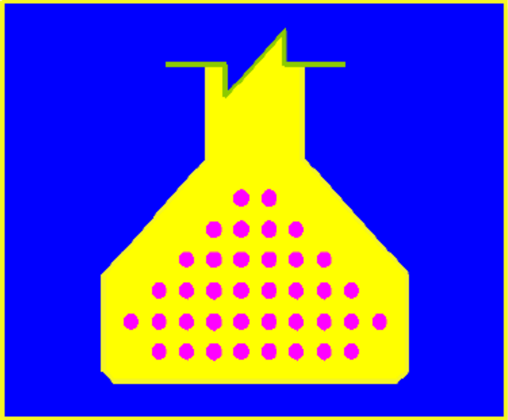
1'-8" Wide Balance Beam

Top of PCEF Bulb Tee

4'-0" Wide Runway

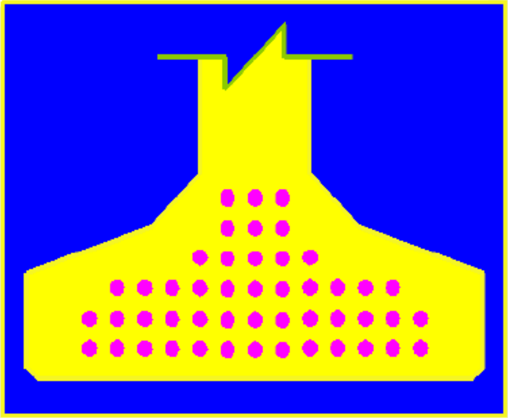
Comparison of Section Properties

Type of Girder	AASHTO III	45” Bulb Tee
Girder Depth	45 inches	45 inches
Moment of Inertia	125,390 in^4	215,151 in^4
Maximum Strands Bottom Flange	38 strands	48 strands



AASHTO III Bottom Flange

PCEF Bulb Tee Bottom Flange



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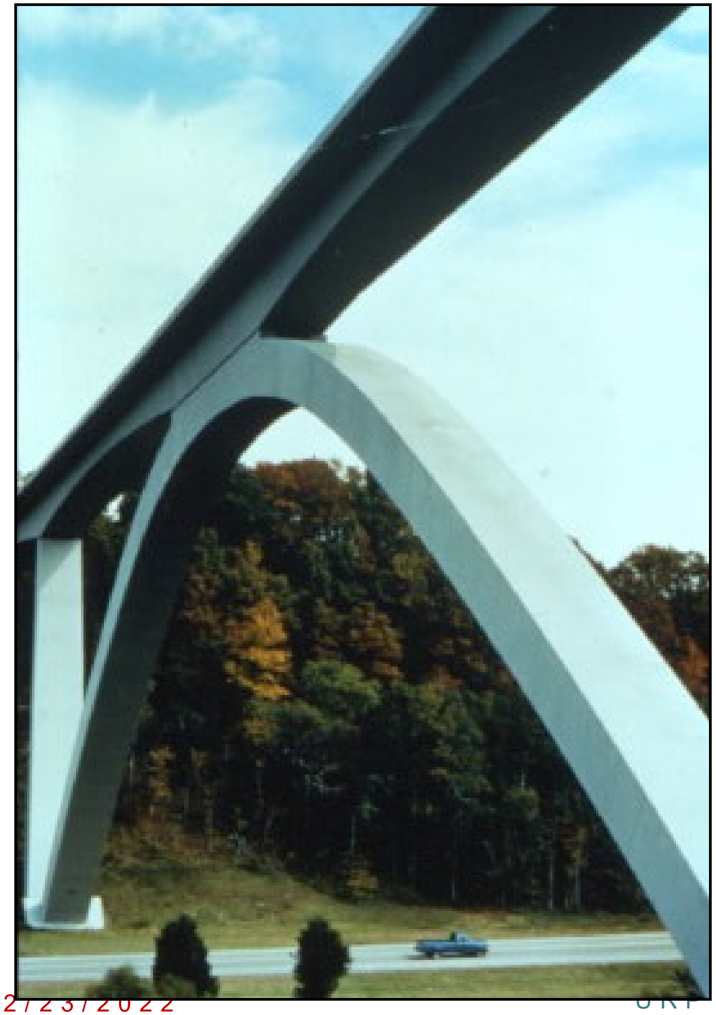
Why Prestressed Concrete Girders?

- Steel girders need paint!
- Concrete girders are generally maintenance free.
- Concrete over water, steel over highways
- Difficult to paint girders over water.
- Steel girders more resilient to vehicle hits.

Arch Bridges



- Most efficient shape for supporting gravity loading
- CIP or precast
- Longest existing concrete arch bridge: Wanxian Bridge, China. Span = 420 m.

Cable-Stayed Bridges

- Structurally efficient use of materials.
- Concrete in compression and steel stays in tension.
- Economical and aesthetically pleasing.
- Most popular type for signature bridges.
- Longest concrete cable-stayed bridge in the U.S.: Dames Point, Jacksonville, Fl. Main Span = 396 m.

Zakim Bunker Hill Bridge, Boston, MA

Over Charles River.
Part of the Central Artery Project.

Design Considerations

- Engineers tend to use familiar designs that worked in the past.
- Clients’ desires, architects’ design, relevant codes, accepted practice, available materials, contractors’ capabilities, economics, environmental concerns, legal factors, political factors.
- Data gathering - topography, function, soil condition, available materials, hydrology, etc.
- Preliminary design
- Design - Build option

Bridge Aesthetics Hints

- About 2% additional cost for short bridges; 5% for longer bridges.
- Equal spans for deep valleys. Odd span numbers.
- Relative proportion of piers and girders.
- Limit pier width to about 1/8 of span length.
- Use order and rhythm.
- Contrast and texture.
- Light and shadow.

Evolution of BRIDGE Design Methodologies

3. LRFD Methodology

Load and Resistance Factor Design

» Recognizes Variability in Loads and Resistances

- Loads Multiplied by a Load Factor → Increases Loads
- Strengths (Resistances) Multiplied by a Resistance Factor → Decreases Resistances

» Consistent Reliability Index, β, at Strength Limit State

» Calibrated Load and Resistance Factors

- $1.25D + 1.75(L+I)$

BRIDGE SPECIFICATIONS: USA

- All Public Bridges in the USA must be designed in conformance with the AASHTO Specifications (with any local additions).

AASHTO
THE VOICE OF TRANSPORTATION

- AASHTO ?

American Association of State Highway and Transportation Officials

AASHTO Bridge Design Specifications

- Standard Specifications for Highway Bridges, 17th Edition, 2002—phased out in 2007 (ASD).
- All new bridges for which States initiate preliminary engineering after October 1, 2007, shall be designed by the LRFD Specifications.
- For modifications to existing structures, use LRFD Specifications or the specifications originally used.

Other Manuals, Guides, Guide Specifications

- AASHTO LRFD Bridge Construction Specifications.
- AASHTO Guide Specifications for LRFD Seismic Bridge Design.
- AASHTO Guide Specification for Seismic Isolation Design.
- AASHTO Guide Specifications for Bridges Vulnerable to Coast Storms.
- AASHTO Guide Specifications and Commentary for Vessel Collision Design of Highway Bridges.

Other Manuals, Guides, Guide Specifications

- AASHTO LRFD Moveable Highway Bridge Design Specifications.
- AASHTO LRFD Guide Specifications for Design of Pedestrian Bridges.
- AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete Bridge Decks and Traffic Railings.
- AASHTO Technical Manual for Design and Construction of Road Tunnels—Civil Elements.
- AASHTO Manual for Bridge Evaluation.

Other Manuals, Guides, Guide Specifications

- AASHTO Bridge Element Inspection Manual.
- Bridge Aesthetics Sourcebook.
- Construction Handbook for Bridge Temporary Works.
- Guide Specifications for Bridge Temporary Works.
- AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing.
- AREMA Manual for Railway Engineering (by American Railway Engineering and Maintenance-of- Way Association [AREMA]).

Objective of the LRFD

Develop a comprehensive and consistent LRFD specification that is calibrated to obtain uniform reliability (a measure of safety) at the <u>strength limit state</u>.

AASHTO addresses the following limit states in the design process:

- Service Limit State
- Fatigue and Fracture Limit State
- Strength Limit State
- Extreme Event Limit State

Definitions

Q = Load

γ = Load Factor

R = Resistance

φ = Resistance Factor

β = Target Reliability Index

For Safe Design

The basic requirement,
for each limit state:

$$\underbrace{\Sigma\ \gamma_i Q_i}_{\boxed{\text{Load}}} \le \underbrace{\phi R}_{\boxed{\text{Resistance}}}$$

Basis of LRFD Methodology

$$\Sigma \eta_i \gamma_i Q_i \leq \phi R_n$$ (Eq. 1.3.2.1-1, page 1-3)

For loads where max. value of γ_i is used:

$$\eta_i = \eta_D \, \eta_R \, \eta_I \quad \geq 0.95$$

For loads where min. value of γ_i is used:

$$\eta_i = 1 / (\eta_D \, \eta_R \, \eta_I) \leq 1.00$$

→ η_i = load modifier

where:

γ_i = load factor: a statistically based multiplier applied to force effects

ϕ = resistance factor: a statistically based multiplier applied to nominal resistance, as specified in Sections 5, 6, 7, 8, 10, 11, and 12

η_i = load modifier: a factor relating to ductility, redundancy, and operational classification

η_D = a factor relating to ductility, as specified in Article 1.3.3

η_R = a factor relating to redundancy as specified in Article 1.3.4

η_I = a factor relating to operational classification as specified in Article 1.3.5

Q_i = force effect

R_n = nominal resistance

R_r = factored resistance: ϕR_n

Load Modifier, η_i

(1.3.3 – 1.3.5)

η_D = ductility factor, Strength Limit State

= 1.05 for non-ductile components

= 1.00 for conventional designs

= 0.95 for additional ductile components

= 1.0 for all other limit states

η_R = redundancy factor, Strength Limit State

= 1.05 for non-redundant members

= 1.0 for conventional design

= 0.95 exceptional levels of redundancy beyond continuity and closed sections

= 1.0 for all other limit states

Load Modifier, η_i

η_I = operational importance factor, Strength Limit State

= 1.05 for critical/essential bridges

= 1.00 for typical bridges

= 0.95 for less important bridges

= 1.0 for all other limit states

Ductility Factor, η_D

Resistance Factors, ϕ

5.5.4.2 (page 5-29)

Tension-controlled sections – RC	0.90
Tension-controlled sections – bonded strands, prestressed	1.00
Tension-controlled sections – unbonded strands, post-tensioned	0.9
Compression-controlled sections	0.75
Shear and torsion – normal weight concrete	0.90
Shear and torsion – lightweight concrete	0.80
Bearing	0.70
Compression - Strut & Tie Model	0.70

Unified Design Provisions for Reinforced and Prestressed Concrete

- ***Emphasize common features***
- ***Eliminate duplication***
- ***Unify design procedures***
- ***Promote the idea of "Structural Concrete"***

Example:

$$M_n = A_{ps}f_{ps}(d_p - {}^{a}/_{2}) + A_s f_s(d_s - {}^{a}/_{2}) - A'_s f'_s(d'_s - {}^{a}/_{2}) + 0.85f'_c(b - b_w)h_f({}^{a}/_{2} - {}^{h_f}/_{2})$$

R.C. case can be obtained by setting the P.S. term to zero!

AASHTO LRFD Bridge Design Specifications - Chapters

1. Introduction
2. General Design and Location Features
3. Loads and Load Factors
4. Structural Analysis and Evaluation
5. Concrete Structures
6. Steel Structures
7. Aluminum Structures

AASHTO LRFD Bridge Design Specifications - Chapters

8. Wood Structures
9. Decks and Deck Systems
10. Foundations
11. Abutments, Piers, and Walls
12. Buried Structures and Tunnel Liners
13. Railings
14. Joints and Bearings
15. Design of Sound Barriers

Questions?