


SHRP2 SOLUTIONS
STRATEGIC HIGHWAY RESEARCH PROGRAM

Design Criteria and Exposure Zones

IBC Workshop: W-8 Service Life Design

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U.S. Department of Transportation
Federal Highway Administration

American Association of State Highway and Transportation Officials
AASHTO

Presentation Overview

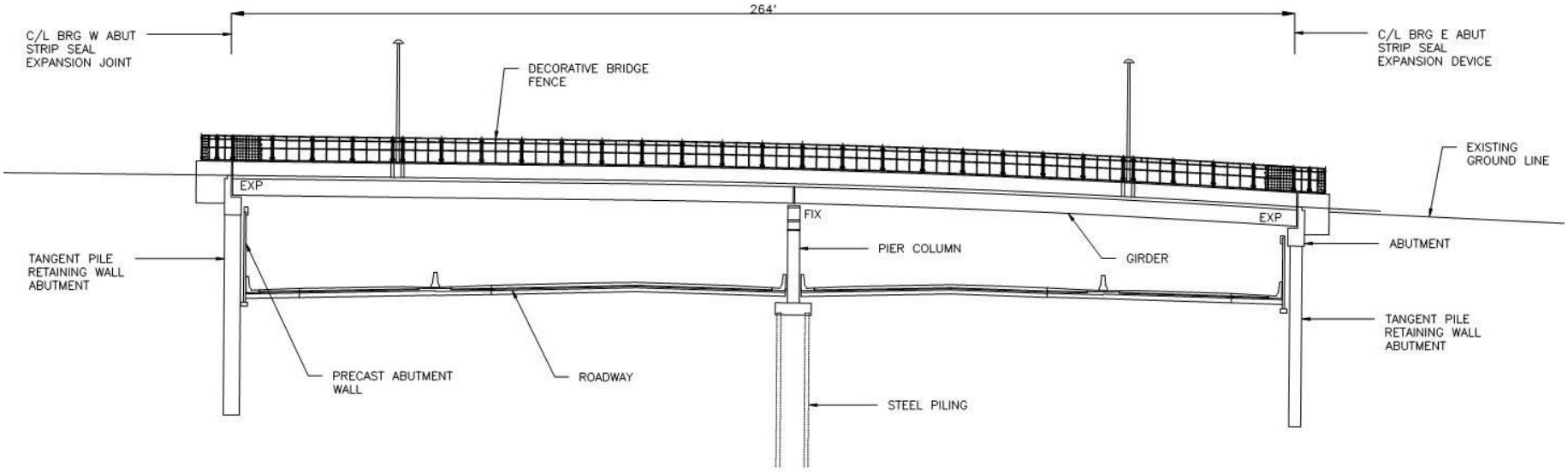
- This part of the worked example covers:
  - Overview of the bridge considered in this design example;
  - Overview of design criteria; and
  - Definition of exposure zones.

Location of the Bridge

- Location:
  - New York City.
  - Highway under the bridge.
  - Urban environment with periods of snow and freeze-thaw cycles.
  - Annual mean temperature of 11.5ºC (52.7ºF).
  - Heavy use of de-icing salts.
  - Some sulfate present in soil: 0.14% by mass of water soluble sulfate was measured.

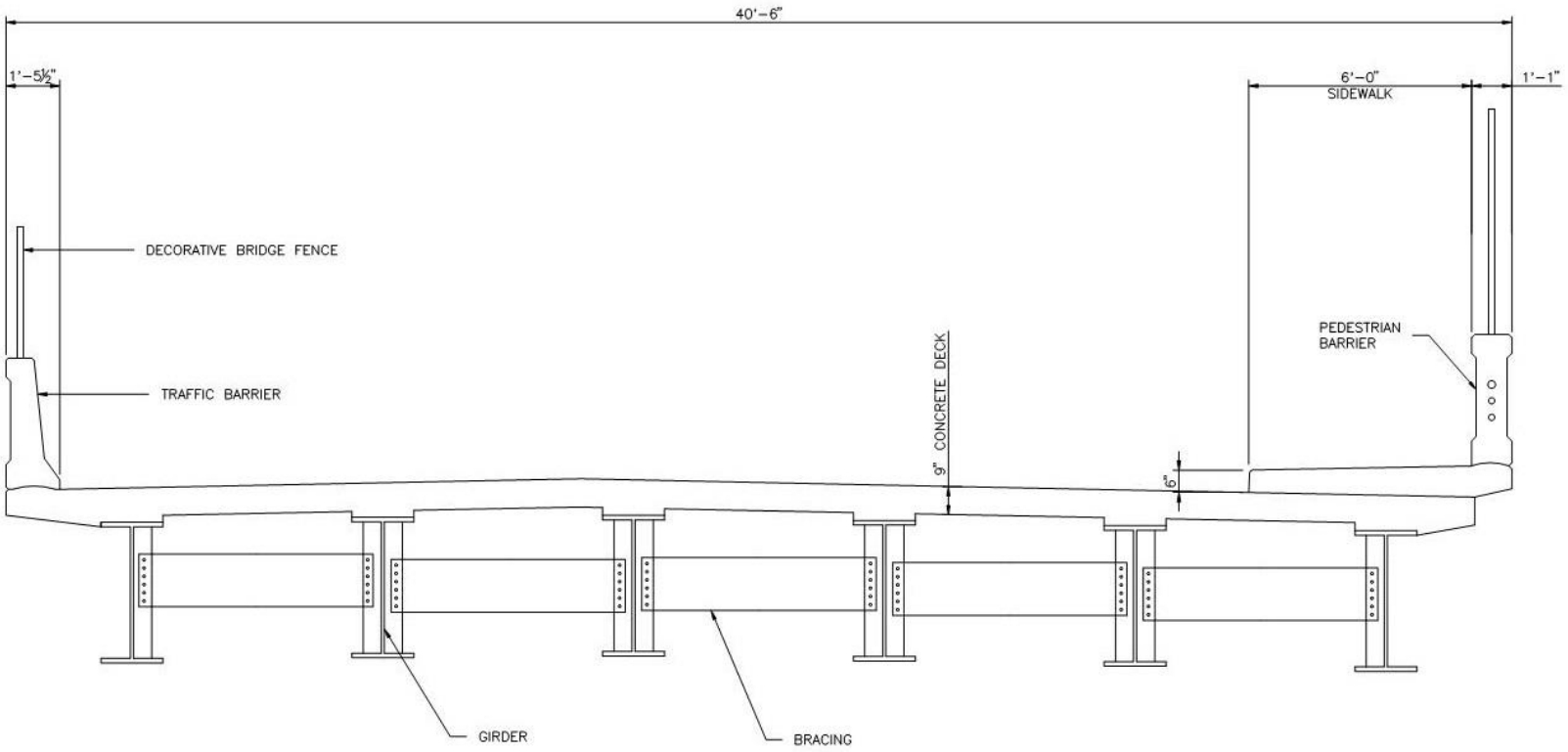
Arrangement of the Bridge

- General bridge characteristics:
  - 264 ft. steel girder bridge with two spans (139 ft. and 125 ft.).
  - Over the abutments, the girders are supported on elastomeric bearings and at the piers, the girders are supported on fixed bearings.
  - Deck and girders are continuous over the pier.
  - Uncoated reinforcement (black steel) used everywhere.



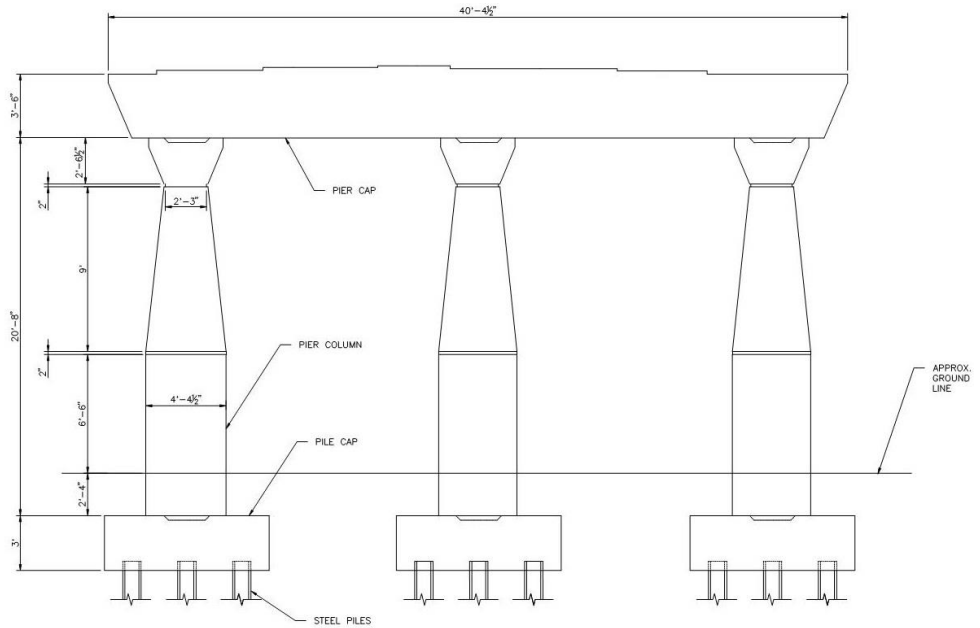
Bridge Superstructure

- General bridge superstructure characteristics:
  - Roadway is 30 ft. wide with two traffic lanes and shoulders, and a 6 ft. sidewalk.
  - Composite cast-in-place, high performance concrete deck on steel girders.
  - Deck is 9 in. thick with 2 ¾” in. top cover and no wearing surface.



Bridge Substructure

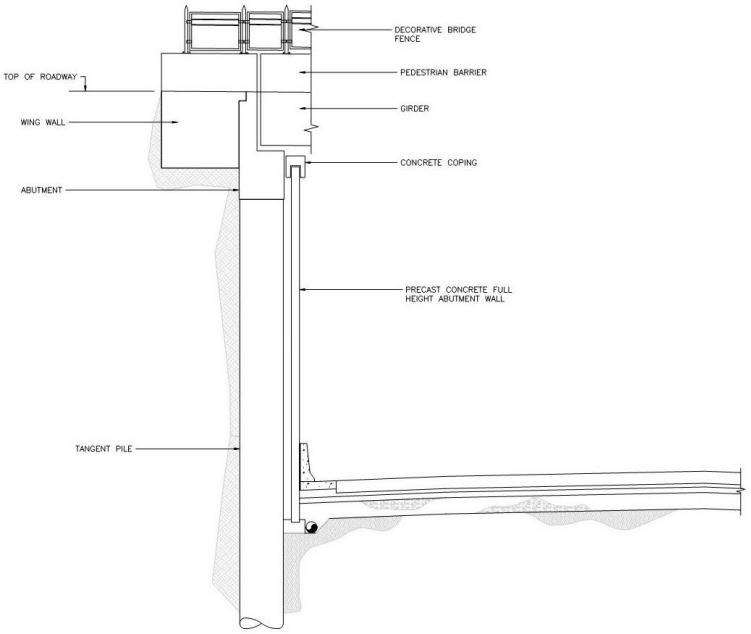
- General bridge substructure characteristics:
  - The central pier has three columns each supported by a pile cap and steel piles driven into bedrock:



  - Uncoated reinforcement (black steel) used everywhere.
  - No mass concrete.

Bridge Substructure

- General bridge substructure characteristics:
  - Abutments are supported by a reinforced concrete tangent pile wall:



  - Full height precast abutment wall in front of the abutments protect them.
  - Expansion joints are located between abutments and concrete deck.

Service Life Requirements

- Service life requirements:
  - Service life is defined as the period without major repairs or maintenance. Normal routine maintenance is expected.
  - Non-replaceable components must meet a minimum service life of 75 years.
  - Replaceable components must meet a minimum service life as below:

Non-Replaceable Components	Minimum Service Life (years)
Foundations, abutments, piers, structural steel, and deck	75
Replaceable Components	**Minimum Service Life (years)**
Bridge bearings	50
Expansion joints	30
Painting	25
Barriers	50

Service Life Requirements

- *fib* Bulletin 34 – Model Code for Service Life Design

Table B1-1: Indicative values for the design service life t_{SL}

design service life t_{SL} [years]	**Examples**
10	Temporary structures (structures or parts of structures that can be dismantled with a view to being re-used should not be considered as temporary)
10 - 25	Replaceable structural parts, e. g. gantry girders, bearings
15 – 30	Agricultural and similar structures
50	Building structures and other common structures
100	Monumental buildings structures, bridges, and other civil engineering structures

Service Life Design Procedure

- Recommended service life design procedure:

  1. Define exposure zones for all bridge components;
  2. Define deterioration mechanisms for each exposure zone;
  3. Define mitigation methods for deterioration mechanisms for concrete components; and
  4. Define mitigation methods for deterioration mechanisms for steel components.

Defined Exposure Conditions

Buried:
Zone permanently buried in soil. Abutment and tangent pile surfaces exposed to soil, pile cap, steel piles.

Atmospheric:
Zone not exposed to soil or de-icing salts. Bottom surface of deck, wing wall surfaces and tangent pile surfaces exposed to atmospheric air.

Indirect de-icing salts:
Zone subject to runoff water or spray containing de-icing salts, typically areas under and within 10 ft. of expansion joints or within 6 ft. to 20 ft. vertically of a roadway. Girder, bracing, pier column, pier cap, abutment wall.

Direct de-icing salts:
Zone directly exposed to the use of de-icing salts. Top surface of deck, traffic barrier, pedestrian barrier, piers directly next to roadway up to 6 ft. vertically of the roadway, fencing.

Defined Exposure Conditions

- American Concrete Institute ACI 318-2014 – Building Code Requirements for Structural Concrete
  - Chapter 19 – Concrete Design and Durability Requirements
    - Table 19.3.1.1 – Exposure categories and classes

ACI 318-14 Exposure Classes

Table 19.3.1.1—Exposure categories and classes

Category	Class	Condition
Freezing and thawing (F)	F0	Concrete not exposed to freezing-and-thawing cycles
	F1	Concrete exposed to freezing-and-thawing cycles with limited exposure to water
	F2	Concrete exposed to freezing-and-thawing cycles with frequent exposure to water
	F3	Concrete exposed to freezing-and-thawing cycles with frequent exposure to water and exposure to deicing chemicals

ACI 318-14 Exposure Classes

Table 19.3.1.1—Exposure categories and classes

Category	Class	Condition	
		Water-soluble sulfate (SO_4^{2-}) in soil, percent by mass[1]	Dissolved sulfate (SO_4^{2-}) in water, ppm[2]
Sulfate (S)	S0	$SO_4^{2-} < 0.10$	$SO_4^{2-} < 150$
	S1	$0.10 \leq SO_4^{2-} < 0.20$	$150 \leq SO_4^{2-} < 1500$ or seawater
	S2	$0.20 \leq SO_4^{2-} \leq 2.00$	$1500 \leq SO_4^{2-} \leq 10{,}000$
	S3	$SO_4^{2-} > 2.00$	$SO_4^{2-} > 10{,}000$

ACI 318-14 Exposure Classes

Table 19.3.1.1—Exposure categories and classes

Category	Class	Condition
In contact with water (W)	W0	Concrete dry in service Concrete in contact with water and low permeability is not required
	W1	Concrete in contact with water and low permeability is required
Corrosion protection of reinforcement (C)	C0	Concrete dry or protected from moisture
	C1	Concrete exposed to moisture but not to an external source of chlorides
	C2	Concrete exposed to moisture and an external source of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources

Defined Exposure Conditions

- European Standard EN 206:2013 – Concrete – Specification, performance, production, and conformity
  - 4.1 Exposure classes related to environmental actions
    - Table 1 – Exposure Classes
    - Table 2 – Limiting values for exposure classes for chemical attack from natural soil and groundwater

EN 206:2013 Exposure Classes

Table 1 – Exposure classes

Class designation	Description of the environment	Informative examples where exposure classes may occur
3 Corrosion induced by chlorides other than from sea water		
Where concrete containing reinforcement or other embedded metal is subject to contact with water containing chlorides, including de-icing salts, from sources other than from sea water, the exposure shall be classified as follows:		
XD1	Moderate humidity	Concrete surfaces exposed to airborne chlorides
XD2	Wet, rarely dry	Swimming pools; Concrete exposed to industrial waters containing chlorides
XD3	Cyclic wet and dry	Parts of bridges exposed to spray containing chlorides. Pavements, Car park slabs
6 Chemical attack		
Where concrete is exposed to chemical attack from natural soils and ground water, the exposure shall be classified as follows:		
XA1	Slightly aggressive chemical environment	Concrete exposed to natural soil and ground water according to Table 2
XA2	Moderately aggressive chemical environment	Concrete exposed to natural soil and ground water according to Table 2
XA3	Highly aggressive chemical environment	Concrete exposed to natural soil and ground water according to Table 2

EN 206:2013 Exposure Classes

Table 2 — Limiting values for exposure classes for chemical attack from natural soil and ground water

Chemical characteristic	Reference test method	XA1	XA2	XA3
Ground water				
SO_4^{2-} mg/l	EN 196-2	≥ 200 and ≤ 600	> 600 and ≤ 3 000	> 3 000 and ≤ 6 000
pH	ISO 4316	≤ 6,5 and ≥ 5,5	< 5,5 and ≥ 4,5	< 4,5 and ≥ 4,0
CO_2 mg/l aggressive	EN 13577	≥ 15 and ≤ 40	> 40 and ≤ 100	> 100 up to saturation
NH_4^+ mg/l	ISO 7150-1	≥ 15 and ≤ 30	> 30 and ≤ 60	> 60 and ≤ 100
Mg^{2+} mg/l	EN ISO 7980	≥ 300 and ≤ 1 000	> 1 000 and ≤ 3 000	> 3 000 up to saturation
Soil				
SO_4^{2-} mg/kg[a] total	EN 196-2[b]	≥ 2 000 and ≤ 3 000[c]	> 3 000[c] and ≤ 12 000	> 12 000 and ≤ 24 000
Acidity according to Baumann Gully ml/kg	prEN 16502	> 200	Not encountered in practice	

Defined Exposure Conditions

- International Standard ISO 12944 – Paints and varnishes – Corrosion protection of steel structures by protective paint systems – Part 2: Classifications of environments
  - 5 Classification of environments
    - Table 1 – Atmospheric-corrosivity categories and examples of typical environments
    - Table 2 – Categories for Soil and Water

ISO 12944 – Part 2
Atmospheric Exposures

Table 1 — Atmospheric-corrosivity categories and examples of typical environments

Corrosivity category	Mass loss per unit surface/thickness loss (after first year of exposure)				Examples of typical environments in a temperate climate (informative only)	
	Low-carbon steel		Zinc		Exterior	Interior
	Mass loss g/m^2	Thickness loss µm	Mass loss g/m^2	Thickness loss µm		
C3 medium	> 200 to 400	> 25 to 50	> 5 to 15	> 0,7 to 2,1	Urban and industrial atmospheres, moderate sulfur dioxide pollution. Coastal areas with low salinity.	Production rooms with high humidity and some air pollution, e.g. food-processing plants, laundries, breweries, dairies.
C4 high	> 400 to 650	> 50 to 80	> 15 to 30	> 2,1 to 4,2	Industrial areas and coastal areas with moderate salinity.	Chemical plants, swimming pools, coastal ship- and boatyards.
C5-M very high (marine)	> 650 to 1 500	> 80 to 200	> 30 to 60	> 4,2 to 8,4	Coastal and offshore areas with high salinity	Buildings or areas with almost permanent condensation and with high pollution.

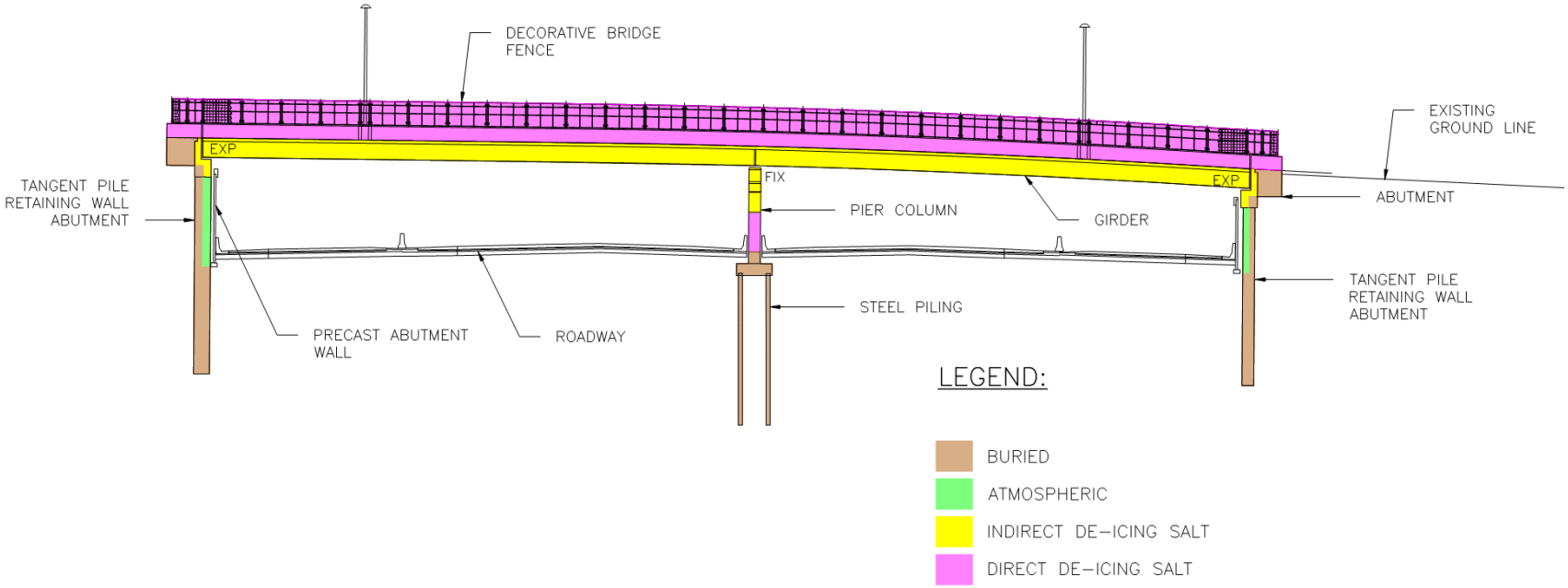
ISO 12944 – Part 2
Water and Soil Exposures

Table 2 — Categories for water and soil

Category	Environment	Examples of environments and structures
Im1	Fresh water	River installations, hydro-electric power plants
Im2	Sea or brackish water	Harbour areas with structures like sluice gates, locks, jetties; offshore structures
Im3	Soil	Buried tanks, steel piles, steel pipes

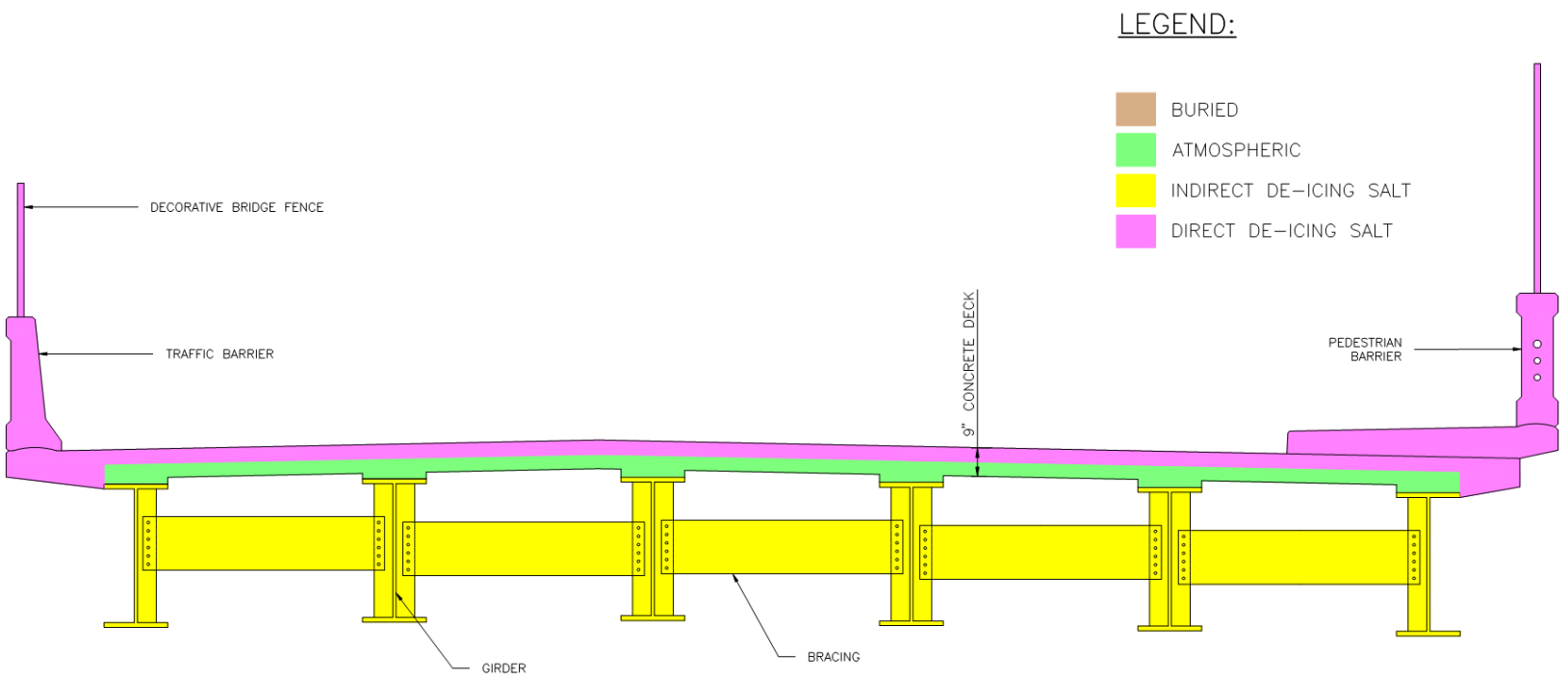
Exposure Zones Color Code

- Exposure zones for longitudinal section of the Bridge:



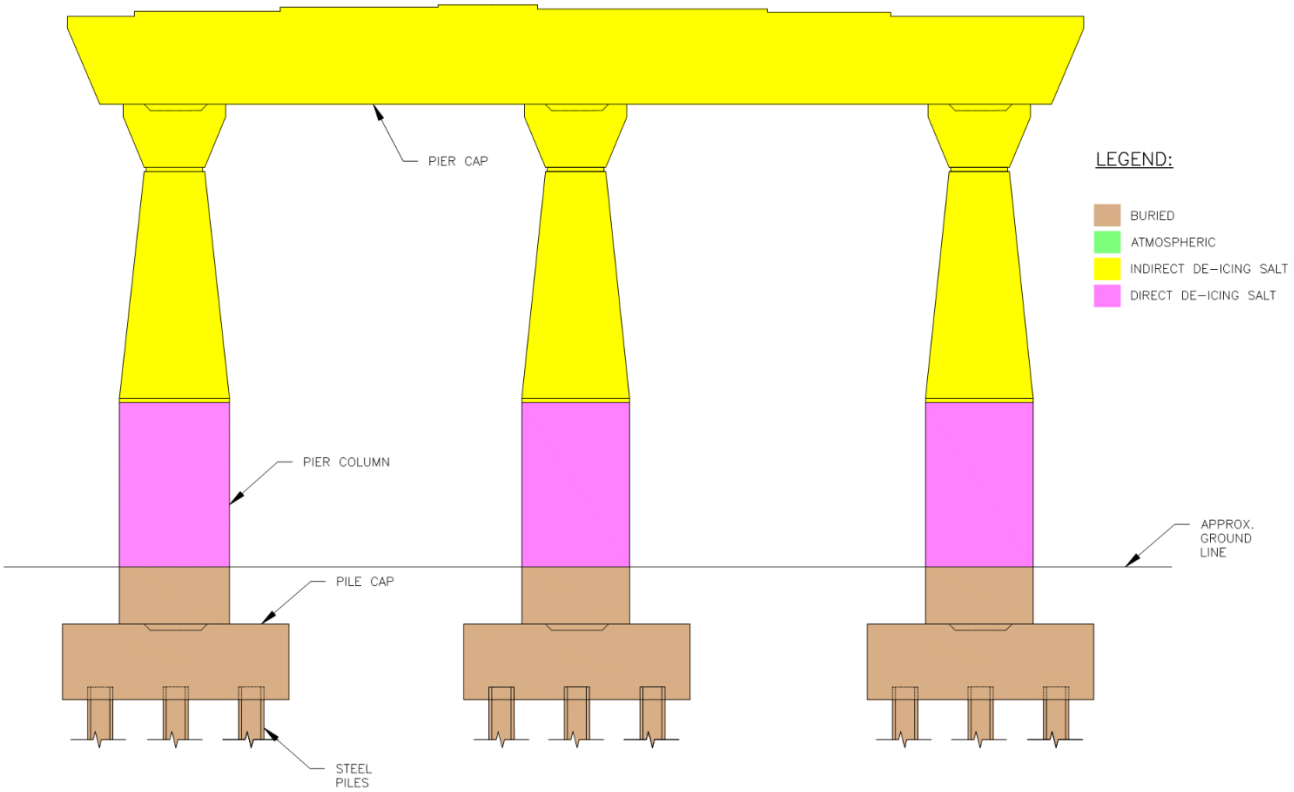
Exposure Zones Color Code

- Exposure zones for superstructure:



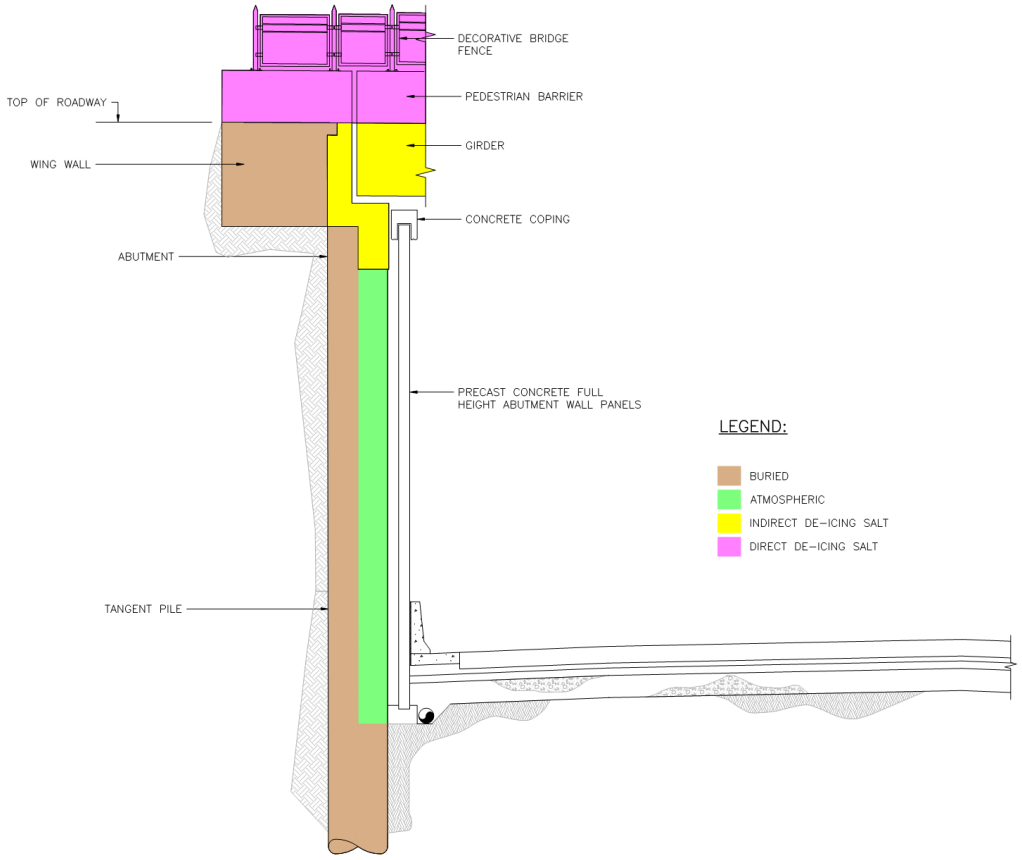
Exposure Zones Color Code

- Exposure zones for substructure:



Exposure Zones Color Code

- Exposure zones for abutments:



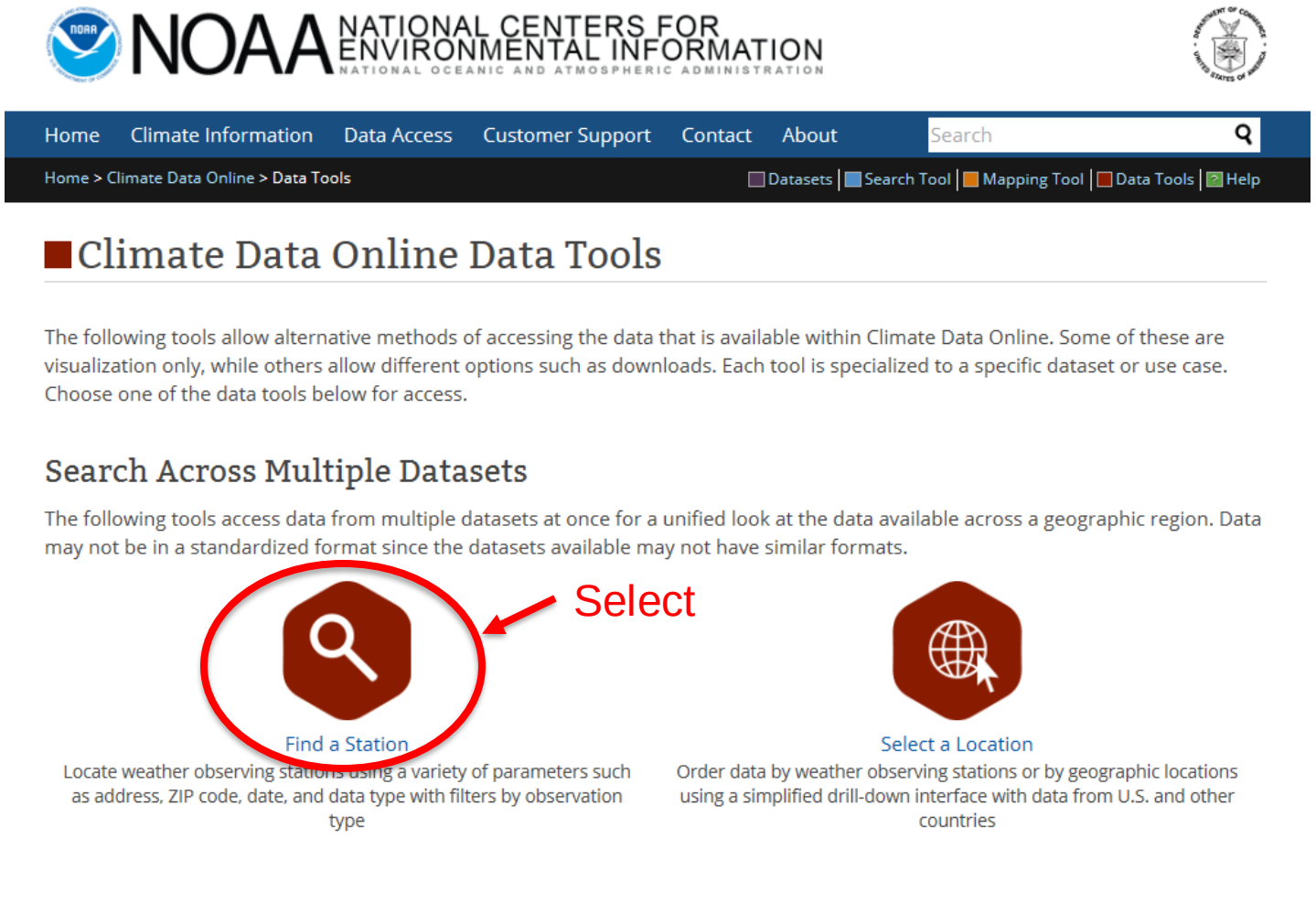
Collecting Environmental Data

- Climate/Weather
  - Temperature
  - Precipitation (Rain and/or Snow)
  - Freeze-Thaw Cycles
  - Relative Humidity
- Surface Chloride Concentration from De-Icing
  - Historical Data
  - Chloride Profiles from Existing/Nearby Structures

NOAA Climate Data

https://www.ncdc.noaa.gov/cdo-web/

NOAA Climate Data



NOAA Climate Data

NOAA NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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Data Tools: Find a Station

Retrieve weather records from observing stations by entering the desired location, data set, data range, and data category. Location can be specified as city, county, state, country, or ZIP code.

Enter Location

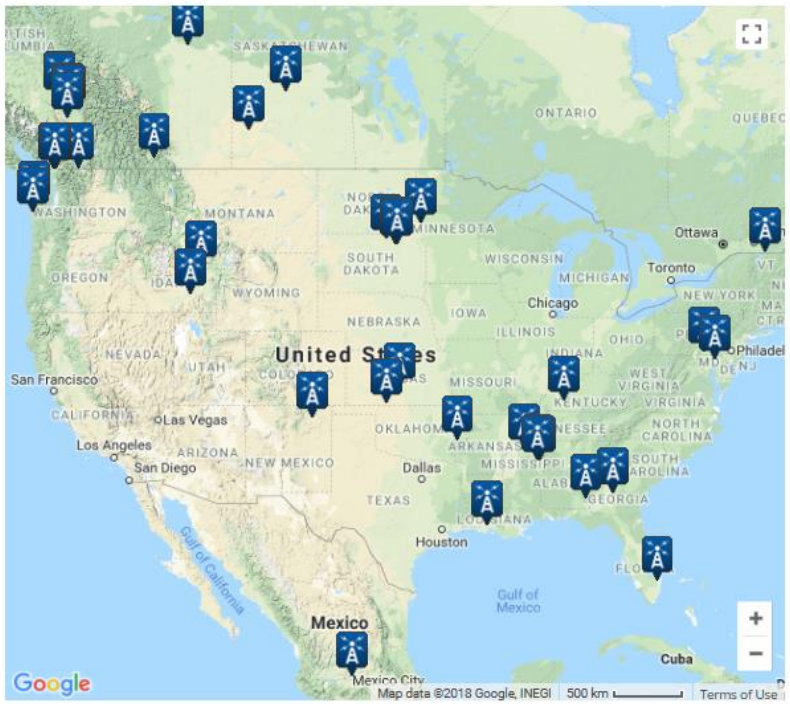
New York

- **New York** NY, USA
- **New York** USA
- **New York** IA, USA
- **New York** Ranch Road Jackson, CA, USA
- **New York** Avenue Northwest Washington, DC, USA

powered by Google

Data Categories

- ☐ Air Temperature
- ☐ Computed
- ☐ Evaporation
- ☐ Land
- ☐ Miscellany



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Enter Location

New York, NY, USA

Select Dataset

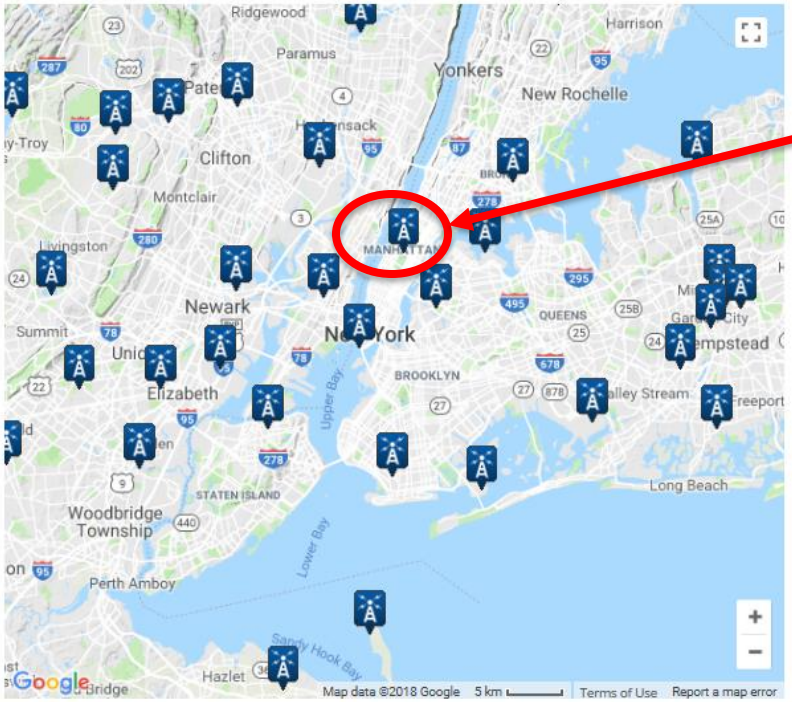
Global Summary of the Year

Select Date Range

1960-01-01 to 2016-12-31

Data Categories

- [x] Air Temperature
- [x] Computed
- [ ] Evaporation
- [ ] Land
- [ ] Miscellany



Select Central Park station

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Enter Location

New York, NY, USA

Select Dataset

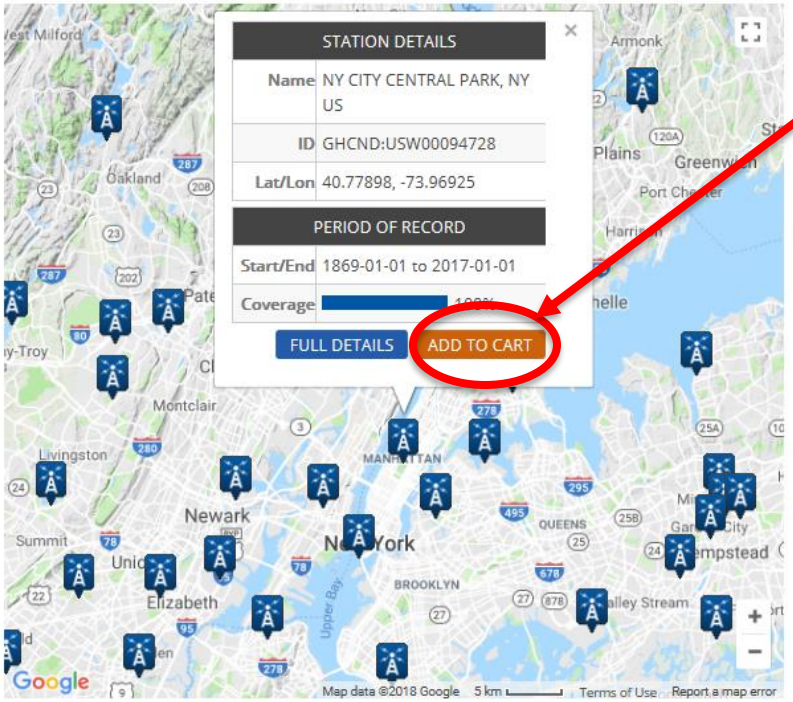
Global Summary of the Year

Select Date Range

1960-01-01 to 2016-12-31

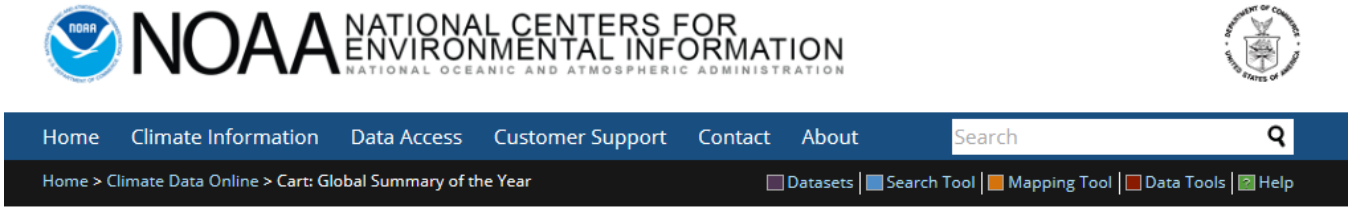
Data Categories

- [x] Air Temperature
- [x] Computed
- [ ] Evaporation
- [ ] Land
- [ ] Miscellany



Select

NOAA Climate Data



NOAA Climate Data (pdf)

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Current Location: Elev: 140 ft. Lat: 40.7790° N Lon: -73.9693° W
Station: **NY CITY CENTRAL PARK, NY US USW00094728**

Global Summary of the Year 1960 - 1985
Generated on 05/25/2018

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Date	Temperature (Fahrenheit)			Degree Days (Base 65 degrees)		Extremes				Number of Days			
Elem->	TAVG	TMAX	TMIN	HTDD	CLDD	EMXT		EMNT		DX90	DX32	DT32	DT00
Year	Annual Mean Temp	Mean Max Temp	Mean Min Temp	Heating Degree Days	Cooling Degree Days	Extreme Max Temp	Date of Occurrence	Extreme Min Temp	Date of Occurrence	Max Temp >= 90F	Max Temp <= 32F	Min Temp <= 32F	Min Temp <= 0F
1960	54.0	61.5	46.5	4898	978	91+	Aug-27	8	Dec-13	5	19	99	0
1961	55.0	62.7	47.4	5110	1344	97	Jul-22	-2	Feb-02	29	22	74	1
1962	53.4	61.5	45.3	4738	977	99	May-19	4+	Dec-31	18	22	79	0
1963	53.5	61.8	45.2	5328	920	98+	Jul-27	-2	Feb-08	16	30	78	1
1964	54.5	62.7	46.4	4859	1033	99+	Jul-01	9	Jan-14	23	13	75	0
1965	54.2	62.0	46.3	5015	991	95	Jun-29	9	Jan-17	15	19	71	0
1966	55.0	63.0	47.1	4818	1322	103	Jul-03	8+	Feb-20	35	19	77	0
1967	52.9	60.6	45.3	5236	989	96	Jun-16	4	Feb-13	9	20	86	0
1968	54.0	62.0	46.1	5246	1109	98	Jul-17	-1	Jan-09	17	26	87	1
1969	54.8	62.1	47.4	4770	1199	97	May-29	11	Jan-28	16	17	90	0
1970	54.2	61.7	46.8	5283	1269	94+	Sep-22	3	Jan-09	22	29	91	0
1971	55.2	62.3	48.1	5057	1305	96	Jul-08	4	Jan-19	18	18	70	0
1972	53.8	61.4	46.2	4743	1033	94+	Aug-24	5	Jan-16	15	19	78	0
1973	56.0	63.8	48.3	4797	1259	98+	Aug-30	7	Feb-17	18	16	60	0
1974	54.7	62.5	46.8	4594	1062	95+	Jul-14	6	Jan-18	17	19	80	0
1975	54.9	62.3	47.5	4771	993	98	Aug-02	15	Jan-21	8	12	75	0
1976	53.3	61.4	45.3	4660	1049	96	Apr-18	-1	Jan-23	15	29	92	1
1977	54.3	61.6	47.0	5502	1234	104	Jul-21	-2	Jan-17	23	40	77	1
1978	52.9	60.1	45.8	5427	992	95	Jul-23	10+	Feb-05	11	38	86	0
1979	55.7	62.8	48.5	4826	1185	95+	Aug-10	0	Feb-18	18	25	63	1
1980	54.9	62.6	47.3	4521	1405	102	Jul-21	-1	Dec-25	32	26	83	1
1981	55.2	62.3	48.0	4953	1206	96	Jul-09	2	Jan-12	16	23	70	0
1982	54.8	62.1	47.6	5074	1034	98	Jul-18	0+	Jan-18	11	21	74	2
1983	56.0	63.2	48.7	4378	1402	99	Sep-11	4	Dec-25	36	18	57	0
1984	55.4	62.4	48.5	4923	1118	96	Jun-09	8	Jan-21	10	21	60	0
1985	55.5	62.9	48.1	4331	1131	95	Aug-15	-2	Jan-21	9	23	81	1

NOAA Climate Data

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Current Location: Elev: 140 ft. Lat: 40.7790° N Lon: -73.9693° W
Station: **NY CITY CENTRAL PARK, NY US USW00094728**

Date	**Temperature (Fahrenheit)**		
Elem->	TAVG	TMAX	TMIN
Year	Annual Mean Temp	Mean Max Temp	Mean Min Temp
2012	57.3	64.3	50.3
2013	55.3	62.3	48.4
2014	54.4	61.6	47.2
2015	56.7	64.1	49.2
2016	57.2	64.6	49.8

NOAA Climate Data

- Annual Snowfall

Frozen Precipitation (Inches)				
SNOW	EMSN		EMSD	
Snowfall	Extreme Max Snowfall	Date of Occurrence	Extreme Max Snow Depth	Date of Occurrence
9.6	4.3+	Nov-07	4	Nov-08
29.7	6.3	Feb-08	11	Feb-09
50.0	11.0	Jan-21	18+	Feb-18
49.1	7.5	Mar-05	19	Mar-06
36.0	27.3	Jan-23	22	Jan-24

- Freeze-Thaw Cycles (DT32 - DX32)

Number of Days			
DX90	DX32	DT32	DT00
Max Temp >= 90F	Max Temp <= 32F	Min Temp <= 32F	Min Temp <= 0F
19	5	38	0
17	20	77	0
8	29	82	0
20	26	71	0
22	12	58	1

NOAA Climate Data (CSV)

- File converted to Excel for data manipulation

	# of Days					Extreme Maximums (in)			Total Annual (in)		Temperature (°F)		
	Rain >0.1"	Snow depth >1"	Snow-fall	Tmin ≤32°F	Tmax ≥32°F	Snowd epth	Snow-fall	Rain-fall	Rain-fall	Snow-fall			
DATE	DP01	DSND	DSNW	DT32	DX32	EMSD	EMSN	EMXP	PRCP	SNOW	TAVG	TMAX	TMIN
1960	115	31	9	99	19	15	12.5	3.56	46.43	41.6	54	61.5	46.5
1961	119	43	9	74	22	24	11.4	2.1	39.36	43.8	55	62.7	47.4
1962	109	17	6	79	22	3	2.9	2.33	37.17	15	53.4	61.5	45.3
1963	115	25	9	78	30	6	6	2.96	34.31	23	53.5	61.8	45.2
1964	113	28	10	75	13	13	11.5	1.29	33.02	36.5	54.5	62.7	46.4
1965	103	21	8	71	19	6	6.3	1.35	26.12	21.3	54.2	62	46.3
1966	116	28	9	77	19	8	6.7	5.54	39.91	30.4	55	63	47.1
1967	126	28	13	86	20	13	12.5	2.15	49.14	51.2	52.9	60.6	45.3
1968	109	21	5	87	26	5	5.5	3.99	43.6	17.8	54	62	46.1
1969	120	34	9	90	17	15	14	3.32	48.54	30	54.8	62.1	47.4

Summary of Environmental Data

- Climate/Weather (Annual Mean Values)
  - Temperature – 55.1˚F = 12.8˚C (Std. Dev. = 0.6˚C)
  - Snowfall – 27 inches (Std. Dev. = 14.3 inches)
  - Freeze-Thaw Cycles – 53.6 (Std. Dev. = 9.3)
- Surface Chloride Concentration from De-Icing
  - Taken from Historical Data – 4% mass of cementitious materials (Std. Dev. = 2%)

Questions?

Implementation Leads:

- Patricia Bush, *AASHTO Program Manager for Engineering,* pbush@aashto.org
- Raj Ailaney, *FHWA Senior Bridge Engineer,* Raj.Ailaney@dot.gov

Subject Matter Expert Team:

- Mike Bartholomew, *Jacobs,* mike.bartholomew@jacobs.com
- Anne-Marie Langlois, *COWI North America,* amln@cowi.com

Resource: AASHTO's R19A Product Page

- http://shrp2.transportation.org/Pages/ServiceLifeDesignforBridges.aspx