Designation: E2103/E2103M – 13

Standard Classification for Bridge Elements—UNIFORMAT II[1]

This standard is issued under the fixed designation E2103/E2103M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This standard establishes a classification of bridge elements within the UNIFORMAT II family of elemental classifications. It covers most highway bridges, railroad bridges, and pedestrian bridges.

1.2 UNIFORMAT II classifications have an elemental format similar to the original UNIFORMAT[2] building elemental classification. However, the title UNIFORMAT II differs from the original in that it now takes into consideration a wide range of constructed entities that collectively form the built environment.

1.3 Elements, as defined here and in other UNIFORMAT II Classifications, are major physical components that are common within constructed entities. Elements perform their given function(s), regardless of the design specification, construction method, or materials used.

1.4 This elemental classification serves as a consistent reference for analysis, evaluation, and monitoring during the feasibility, planning, and design stages when constructing bridges.

1.5 Using UNIFORMAT II elemental classifications ensures a consistency in the economic evaluation of construction projects over time and from project to project.

1.6 UNIFORMAT II classifications also enhance reporting at all stages of a constructed entity's life cycle—from feasibility and planning through the preparation of working documents, construction, maintenance, rehabilitation, and disposal.

1.7 This classification is unsuitable for process applications or for preparing trade estimates.

1.8 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

E631 Terminology of Building Constructions
E833 Terminology of Building Economics
E917 Practice for Measuring Life-Cycle Costs of Buildings and Building Systems
E964 Practice for Measuring Benefit-to-Cost and Savings-to-Investment Ratios for Buildings and Building Systems
E1057 Practice for Measuring Internal Rate of Return and Adjusted Internal Rate of Return for Investments in Buildings and Building Systems
E1074 Practice for Measuring Net Benefits and Net Savings for Investments in Buildings and Building Systems
E1121 Practice for Measuring Payback for Investments in Buildings and Building Systems
E1185 Guide for Selecting Economic Methods for Evaluating Investments in Buildings and Building Systems
E1369 Guide for Selecting Techniques for Treating Uncertainty and Risk in the Economic Evaluation of Buildings and Building Systems
E1699 Practice for Performing Value Analysis (VA) of Buildings and Building Systems and Other Constructed Projects
E1804 Practice for Performing and Reporting Cost Analysis During the Design Phase of a Project
E1946 Practice for Measuring Cost Risk of Buildings and Building Systems and Other Constructed Projects
E2013 Practice for Constructing FAST Diagrams and Performing Function Analysis During Value Analysis Study

[1] This classification is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.81 on Building Economics.

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[2] The original UNIFORMAT classification was developed jointly by the General Services Administration (GSA) and the American Institute of Architects (AIA).

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

E2506 Guide for Developing a Cost-Effective Risk Mitigation Plan for New and Existing Constructed Facilities
E2691 Practice for Job Productivity Measurement

2.2 *ASTM UNIFORMAT II Classification Standards Family:*[3]
E1557 Classification for Building Elements and Related Sitework—UNIFORMAT II
E2083 Classification for Building Construction Field Requirements, and Office Overhead & Profit
E2168 Classification for Allowance, Contingency, and Reserve Sums in Building Construction Estimating
E2514 Practice for Presentation Format of Elemental Cost Estimates, Summaries, and Analyses
E2516 Classification for Cost Estimate Classification System

2.3 *ASTM Adjuncts:*[4]
Discount Factor Tables Adjunct to Practices E917, E964, E1057, E1074, and E1121

3. Terminology

3.1 *Definitions*—For definitions of general terms related to building construction used in this classification, refer to Terminology E631, and for general terms related to building economics, refer to Terminology E833.

4. Significance and Use

4.1 This standard builds on the concepts and organizational framework first established in Classification E1557. This classification describes bridge elements that are major components of most highway, railroad, and pedestrian bridges. The elemental classification is the common thread linking activities and participants in a bridge project from initial planning through operations, maintenance, and disposal.

NOTE 1—As this classification refers solely to permanent, physical parts of any construction, two additional classifications, Classifications E2083 and E2168, need to be included when calculating construction cost. These standards provide for the inclusion of construction enabling, temporary, and risk mitigation cost figures. Procedures for reporting all these figures are described in Practices E1804 and E2514 and Classification E2516. While these three latter standards were primarily written for building construction, they are nonetheless appropriate and readily applied to other forms of construction as well.

4.2 *The Users of Bridge UNIFORMAT II Include:*
4.2.1 *Financial and Investment*—Typically owners, developers, bankers, lenders, accountants, and financial managers.
4.2.2 *Implementation*—Primarily project managers; facilities programmers; designers, including engineers; and project controls specialists, including cost planners, estimators, schedulers, specification writers, and risk analysts.
4.2.3 *Facilities Management*—Comprising property portfolio managers, operating staff, and maintenance staff.
4.2.4 *Others*—Public officials, manufacturers, educators, students, and other project stakeholders.

4.3 *Apply This Classification When Undertaking the Following Work on Bridges:*[5]
4.3.1 *Financing and Investing:*
4.3.1.1 Structuring costs on an elemental basis for economic evaluations (Guide E1185 and Practices E917, E964, E1057, E1074, E1121, and E1804) early in the design process helps reduce the cost of early financial analysis and can contribute to substantial design and operational savings before decisions have been made that limit options for potential savings.
4.3.2 *Implementing:*
4.3.2.1 *Cost Modeling, Cost Planning, Estimating and Controlling Project Time and Cost During Planning, Design, and Construction*—Use the bridge UNIFORMAT II classification to prepare budgets and to establish elemental cost plans before design begins. Project managers and project controls specialists use these cost plans against which to measure and control project cost, and quality, and to set design-to-cost targets.
4.3.2.2 Conducting Value Engineering Workshops—Conducting value engineering workshops (Practices E1699 and E2013). Use this classification as a checklist to ensure that alternatives for all elements of significant cost in the bridge project are analyzed in the creativity phase of the job plan. Also, use the elemental cost data to expedite the development of cost models for bridge systems.
4.3.2.3 *Developing Initial Project Master Schedules*—Since projects are essentially built element by element, UNIFORMAT II classifications are an appropriate basis for preparing construction schedules at the start of the design process. Project managers and project controls specialists use these time plans against which to measure and control project time (Practice E2691), and to set milestone target dates.
4.3.2.4 Performing Risk Analyses—Simulation (Guides E1369 and E2506) is one technique for developing probability distributions of bridge costs when evaluating the economic risk in undertaking a bridge project. Use individual elements and group elements in this classification for developing probability distributions of elemental costs. From these distributions, build up probability distributions of total costs to establish project contingencies (Practices E1946 and E2168) or to serve as inputs to an economic analysis.
4.3.2.5 *Structuring Preliminary Project Descriptions During the Conceptual Design Phase*—This classification facilitates the description of the scope of the project in a clear, concise, and logical sequence for presentation to the client; it provides the basis for the preparation of more detailed elemental estimates during the early concept and preliminary design phases, and it enhances communication between designers and clients by providing a clear statement of the designer's intent.
4.3.2.6 *Coding and Referencing Standard Details In Computer-Aided Design Systems*—This classification allows a designer, for example, to reference an assembly according to

[4] Available from ASTM International Headquarters. Order Adjunct No. ADJE091703. Original adjunct produced in 1984. Adjunct last revised in 1985.

[5] For a more comprehensive discussion of the uses of UNIFORMAT II, see Bowen, Charette, and Marshall, *UNIFORMAT II—A Recommended Classification for Building Elements and Related Sitework*, National Institute of Standards and Technology Special Publication 841, Gaithersburg, MD, 1992; and Charette and Marshall, *UNIFORMAT II Elemental Classification for Building Specifications, Cost Estimating, and Cost Analysis*, National Institute of Standards and Technology NISTIR 6389, Gaithersburg, MD, 1999.

this classification's element designations and build up a database of standard details. This is particularly appropriate to design modeling and building information modeling (BIM) applications.

4.3.3 *Managing Facilities:*

4.3.3.1 Recording and writing property condition assessment reports in a structured way, using UNIFORMAT II classifications, provides for a consistent, accessible, and searchable database of real property inventory.

4.3.4 *Other Activities:*

4.3.4.1 Structuring cost manuals and recording construction, operating, and maintenance costs in a computer database. Having a cost manual or computer database in an elemental format assists the preparation of an economic analysis early in the design stage and at a reasonable cost.

5. Basis of Classification

5.1 The framework in Fig. 1 shows the various constructed entities that collectively are used to create the built environment. Each entity is treated as a module. Appropriate modules used together will effectively describe any planned or built development. This standard classification describes exclusively the elements that make up one of those constructed entities, bridge structures, shown as the shaded block under the heading of Heavy (Civil) Entities.

5.1.1 This bridge classification is applicable to most types of highway, railroad, and pedestrian bridges crossing over highways, railroads, walkways, and waterways. The classification includes slab bridges; beam/girder bridges; truss bridges; true and tied-arch bridges; cable-stayed bridges; and suspension bridges. The classification does not include the following movable bridge types: draw bridges; lift bridges; and bascule bridges.

5.2 The classification is consistent with typical costing practices used at the conceptual design phase.

5.3 Each element has a significant impact on the cost, and it usually occurs frequently.

5.4 Each element performs a specific function.

5.5 Table 1 divides the classification of bridge elements into three hierarchical levels: Level 1—Major Group Elements, Level 2—Group Elements, and Level 3—Individual Elements. The major groups are listed in the normal chronological order of construction.

5.6 Sub-Classifications are named Sub-Elements and comprise as many hierarchical levels (Level 4 and below) as are deemed appropriate to the needs of that specific example. Appendix X1 provides an example Sub-Classification of bridge elements.

5.7 The decision as to where among the classification elements to include specific construction items will rely on professional judgment as to where professionals in current practice normally look for such items.

5.8 Only items that impact the choice and cost of the bridge elements are included. Other civil works in the transportation system are not included. Consequently, this classification does

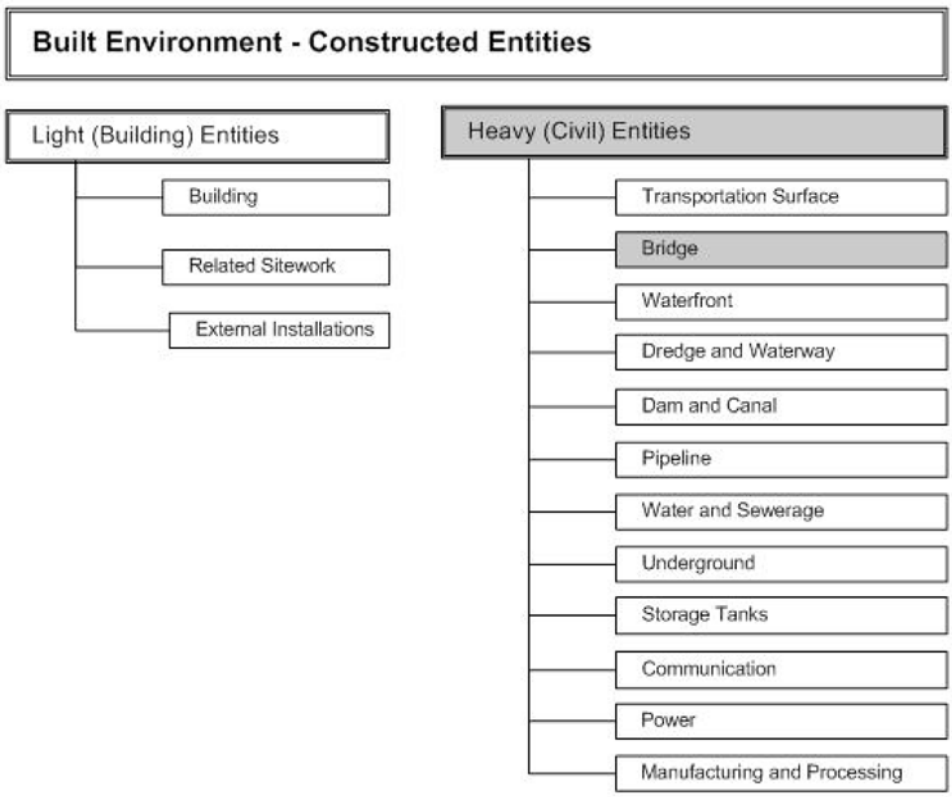


FIG. 1 List of Constructed Entities Suitable for Inclusion in the Family of UNIFORMAT II Elemental Classifications

TABLE 1 UNIFORMAT II Classification of Bridge Elements

Level 1 Major Group Elements	Level 2 Group Elements	Level 3 Individual Elements
Substructure	Piers	Foundations
		Walls
		Columns
		Cap Beams
	Towers	Foundations
		Walls
		Columns
		Cap Beams
	Abutments	Foundations
		Stems
		Wing Walls
	Other Supports	Thrust Blocks
		Anchorages
Superstructure	Short Span Assemblies	Flexural Members
		Diaphragms
		Bracings
		Bearings
	Long Span Assemblies	Ribs
		Cables
		Hangers
		Spandrels
		Ties
		Truss Members
		Segmental Box Girders
	Deck	Structural Surface
		Wearing Surface
Protection	Structure Protection	Slope Walls
		Expansion Joints
		Protective Coats
		Sacrificial Beams
		Drainage Systems
		Inspection and Maintenance Systems
	Traffic Protection	Barriers
		Protective Shields
		Traffic Controls
	Other Protection	Lighting
		Signage
		Sound Barrier Walls
		Air Pressure Barriers
		Enclosure
Sitework	Site Preparation	Clearing and Grubbing
		Demolition and Relocation
		Earthwork
		Hazardous Material Handling
		Environmental Restoration/Replacement
	Approach Construction	Approach Slabs
		Sleeper Slabs
		Earth Retention Systems

not include utilities—pipelines (water, natural gas, and petroleum) and transmission lines (electrical, communication, and video)—sharing the same right of way as the transportation system.

5.9 Elements, as used and defined in UNIFORMAT II, will ideally display the following additional attributes:

5.9.1 Capable of being defined precisely;

5.9.2 Self explanatory;

5.9.3 Separable at all stages of development;

5.9.4 Quantifiable at all stages of development;

5.9.5 Capable of reconciliation with other elemental classifications;

5.9.6 Allow comparisons, project to project, in a meaningful way;

5.9.7 Is a functional component of the constructed entity.

5.10 Sitework elements are provided for exclusive use in support of the construction of bridges, not to classify elements of major civil construction works. Sitework elements presented in Table 1 are designed to provide sufficient detail to planners so they will not need to resort to other elemental classifications when working on a bridge project.

6. Description of Project Elements

6.1 *Elements and Functions*—Table 2 provides, for each Level 3 Individual Element, the name, functions, description, inclusions, exclusions, and unit of measure. The functions are classified as Primary, Secondary, and Tertiary. All three levels of functions may be served. However, one or two functions may be the driving force behind the existence of the element, and they are classified as Primary functions.

TABLE 2 Description of UNIFORMAT II Bridge Elements

SUBSTRUCTURE	
Piers	
	Foundations
Primary Function	Transfer load, Minimize settlement
Secondary Function	Minimize maintenance
Tertiary Function	Facilitate construction
Description	Foundations are structures that transfer the load of the bridge substructures to the ground. They may be spread footings, piles, or drilled shafts. The type depends upon the soil conditions.
Includes	Excavation and backfilling
Excludes	
Unit of Measure	m^3 [yd^3] or m [ft]
	Walls
Primary Function	Distribute load, Protect foundation
Secondary Function	Enhance appearance
Tertiary Function	Expedite construction
Description	Walls are structures that support the columns; in addition to transferring the load from the columns to the foundation, they protect the pier against impacts from vehicles, vessels, and debris.
Includes	
Excludes	
Unit of Measure	m^3 [yd^3] or kg [lb]
	Columns
Primary Function	Distribute load
Secondary Function	Enhance appearance
Tertiary Function	Expedite construction
Description	Columns are structures that support the cap beam and transfer the load from the cap beam to the wall below.
Includes	
Excludes	
Unit of Measure	m^3 [yd^3] or kg [lb]
	Cap Beams
Primary Function	Distribute load
Secondary Function	Enhance appearance
Tertiary Function	Expedite construction
Description	Cap beams are structures that receive and transfer beam loads from the deck to the bridge columns.
Includes	Bridge seat
Excludes	Bearings and anchor bolts (see Bearings, Flexural Members)
Unit of Measure	m^3 [yd^3] or kg [lb]
SUBSTRUCTURE	
Towers	
	Foundations
Primary Function	Transfer load, Minimize settlement
Secondary Function	Minimize maintenance
Tertiary Function	Facilitate construction
Description	Foundations are structures that transfer the load of the bridge substructures to the ground. They may be spread footings, piles, or drilled shafts. The type depends upon the soil conditions.
Includes	Excavation and backfilling
Excludes	
Unit of Measure	m^3 [yd^3] or m [ft]
	Walls
Primary Function	Distribute load, Protect foundation
Secondary Function	Enhance appearance
Tertiary Function	Expedite construction
Description	Walls are structures that support the columns; in addition to transferring the load from the columns to the foundation, they protect the pier against impacts from vehicles, vessels, and debris.
Includes	
Excludes	
Unit of Measure	m^3 [yd^3] or kg [lb]
	Columns
Primary Function	Distribute load
Secondary Function	Enhance appearance
Tertiary Function	Expedite construction
Description	Columns are structures that support the cap beam and transfer the load from the cap beam to the wall below.
Includes	
Excludes	
Unit of Measure	m^3 [yd^3] or kg [lb]
	Cap Beams
Primary Function	Distribute load
Secondary Function	Enhance appearance
Tertiary Function	Expedite construction
Description	Cap beams are structures that receive and transfer beam loads from the deck to the bridge columns.
Includes	Bridge seat
Excludes	Bearings and anchor bolts (see Bearings, Flexural Members)
Unit of Measure	m^3 [yd^3] or kg [lb]
SUBSTRUCTURE	
Abutments	
	Foundations
Primary Function	Transfer load, Minimize settlement
Secondary Function	Minimize maintenance
Tertiary Function	Facilitate construction
Description	Foundations are structures that transfer the load of the bridge substructures to the ground. They may be spread footings, piles, or drilled shafts. The type depends upon the soil conditions.
Includes	Excavation and backfilling
Excludes	
Unit of Measure	m^3 [yd^3] or m [ft]
	Stems
Primary Function	Distribute load, Retain earth
Secondary Function	Minimize erosion
Tertiary Function	Minimize settlement
Description	Stems are usually supported on piles; they partially or fully retain earth behind, support the ends of the first and last spans of the bridge, and support the approach slab.
Includes	Bridge seat, reinforcing, concrete, and finishing
Excludes	Slope wall, foundation, and anchor bolts and bearings (see Foundations, Barriers, Slope Wall, Bearings)
Unit of Measure	m^3 [yd^3] or kg [lb]
	Wing Walls
Primary Function	Retain earth
Secondary Function	Minimize erosion
Tertiary Function	Enhance appearance
Description	Wing walls (parallel, perpendicular, or angled) are structures connected to the abutment and supported by piles that retain the embankment below the approach road.
Includes	Reinforcing, concrete, and finishing
Excludes	Approach slab and parapet (see Approach Slab, Barriers)
Unit of Measure	m^3 [yd^3]
SUBSTRUCTURE	
Other Supports	
	Thrust Blocks
Primary Function	Transfer load, Transfer thrust
Secondary Function	Minimizes movement
Tertiary Function	
Description	Thrust blocks are a special substructure of a true arch bridge that receive loads from the ribs and transfer loads to the foundation.
Includes	Structure excavation, reinforcing, concrete, and finishing
Excludes	Furnishing and installation of anchor bolts, bearing plates, utility relocation (see Demolition and Relocation, Flexural Members)
Unit of Measure	m^3 [yd^3]
	Anchorages
Primary Function	Secure cable, Transfer load
Secondary Function	Maintain even distribution
Tertiary Function	
Description	Anchorages are a special substructure to which the weight of the deck and supporting superstructure is secured via cables and steel eye bars imbedded in solid rock or massive concrete blocks.
Includes	Structure excavation, reinforcing, concrete, finishing, and cable support (Steel Eye Bar)
Excludes	
Unit of Measure	m^3 [yd^3]

TABLE 2 *Continued*

SUPERSTRUCTURE	
Short Span Assemblies	
	Flexural Members
Primary Function	Support Load
Secondary Function	Minimize deflection
Tertiary Function	Increase redundancy
Description	Flexural members are commonly known as beams and girders that support the bridge deck. When the depth of the girder is shallow, it is referred to as a beam.
Includes	Fabrication and installation of beams and girders
Excludes	Diaphragms, bracings, bearings (see Diaphragms, Bracings, Bearings)
Unit of Measure	kg [lb] or m [ft]
	Diaphragms
Primary Function	Stabilize girder, Brace girders
Secondary Function	Facilitate deck reconstruction
Tertiary Function	
Description	Diaphragms are braces for shallow-depth beams.
Includes	
Excludes	
Unit of Measure	kg [lb] or m^3 [yd^3]
	Bracings
Primary Function	Stabilize girders
Secondary Function	Facilitate deck reconstruction
Tertiary Function	
Description	Bracings are steel angles used to brace deep-depth girders.
Includes	Fabrication and erection of structural steel angles
Excludes	
Unit of Measure	kg [lb]
	Bearings
Primary Function	Transfer load
Secondary Function	Facilitate expansion and contraction
Tertiary Function	Minimize maintenance
Description	Bearings are mechanical systems that transfer vertical and longitudinal forces; expansion bearings allow rotational and longitudinal movement, whereas fixed bearings allow only rotational movement.
Includes	Fabrication and erection of bearings and anchor bolts
Excludes	Bridge seat (see Cap Beams, Stem Abutments)
Unit of Measure	EACH
SUPERSTRUCTURE	
Long Span Assemblies	
	Ribs
Primary Function	Transfer load
Secondary Function	Facilitate inspection
Tertiary Function	Enhance appearance
Description	Ribs are rectangular-, square-, or circular-shaped parts of the superstructure for arch bridges; they receive loads from hangers and spandrels and transfer them to the foundation.
Includes	
Excludes	Bracings, bearings (see Bracings, Bearings)
Unit of Measure	kg [lb], or m^3 [yd^3], or m [ft]
	Cables
Primary Function	Transfer load
Secondary Function	Enhance appearance
Tertiary Function	
Description	Cables, made of steel wires bound together and draped over towers to anchors at each cable end, receive through hangars the load from the deck.
Includes	Fabrication and installation of cables, cable support
Excludes	Anchorage (see Anchorage)
Unit of Measure	m [ft]
	Hangers
Primary Function	Transfer load
Secondary Function	Increase vertical clearance
Tertiary Function	Enhance appearance
Description	Hangers are rods or strands that connect the deck to the ribs (arch bridges) or the main cable (cable-stayed or suspension bridges); they receive loads from the deck and transfer loads to the ribs or main cable in tension.
Includes	Splices (rod), strand assembly, protection
Excludes	End connections (see Flexural Members and Ribs)
Unit of Measure	m [ft]

TABLE 2 *Continued*

	Spandrels
Primary Function	Transfer load
Secondary Function	Increase reliability
Tertiary Function	Enhance appearance
Description	Spandrels are concrete or steel members that connect the deck to the ribs (arch bridges); they receive loads from the deck and transfer loads to the ribs in compression. They are below the deck and above the rib.
Includes	Concrete or steel members, protection
Excludes	End connections (see Flexural Members and Ribs)
Unit of Measure	m [ft]
	Ties
Primary Function	Eliminate thrust
Secondary Function	
Tertiary Function	
Description	A tie is a horizontal tension member that connects the two ends of the compression ribs of an arch bridge and balances the horizontal thrust.
Includes	Fabrication and erection of structural steel, stiffeners, splices, and other connections
Excludes	Hangers, bearings (see Bearings, Hangers and Spandrels)
Unit of Measure	kg [lb]
	Truss Members
Primary Function	Support load, Reduce weight
Secondary Function	Minimize deflection
Tertiary Function	
Description	Truss members, connected at nodes by plates, are two-dimensional structures that support the superstructure.
Includes	Splices and other connections
Excludes	Bracings, bearings (see Bracings, Bearings)
Unit of Measure	kg [lb], or m^3 [yd^3], or m [ft]
	Segmental Box Girders
Primary Function	Support Load
Secondary Function	Minimize deflection
Tertiary Function	Facilitate Construction
Description	Segmental box girders are concrete box sections with or without overhanging flanges. The segments are precast sections which are post tensioned in the field.
Includes	Post tensioning
Excludes	Bracings, bearings (see Bracings, Bearings)
Unit of Measure	m [ft]
SUPERSTRUCTURE	
Deck	
	Structural Surface
Primary Function	Transfer load
Secondary Function	Minimize maintenance
Tertiary Function	Facilitate future expansion
Description	The structural surface supports the wearing surface and traffic.
Includes	Reinforcing, concrete, and finishing
Excludes	Expansion joint assembly, parapet, barriers (see Expansion Joints, Barriers, Drainage Systems)
Unit of Measure	m^3 [yd^3] or EACH
	Wearing Surface
Primary Function	Protect structure, Guide traffic
Secondary Function	Comfort riders
Tertiary Function	Reduce maintenance
Description	The wearing surface is the part of the road or rail system that comes into contact with the vehicle or train car wheels.
Includes	Concrete or asphalt overlay or rails, striping, marking,
Excludes	
Unit of Measure	m^2 [yd^2]
PROTECTION	
Structure Protection	
	Slope Walls
Primary Function	Protect abutment
Secondary Function	Prevent erosion
Tertiary Function	Enhance appearance
Description	Slope walls, made of stone, concrete, gravel, or gravel with asphalt mix, support the sloped surface and protect the bridge abutment.
Includes	Reinforcing, concrete, and finishing
Excludes	Excavation and backfill (see Earthwork)

TABLE 2 *Continued*

Unit of Measure	m^2 [yd^2]
	Expansion Joints
Primary Function	Facilitate expansion and contraction
Secondary Function	Maintain smooth surface
Tertiary Function	Facilitate replacement
Description	Expansion joints allow expansion and contraction of the slab while keeping the substructure stationary.
Includes	Furnishing and installation of expansion joint support and expansion joint
Excludes	
Unit of Measure	m [ft]
	Protective Coats
Primary Function	Protect structure
Secondary Function	Minimize maintenance
Tertiary Function	
Description	Protective coats are paints, sealants, or preservatives that are applied to concrete surfaces of the bridge.
Includes	Minor repair work, cleaning surface, and coating
Excludes	Major repair work to other bridge elements
Unit of Measure	m^2 [yd^2]
	Sacrificial Beams
Primary Function	Protect girders
Secondary Function	Reduce maintenance
Tertiary Function	
Description	Sacrificial beams have a lower clearance than the main beams to ensure that excessive-height vehicles will hit the sacrificial beam before impacting the main beams.
Includes	Fabrication and erection of structural steel, stiffeners, splices, and other connections
Excludes	Bracings, bearings (see Bracings, Bearings)
Unit of Measure	kg [lb]
	Drainage Systems
Primary Function	Minimize erosion
Secondary Function	Protect traffic
Tertiary Function	Protect structure
Description	Drainage systems are scuppers to drain the bridge deck, downspouts to carry off the water from the scuppers, and buried drains behind abutments and adjacent to sleeper slabs.
Includes	Fabrication and installation of scuppers, drain tiles, drain pipes, and related earthwork
Excludes	Structural surface (see Structural Surface)
Unit of Measure	EACH or m [ft]
	Inspection and Maintenance Systems
Primary Function	Facilitate inspection
Secondary Function	Facilitate maintenance
Tertiary Function	
Description	These systems include platforms, railings, stairways, and hoist ways to facilitate inspection and maintenance.
Includes	Handrails or other type of barriers
Excludes	
Unit of Measure	m^2 [yd^2]
PROTECTION	
Traffic Protection	
	Barriers
Primary Function	Separate traffic, Protect occupants
Secondary Function	Protect structure
Tertiary Function	Minimize maintenance
Description	Barriers are structures designed to: withstand forces due to crashes; separate the opposing traffic; and protect bridge structures adjacent to live traffic.
Includes	Noise wall support, or light pole support
Excludes	
Unit of Measure	m^3 [yd^3]
	Protective Shields
Primary Function	Protect traffic (below)
Secondary Function	
Tertiary Function	
Description	Protective shields are barriers below the bridge deck to protect traffic below from falling objects.
Includes	Membranes and supports designed to catch falling objects
Excludes	
Unit of Measure	m^2 [yd^2]
	Traffic Controls

TABLE 2 *Continued*

Primary Function	Manage Traffic
Secondary Function	
Tertiary Function	
Description	Traffic controls are an assembly of signals, supports, and conduits.
Includes	Power source and related items
Excludes	
Unit of Measure	EACH
PROTECTION	
Other Protection	
	Lighting
Primary Function	Protect traffic
Secondary Function	Guide traffic
Tertiary Function	Discourage vandalism
Description	Lighting is illumination from fixtures that provide vehicle traffic direction, ship navigation direction, task lighting, and vandalism discouragement.
Includes	Fabrication and installation of mast, lights, base plates, and power
Excludes	Base support (see Barriers)
Unit of Measure	EACH
	Signage
Primary Function	Guide traffic
Secondary Function	Simplify or consolidate message
Tertiary Function	
Description	Signage is the provision of information through electronic or printed message boards.
Includes	Fabrication and installation of sign and support, and power
Excludes	
Unit of Measure	EACH
	Sound Barrier Walls
Primary Function	Abate traffic noise
Secondary Function	Create visual barrier
Tertiary Function	Enhance appearance
Description	A sound barrier wall is a structure to mask traffic noise from the surrounding neighborhood.
Includes	Wall panel, support, and connection to barrier
Excludes	Base (see Barriers)
Unit of Measure	m^2 [yd^2]
	Air Pressure Barriers
Primary Function	Protect people
Secondary Function	Protect property
Tertiary Function	
Description	Air pressure barriers are structures to mitigate the impact of significant air pressure differentials created by the passing of high speed transportation vehicles.
Includes	Barriers mounted on bridges to mitigate the impact of air pressure differentials.
Excludes	Base (see Barriers)
Unit of Measure	m^2 [yd^2]
	Enclosure
Primary Function	Protect pedestrians and protect traffic
Secondary Function	Facilitate maintenance
Tertiary Function	Enhance appearance
Description	An enclosure is a vertical envelope with roof to protect pedestrians and traffic crossing over a bridge.
Includes	Structural and architectural members to contain pedestrians and traffic with expansion joints at the ends
Excludes	
Unit of Measure	m^2 [yd^2]
SITEWORK	
Site Preparation	
	Clearing and Grubbing
Primary Function	Eliminate obstacles
Secondary Function	Create staging area
Tertiary Function	Provide temporary drainage
Description	Clearing is the removal from the construction site of trees and abandoned utilities, and the grading and leveling of the site. Grubbing is the removal of stumps and tree roots.
Includes	Tree removal, abandoned utilities, minor earthwork
Excludes	Major earth work and major utility removal (see Demolition and Relocation, Earthwork)
Unit of Measure	EACH or Hectare (Acre)
	Demolition and Relocation

TABLE 2 *Continued*

Primary Function	Eliminate obstacles
Secondary Function	Protect structures
Tertiary Function	Protect environment
Description	Demolition is the complete or partial (for example, deck or superstructure) removal of an existing bridge, carried out on the whole bridge at once or by removing a portion of the deck or superstructure in stages to maintain traffic; relocation is the removal and reinstallation of utilities.
Includes	Removal of bridge elements and disposal, relocation of utilities such as storm sewer
Excludes	
Unit of Measure	EACH
	Earthwork
Primary Function	Prepare grade
Secondary Function	Protect structures
Tertiary Function	Protect environment
Description	Earthwork is excavation, placement, and compaction of material to raise the bridge profile (material is hauled in and compacted) and to lower the bridge profile (material is excavated and hauled away).
Includes	Shrinkage factor for embankment, hauling material to or from the site
Excludes	Removal of hazardous material, structure excavation and back fill (see Demolition and Relocation, Foundations)
Unit of Measure	m^3 [yd^3]
	Hazardous Material Handling
Primary Function	Protect environment
Secondary Function	Dispose hazardous waste
Tertiary Function	Protect workers
Description	Hazardous material handling is the discovery, excavation, recovery, and disposal of hazardous materials.
Includes	Excavation and disposal of material
Excludes	General excavation (see Demolition and Relocation, Earthwork)
Unit of Measure	m^3 [yd^3]
	Environmental Restoration/Replacement
Primary Function	Protect environment
Secondary Function	
Tertiary Function	
Description	Environmental restoration/replacement is the activity of restoring or replacing elements of the environment disturbed by construction.
Includes	Restoration or replacement of wetlands
Excludes	
Unit of Measure	Hectare (Acre)
SITEWORK	
Approach Construction	
	Approach Slabs
Primary Function	Provide transition
Secondary Function	Minimize settlement effects
Tertiary Function	Facilitate construction
Description	An approach slab, supported by the bridge abutment on one side and a sleeper slab or soil on the other, provides a smooth transition between the roadway and the bridge, and spans any settlement gap between the abutment and the roadway.
Includes	Granular fill, drain tiles, concrete, reinforcing, and finishing
Excludes	Barrier and wing wall (see Barriers, Wing Walls)
Unit of Measure	m^2 [yd^2]
	Sleeper Slabs
Primary Function	Protect substructure
Secondary Function	Exclude water
Tertiary Function	Minimize maintenance
Description	Sleeper slabs are rectangular concrete foundations that support approach slabs.
Includes	Excavation and backfill, concrete, reinforcing and finishing
Excludes	Approach slab (see Approach Slabs)
Unit of Measure	m^3 [yd^3]
	Earth Retention Systems
Primary Function	Retain embankment
Secondary Function	Enhance appearance
Tertiary Function	Facilitate construction
Description	Earth retention systems are designed to support embankments when the grades are not uniform.
Includes	Its foundation and wall
Excludes	Excavation and backfill (see Earthwork)
Unit of Measure	m^3 [yd^3] or m^2 [yd^2]

6.2 *Description*—The element descriptions help you understand the purpose and application of the element.

6.3 *Includes*—The purpose of the element inclusions is to list features that make up the element.

6.4 *Excludes*—The purpose of the element exclusions is to list features that are not included in the element but which are included elsewhere in this classification.

NOTE 2—Because this classification refers solely to permanent physical parts of bridge constructions, references to construction enabling (cranes and formwork), temporary construction (cofferdams and traffic detours), and risk mitigation (allowances and contingencies) cost figures are omitted from the element exclusions.

6.5 *Unit of Measure*—The purpose of the unit of measure is to provide a means for calculating the magnitude, or size, of each element in any bridge description; units of measure are important to all users of elemental classifications. Units of measure are of prime importance in the elemental cost management process. Both SI and inch-pound units are reported. SI units are reported first followed by inch-pound units within brackets. Table 2 uses the following unit of measure abbreviations: linear metres (m) and linear feet (ft); square metres (m^2) and square feet (ft^2); cubic metres (m^3) and cubic yards (yd^3); and kilograms (kg) and pounds (lb).

7. Application

7.1 Appendix X2 uses a case study of the Gateway Arch Bridge construction project to demonstrate how to use the Classification E2103 and the example Sub-Classification to analyze and manage bridge design and construction costs. The Gateway Arch Bridge was part of the reconstruction of Interstate 94 for the Super Bowl XL game held in 2006.[6]

8. Keywords

8.1 bridge assemblies; bridge cost estimation; bridge cost planning; bridge elemental format; bridge elements; bridge functional elements; bridge systems classification; construction; design economics; economic analysis; economic evaluation; elemental bridge classification; elemental/systems classification; life-cycle costing; master schedules; outline specifications; preliminary project description; risk analysis; sitework; standard classifications of bridge systems; UNIFORMAT II; value engineering

[6] For a comprehensive discussion of the uses of ASTM Building Economics Standards to design and construction applications in general and to the Gateway Arch Bridge in particular, see Kasi and Chapman, *Benefits of Using ASTM Building Economics Standards for the Design, Construction, and Operation of Constructed Facilities*, National Institute of Standards and Technology, Special Publication 1098, Gaithersburg, MD, 2012.

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLE SUB-CLASSIFICATION OF BRIDGE ELEMENTS

X1.1 This appendix presents an example Sub-Classification of bridge elements. The Sub-Classification expands the Classification E2103 Level 3 Individual Elements into their constituent parts. These constituent parts include a Level 4 for all Individual Elements and, where necessary, a Level 5.

X1.2 The example Sub-Classification is presented in Table X1.1. Table X1.1 is laid out in a five-column format. The first column lists the Level 1 Major Group Elements. The second column lists the Level 2 Group Elements associated with each Level 1 Major Group Element. The third column lists the Level 3 Individual Elements associated with each Level 2 Group Element. The fourth column lists the Level 4 Sub-Elements associated with each Level 3 Individual Element. The fifth column lists any Level 5 Sub-Elements associated with a Level 4 Sub-Element. Where appropriate, the Level 5 Sub-Elements are listed in the normal chronological order of construction.

X1.3 Alphanumeric designators are included for all Level 1 Major Group Elements, Level 2 Group Elements, Level 3 Individual Elements, Level 4 Sub-Elements, and Level 5 Sub-Elements. It is anticipated that the alphanumeric designators will be useful in structuring cost manuals and in recording construction, operating, and maintenance costs in computer databases.

X1.4 Alphanumeric designators for the Classification E2103 presented in this appendix use a format similar to that employed in Classification E1557. Specifically, the format for the alphanumeric designators is as follows: Level 1, Major Group Elements, use a single capital letter; Level 2, Group Elements, use a two-digit number preceded by the Level 1 letter; and Level 3, Individual Elements, use a two-digit number preceded by the Level 2 character string.

X1.5 The alphanumeric designators for the example Sub-Classification uses the Level 3 Individual Element character string as their reference point. For example, the first Level 4 Sub-Element associated with the A1010 Foundations Level 3 Individual Element is A101010 Spread Footings. Additional Level 4 Sub-Elements associated with A1010 Foundations are: A101020 Piles and A101030 Drilled Shafts. For Level 5 Sub-Elements, the alphanumeric designator uses the Level 4 Sub-Element character string as their reference point. For example, the first Level 5 Sub-Element associated with the A101010 Spread Footings Level 4 Sub-Element is A10101010 Excavation. Additional Level 5 Sub-Elements associated with A101010 Spread Footings are: A10101020 Reinforcement; A10101030 Placement; and A10101040 Backfilling.

TABLE X1.1 Example Sub-Classification of Bridge Elements

Level 1 Major Group Elements	Level 2 Group Elements		Level 3 Individual Elements		Level 4 Sub-Elements		Level 5 Sub-Elements	
A Substructure	A10	Piers	A1010	Foundation	A101010	Spread Footings	A10101010	Excavation
							A10101020	Reinforcement
							A10101030	Placement
							A10101040	Backfilling
					A101020	Piles	A10102010	Test Piles
							A10102020	Piles
							A10102030	Pile Cap
					A101030	Drilled Shafts	A10103010	Permanent Casing
							A10103020	Rock Socket
							A10103030	Bell
							A10103040	Reinforcement
							A10103050	Placement
							A10103060	Cap
			A1020	Walls	A102010	Cast-in-Place Concrete	A10201010	Reinforcement
							A10201020	Placement
							A10201030	Finishing
							A10201040	Coating
					A102020	Precast Concrete	A10202010	Fabrication
							A10202020	Erection
			A1030	Columns	A103010	Cast-in-Place Concrete	A10301010	Reinforcement
							A10301020	Placement
							A10301030	Finishing
					A103020	Precast Concrete	A10302010	Fabrication
							A10302020	Erection
					A103030	Steel	A10303010	Fabrication
							A10303020	Erection
					A103040	Timber	A10304010	Fabrication
							A10304020	Erection
			A1040	Cap Beams	A104010	Cast-in-Place Concrete	A10401010	Reinforcement
							A10401020	Placement
							A10401030	Finishing
					A104020	Precast Concrete	A10402010	Fabrication
							A10402020	Erection
					A104030	Steel	A10403010	Fabrication
							A10403020	Erection
					A104040	Timber	A10404010	Fabrication
							A10404020	Erection
	A20	Towers	A2010	Foundations	A201010	Spread Footings	A20101010	Excavation
							A20101020	Reinforcement
							A20101030	Placement
							A20101040	Backfilling
					A201020	Pile Foundations	A20102010	Test Piles
							A20102020	Piles
							A20102030	Pile Cap
					A201030	Drilled Shafts	A20103010	Permanent Casing
							A20103020	Rock Socket
							A20103030	Bell
							A20103040	Reinforcement
							A20103050	Placement
							A20103060	Cap
			A2020	Walls	A202010	Cast-in-Place Concrete	A20201010	Reinforcement
							A20201020	Placement
							A20201030	Finishing
							A20201040	Coating
					A202020	Precast Concrete	A20202010	Fabrication
							A20202020	Erection
			A2030	Columns	A203010	Cast-in-Place Concrete	A20301010	Reinforcement
							A20301020	Placement
							A20301030	Finishing
					A203020	Precast Concrete	A20302010	Fabrication
							A20302020	Erection
					A203030	Steel	A20303010	Fabrication
							A20303020	Erection
					A203040	Timber	A20304010	Fabrication
							A20304020	Erection
			A2040	Cap Beams	A204010	Cast-in-Place Concrete	A20401010	Reinforcement
							A20401020	Placement
							A20401030	Finishing
					A204020	Precast Concrete	A20402010	Fabrication
							A20402020	Erection
					A204030	Steel	A20403010	Fabrication
							A20403020	Erection
					A204040	Timber	A20404010	Fabrication

TABLE X1.1 *Continued*

Level 1 Major Group Elements	Level 2 Group Elements		Level 3 Individual Elements		Level 4 Sub-Elements		Level 5 Sub-Elements	
							A20404020	Erection
	A30	Abutments	A3010	Foundations	A301010	Spread Footings	A30101010	Excavation
							A30101020	Reinforcement
							A30101030	Placement
							A30101040	Backfilling
					A301020	Piles	A30102010	Test Piles
							A30102020	Piles
							A30102030	Pile Cap
					A301030	Drilled Shafts	A30103010	Permanent Casing
							A30103020	Rock Socket
							A30103030	Bell
							A30103040	Reinforcement
							A30103050	Placement
							A30103060	Cap
			A3020	Stems	A302010	Cast-in-Place Concrete	A30201010	Reinforcement
							A30201020	Placement
							A30201030	Finishing
					A302020	Precast Concrete	A30202010	Fabrication
							A30202020	Erection
			A3030	Wing Walls	A303010	Cast-in-Place Concrete	A30301010	Reinforcement
							A30301020	Placement
							A30301030	Finishing
					A303020	Precast Concrete	A30302010	Fabrication
							A30302020	Erection
	A40	Other Supports	A4010	Thrust Blocks	A401010	Cap	A40101010	Reinforcement
							A40101020	Placement
							A40101030	Finishing
					A401020	Foundation	A40102010	Spread Footings
							A40102020	Piles
							A40102030	Drilled Shafts
			A4020	Anchorages	A402010	Prestressed	A40201010	Spray Saddle
							A40201020	Anchor
					A402020	Cast-in-Place Concrete	A40202010	Reinforcement
							A40202020	Placement
					A402030	Foundations	A40203010	Spread Footings
							A40203020	Piles
							A40203030	Drilled Shafts
B Superstructure	B10	Short Span Assemblies	B1010	Flexural Members	B101010	Cast-in-Place Concrete	B10101010	Reinforcement
							B10101020	Placement
							B10101030	Finishing
					B101020	Precast Concrete	B10102010	Fabrication
							B10102020	Erection
					B101030	Steel	B10103010	Fabrication
							B10103020	Erection
					B101040	Timber	B10104010	Fabrication
							B10104020	Erection
			B1020	Diaphragms	B102010	Cast-in-Place Concrete	B10201010	Reinforcement
							B10201020	Placement
					B102020	Precast Concrete	B10202010	Fabrication
							B10202020	Erection
					B102030	Steel	B10203010	Fabrication
							B10203020	Erection
					B102040	Timber		
			B1030	Bracings	B103010	Steel	B10301010	Fabrication
							B10301020	Erection
					B103020	Timber		
			B1040	Bearings	B104010	Elastomeric		
					B104020	Sliding		
					B104030	Roller		
	B20	Long Span Assemblies	B2010	Ribs	B201010	Cast-in-Place Concrete	B20101010	Reinforcement
							B20101020	Placement
					B201020	Precast Concrete	B20102010	Fabrication
							B20102020	Erection
					B201030	Steel	B20103010	Fabrication
							B20103020	Erection
			B2020	Cables	B202010	Wires		
					B202020	Sockets		
					B202030	Saddles		
					B202040	Housings		
					B202050	Strands		
					B202060	Anchor Sockets		
			B2030	Hangers	B203010	Top Anchor Socket		

TABLE X1.1 *Continued*

Level 1 Major Group Elements	Level 2 Group Elements		Level 3 Individual Elements		Level 4 Sub-Elements		Level 5 Sub-Elements	
					B203020	Strand		
					B203030	Rod		
					B203040	Boot		
					B203050	Spacer		
					B203060	Bottom Anchor Socket		
			B2040	Spandrels	B204010	Cast-in-Place Concrete	B20401010	Reinforcement
							B20401020	Placement
							B20401030	Finishing
					B204020	Precast Concrete	B20402010	Fabrication
							B20402020	Erection
					B204030	Steel	B20403010	Fabrication
							B20403020	Erection
			B2050	Ties	B205010	Cast-in-Place Concrete	B20501010	Reinforcement
							B20501020	Placement
					B205020	Precast Concrete	B20502010	Fabrication
							B20502020	Erection
					B205030	Steel	B20503010	Fabrication
							B20503020	Erection
					B205040	Splices		
					B205050	Connections		
			B2060	Truss Members	B206010	Members		
					B206020	Splices		
					B206030	Connections		
			B2070	Segmental Box Girders	B207010	Main Members		
					B207020	Placement	B20702010	Erection
							B20702020	Permanent Post Tensioning
							B20702030	Closure Piece Placement
	B30	Deck	B3010	Structural Surface	B301010	Cast-in-Place Concrete	B30101010	Reinforcement
							B30101020	Placement
							B30101030	Finishing
					B301020	Precast Concrete	B30102010	Fabrication
							B30102020	Erection
					B301030	Steel	B30103010	Metal Deck
							B30103020	Connections
					B301040	Timber	B30104010	Plank
							B30104020	Connections
			B3020	Wearing Surface	B302010	Cast-in-Place Concrete	B30201010	Placement
							B30201020	Finishing
					B302020	Asphalt	B30202010	Placement
							B30202020	Finishing
					B302030	Rails		
C Protection	C10	Structure Protection	C1010	Slope Walls	C101010	Cast-in-Place Concrete	C10101010	Reinforcement
							C10101020	Placement
							C10101030	Finishing
					C101020	Asphalt	C10102010	Gravel
							C10102020	Placement
					C101030	Stone		
			C1020	Expansion Joints	C102010	Strip-Seal		
					C102020	Modular		
					C102030	Finger Plate		
			C1030	Protective Coats	C103010	Preparation		
					C103020	Application		
			C1040	Sacrificial Beams	C104010	Fabrication		
					C104020	Erection		
			C1050	Drainage Systems	C105010	Scuppers		
					C105020	Drain Pipes		
					C105030	Buried Drains	C10503010	Pipe
							C10503020	Head Wall
							C10503030	End Walls
			C1060	Inspection and Maintenance Systems	C106010	Hangers		
					C106020	Beams		
					C106030	Platform		
					C106040	Railing		
					C106050	Connections		
	C20	Traffic Protection	C2010	Barriers	C201010	Parapet		
					C201020	Railing		
					C201030	Glare Screen		
					C201040	Median		
					C201050	Curb		
					C201060	Guardrail		

TABLE X1.1 *Continued*

Level 1 Major Group Elements	Level 2 Group Elements		Level 3 Individual Elements		Level 4 Sub-Elements		Level 5 Sub-Elements
					C201070	Screen	
			C2020	Protective Shields	C202010	Fabrication	
					C202020	Erection	
			C2030	Traffic Controls	C203010	Signals	
					C203020	Arms	
					C203030	Mast	
					C203040	Base Plate	
					C203050	Conduits	
	C30	Other Protection	C3010	Lighting	C301010	Lights	
					C301020	Arms	
					C301030	Mast	
					C301040	Base Plate	
					C301050	Conduits	
			C3020	Signage	C302010	Sign Board	
					C302020	Support	
					C302030	Lights	
					C302040	Conduits	
			C3030	Sound Barrier Walls	C303010	Panels	
					C303020	Support	
					C303030	Connections	
			C3040	Air Pressure Barriers	C304010	Panels	
					C304020	Support	
					C304030	Connections	
			C3050	Enclosure	C305010	Vertical Envelope	
					C305020	Roof	
D Sitework	D10	Site Preparation	D1010	Clearing and Grubbing	D101010	Clearing	
					D101020	Grubbing	
			D1020	Demolition and Relocation	D102010	Structures	
					D102020	Utilities	
					D102030	Trees	
			D1030	Earthwork	D103010	Cut	
					D103020	Fill	
			D1040	Hazardous Material Handling	D104010	Excavation	
					D104020	Disposal	
			D1050	Environmental Restoration/ Replacement	D105010	Environmental Restoration	
					D105020	Environmental Replacement	
	D20	Approach Construction	D2010	Approach Slabs	D201010	Reinforcement	
					D201020	Placement	
					D201030	Finishing	
			D2020	Sleeper Slabs	D202010	Excavation	
					D202020	Reinforcement	
					D202030	Placement	
					D202040	Backfilling	
			D2030	Earth Retention Systems	D203010	Foundation	
					D203020	Wall	
					D203030	Cap	

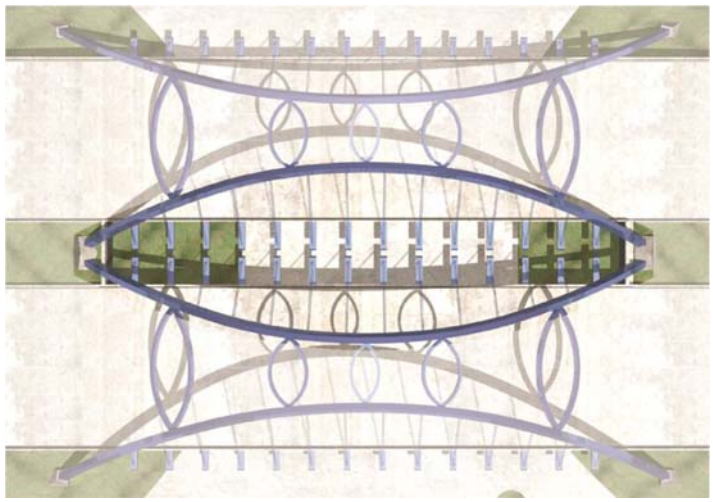
X2. CASE ILLUSTRATIONS TO A SINGLE-SPAN, MODIFIED TIED-ARCH BRIDGE

X2.1 Summary of Key Bridge Characteristics

X2.1.1 The material presented in this appendix is abstracted from NIST Special Publication 1098.[7] This appendix uses a case study bridge construction project to demonstrate how to use the Classification E2103 and example Sub-Classification in conjunction with Practice E2013 to analyze and manage bridge design and construction costs. The bridge is a dual single-span, modified tied-arch carrying six lanes of Interstate 94 (I-94) traffic (three eastbound and three westbound) over Telegraph Road in Taylor, Michigan. Fig. X2.1 provides an overhead view of the two bridge structures. This bridge was part of the reconstruction of I-94 for the Super Bowl XL game held in 2006. Fig. X2.2 and Fig. X2.3 provide different perspectives of the bridge as seen from Telegraph Road (Fig. X2.2) and from I-94 (Fig. X2.3).

X2.1.2 Many modern bridges are either true arches or tied arches. The modified tied-arch bridge in Taylor, Michigan combined the two concepts for aesthetic and safety reasons. Tied arches, where the tie is exposed, might be hit by trucks and are not desirable for grade separation structures. True arches, where the thrust must be taken by the foundation

[7] Kasi and Chapman, *Benefits of Using ASTM Building Economics Standards for the Design, Construction, and Operation of Constructed Facilities*, National Institute of Standards and Technology, Special Publication 1098, Gaithersburg, MD, 2012.



Source: Alfred Benesch & Company

FIG. X2.1 Overhead View of the Gateway Arch Bridge

Source: Alfred Benesch & Company

FIG. X2.2 Gateway Arch Bridge as Seen from Telegraph Road

elements, are exposed to risk when the soil conditions are poor. The Gateway Arch, as it is now called, is a signature structure modified to look like a true arch with a tied foundation.

X2.1.3 The project team was challenged with two major criteria: cost and structural integrity. The team approached the design by analyzing its functions and its worth. The team value engineered the conventional design of elements and identified the function, cost, and performance of each element using Practice E2013. If the function need/performance is high and cost is low, it has value. If the function need/performance is low and cost is high, it becomes a mismatch. When mismatches of conventional design were identified, the team developed innovative solutions to create value of the elements that had a higher need/performance at a comparable or lower cost.

X2.1.4 Through repeated use of Practice E2013 the project team was able to develop and implement five key design innovations that balanced safety and aesthetics with life-cycle cost considerations. The five key design innovations are: (*1*) unique foundation system composed of longitudinal and transverse foundation ties and battered piles; (*2*) inclined arch ribs of unequal lengths that make the bridge appear as a true arch; (*3*) pressurized arch ribs to minimize future maintenance costs; (*4*) dual strand hanger assemblies to provide redundancy and

Source: Alfred Benesch & Company

FIG. X2.3 Gateway Arch Bridge as Seen from I-94

facilitate the replacement of individual strands; and (*5*) transverse girders composed of a plate girder in the middle and a box section on the ends for torsional stiffness.

X2.2 Cost Analysis of the Gateway Arch Bridge Using the UNIFORMAT II Elemental Classification and Example Sub-Classification

X2.2.1 The total contract award cost for one of the two bridge structures making up the Gateway Arch Bridge is $6.67 million. Since the two bridge structures are identical, their total contract award cost is $13.34 million. The cost analysis of the Gateway Arch Bridge using the Classification E2103 and example Sub-Classification is presented in Fig. X2.4 and summarized in Fig. X2.5. Fig. X2.4 records information for each of the three levels in the Classification E2103 and the two additional levels in the example Sub-Classification. Fig. X2.4 includes alphanumeric designations and Element/Sub-Element names, dollar values, and percent of total cost associated with those dollar values. Fig. X2.5 records the cost distribution of selected Group Elements and Individual Elements. The costs summarized in Fig. X2.5 are the major Substructure and Superstructure Group Elements and Individual Elements; they account for approximately 85 % of the Gateway Arch Bridge's total cost.

X2.2.2 Fig. X2.4 is organized so that the costs from each lower level in the UNIFORMAT II hierarchy can be easily aggregated. The first three columns correspond to Levels 1, 2, and 3 of the Classification E2103. The fourth column corresponds to Level 4 of the example Sub-Classification. The fifth column lists detailed cost information, including any Level 5 Sub-Elements of the example Sub-Classification. In several cases, the entries under the Detailed Cost Information heading correspond to a Level 4 Sub-Element or a Level 3 Individual Element. Two intermediate columns under the Detailed Cost Information heading report the percent of total cost and the cost for each detailed cost item. The cost of each Level 4 Sub-Element is obtained by summing over all Level 5 Sub-Elements associated with it. The two intermediate columns under the Level 4 heading summarize the cost characteristics of each Level 4 Sub-Element, specifically the per cent of total cost and the cost associated with that Sub-Element. For example, the Level 4 Sub-Element, A301020 Piles, has a cost of $269 000. Given that the total cost of the bridge is $6.67 million, this value represents 4.03 % of the total cost.

X2.2.3 The cost of a Level 3 Individual Element is obtained by summing over all of its Level 4 Sub- Elements. In a similar fashion, the cost of a Level 2 Group Element is obtained by summing over all of its Level 3 Individual Elements and the cost of a Level 1 Major Group Element is obtained by summing over all of its Level 2 Group Elements. The cost for each Major Group Element and Group Element, along with its per cent of total cost, are recorded in the first two columns of Fig. X2.4. Note that some Group Elements have a single Level 3 Individual Element. For example, Group Element A40, Other Supports, has a single Individual Element, A4010 Thrust Blocks. In such cases the values recorded under the Level 2 Group Element heading correspond to those associated with the Level 3 Individual Element.

X2.2.4 The values recorded in Fig. X2.4 provide the basis for Fig. X2.5. Fig. X2.5 presents a cost distribution of selected Group Elements and Individual Elements tied to a graphical representation of a longitudinal view of the Gateway Arch Bridge. The figure includes the alphanumeric string, the name of the Group Element or Individual Element, its cost, and its per cent of total cost. Two Group Elements and six Individual Elements are highlighted in Fig. X2.5. Reference to Fig. X2.5 reveals that the Level 2 Group Element A30 Abutments has a cost of $824 000, which corresponds to 12.3 % of the total cost. The other Level 2 Group Element shown in Fig. X2.5, B30 Deck, has a cost of $658 000 or 9.9 % of total cost. Two Individual Elements, B1010 Flexural Members and B2010

Level 1		Level 2		Level 3			Level 4			Detailed Cost Information		
Major Group Elements		Group Elements		Individual Elements	% Total Cost	Cost	Level 4 Sub-Elements	% Total Cost	Cost	Level 5 Sub-Elements	% Total Cost	Cost
A Substruture		A30 Abutments		A3010 Foundation	4.03%	$268,875	A301020 Piles	4.03%	$268,875	A30102010 Test Piles	0.25%	$16,575
$1,369,210	20.5%	$823,485	12.3%							A30102020 Piles	3.17%	$211,800
										A10102030 Pile Cap	0.61%	$40,500
				A3020 Stems	8.12%	$541,650	A302010 Cast -in-Place Concrete	8.12%	$541,650	A30201010 Reinforcement	1.06%	$70,650
										A30201020 Placement	7.06%	$471,000
				A3030 Wing walls	0.19%	$12,960	A303010 Cast -in- Place Concrete	0.19%	$12,960	A30301010 Reinforcement	0.04%	$2,560
										A30301010 Placement	0.16%	$10,400
		A40 Other Supports		A4010 Thrust Blocks	8.18%	$545,725	A401010 Cap	5.00%	$333,925	A40101010 Reinforcement	0.95%	$63,175
		$545,725	8.2%							A40101020 Placement	4.06%	$270,750
							A401020 Foundations	3.17%	$211,800	A40102020 Piles	3.17%	$211,800
B Superstructure		B10 Short span assemblies		B1010 Flexural Members	22.36%	$1,492,311	B101030 Steel	22.36%	$1,492,311	B10103010 Fabrication	12.78%	$852,749
$4,493,274	67.3%	$1,772,355	26.6%							B10103020 Erection	9.58%	$639,562
				B1020 Diaphragms	1.10%	$73,500	B102030 Steel	1.10%	$73,500	B10203010 Fabrication	0.63%	$42,000
										B10203020 Erection	0.47%	$31,500
				B1030 Bracings	2.20%	$146,544	B103010 Steel	2.20%	$146,544	B10301010 Fabrication	1.20%	$79,933
										B10301020 Erection	1.00%	$66,611
				B1040 Bearings	0.90%	$60,000	B104020 Sliding	0.90%	$60,000		0.90%	$60,000
		B20 Long Span Assemblies		B2010 Ribs	21.91%	$1,462,206	B201030 Steel	21.91%	$1,462,206	B20103010 Fabrication	11.95%	$797,567
		$2,063,325	30.9%							B20103020 Erection	9.96%	$664,639
				B2030 Hangers	5.25%	$350,450					5.25%	$350,450
				B2050 Ties	3.76%	$250,669	B205010 Cast- in- Place Concrete	3.76%	$250,669	B20501010 Reinforcement	0.89%	$59,569
										B20501020 Placement	2.86%	$191,100
		B30 Deck		B3010 Structural Surface	7.13%	$476,094	B301010 Cast- in- Place Concrete	7.13%	$476,094	B30101010 Reinforcement	2.51%	$167,344
		$657,594	9.9%							B30101020 Placement	4.63%	$308,750
				B3020 Wearing Surface	2.72%	$181,500					2.72%	$181,500
C Protection		C10 Structure Protection		C1020 Expansion Joint	0.06%	$4,000					0.06%	$4,000
$186,440	2.8%	$4,000	0.1%									
		C20 Traffic protection		C2010 Barriers	0.49%	$33,000					0.49%	$33,000
		$57,440	0.9%	C2020 Protective Shields	0.37%	$24,440					0.37%	$24,440
		C30 Other Protection		C3010 Lighting	1.87%	$125,000					1.87%	$125,000
		$125,000	1.9%									
D Sitework		D10 Site Preparation		D1010 Clearing and Grubbing	0.97%	$65,000					0.97%	$65,000
$624,998	9.4%	$572,938	8.6%	D1020 Demolition and Relocation	7.25%	$483,615					7.25%	$483,615
				D1030 Earthwork	0.36%	$24,323	D103010 Cut	0.36%	$24,323		0.36%	$24,323
		D20 Approach Construction		D2010 Approach Slabs	0.72%	$48,060					0.72%	$48,060
		$52,060	0.8%	D2020 Sleeper Slabs	0.06%	$4,000					0.06%	$4,000
Total Bridge Cost						$6,673,921						

FIG. X2.4 Cost Analysis of the Gateway Arch Bridge Using the UNIFORMAT II Elemental Classification and Example Sub-Classification

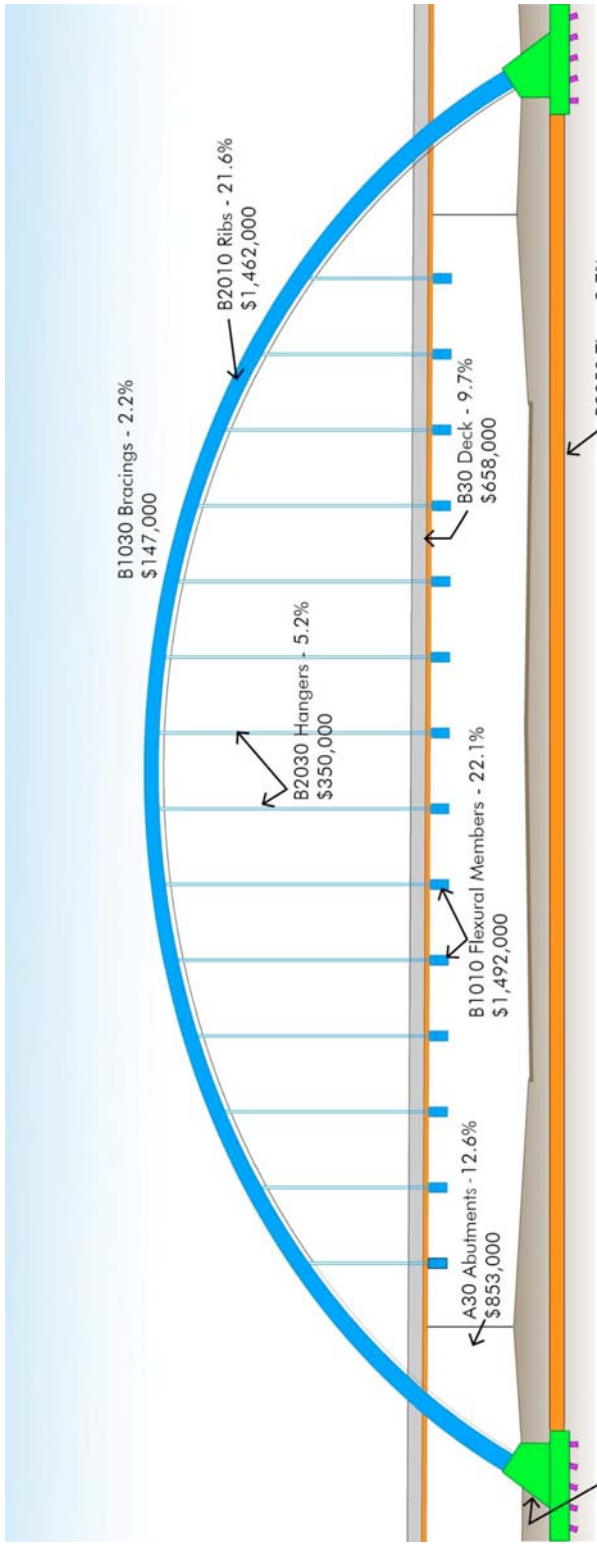


FIG. X2.5 Cost Distribution of Selected Group Elements and Individual Elements for the Gateway Arch Bridge

Ribs, are of particular importance, since they each represent more than 20 % of the total cost of the bridge. Fig. X2.4 and Fig. X2.5 illustrate how the Classification E2103 and example Sub-Classification can be used to focus attention on those elements that drive the overall costs of a bridge project, as well as those elements that are associated with special characteristics—in this case the unique foundation system and other design innovations—of a particular bridge.

X2.2.5 The Gateway Arch Bridge won six awards, including two national awards. The two national awards were the 2006 Outstanding Project Award from the National Council of Structural Engineers Association and the 2007 Prize Bridge—Medium Span Award from the National Steel Bridge Alliance. In addition to the two national awards, the Gateway Arch Bridge won the 2006 Best Medium Structure Award from the Structural Engineers Association of Illinois; the 2006 Engineering Honorable Conceptor Award from the Michigan Chapter of the American Council of Engineering Companies; the 2008 Partnering Award from the Michigan Construction Quality Partnership; and the 2008 Making a Difference Gold Award for Partnering from the National Partnership for Highway Quality. A major criterion for its selection as an award recipient was its cost effectiveness.