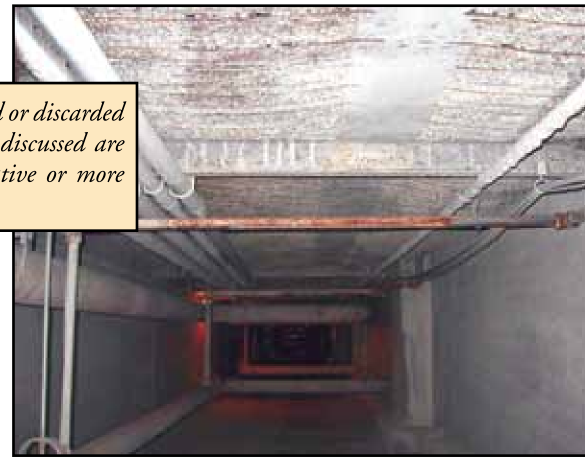
Engineer's Notebook
aids for the structural engineer's toolbox

Antiquated Structural Systems Series

Part 10

By D. Matthew Stuart, P.E., S.E., F. ASCE, SECB

For this series of articles, "antiquated" has been defined as meaning outmoded or discarded for reasons of age. In reality, however, most of the systems that have been discussed are no longer in use simply because they have been replaced by more innovative or more economical methods of construction.



Draped Mesh Floor.

This article includes a compilation of miscellaneous systems and information for use by the practicing engineer. It is hoped that this final article – along with the previous nine – has provided a resource of information to structural engineers involved with the renovation of existing structural systems that are capable of being adapted or reanalyzed for safe reuse in the marketplace of today and the future.

Additional Antiquated Systems

Masonry

Masonry bearing walls were rarely, if ever, designed for actual loading conditions. However, analysis of a typical 8-inch, double-wythe brick wall for a three- to five-story building indicates that the compressive stresses are well below the allowable values that were common in the 20th Century.

Wainwright Building (St. Louis, Mo.). Example of steel skeleton framing clad with brick masonry.

Building codes in New York City first addressed masonry walls in 1830. The code provisions for brick became more complicated with each revision and, by 1892, the portion of the code dealing with masonry was its most complex part. The NYC code, like many other codes from different major cities, specified the minimum wall thickness for varying heights of buildings. The 1892 NYC code generally called for an increase of 4 inches (i.e., one wythe of brick) in wall thickness for each 15 feet down from the top of the building. The minimum thickness for "curtain" masonry brick walls was generally 4 inches less than that required for load-bearing walls at the same height of the building. As it is sometimes difficult to ascertain the thickness of brick masonry walls in existing buildings, a listing of the various minimum wall thicknesses is provided here (*Table 1, page 26*) for a number of major cities from the 1920s.

Load-bearing brick masonry walls were eventually replaced by cage and skeleton wrought iron and steel frame construction, often using cast iron columns. Cage construction involved the use of brick façade walls that were as thick as those used for load-bearing construction; the only difference was that the frame and supporting columns, including those that would eventually be embedded in the brick masonry façade wall, were first erected ahead of the masonry. Skeleton framing, although partially embedded in the exterior masonry walls, was only clad with what amounted to a brick curtain wall. All three of these forms of construction co-existed between 1880 and 1900.

Floor Framing

Draped mesh slabs became popular in the 1920s. Draped mesh construction is a type of reinforced slab framing that involves the use of wires that drape between the tops of adjacent beams. The types of mesh used included triangular wire mesh, ordinary wire mesh, expanded metal sheets, plain round and square rods and twisted square rods. The use of wire mesh was actually preceded by expanded metal sheets. Welding of wires together to form the mesh did not begin until the 1930s. Prior to that, the wires were attached at the intersection points by staples or washers, or by wrapping the transverse wires around the longitudinal wires.

In a draped mesh slab, the concrete serves only as the wear surface and as the mechanism by which the imposed loads are transmitted to the mesh. The mesh alone is what physically spans between the beams by means of catenary action. Because the concrete is not structurally stressed in this type of system, the composition and quality of the concrete is not as important as in a true flexural slab. As a result, it was common to use cinder concrete with compressive strengths under

Web Resources

Additional information concerning draped mesh construction can be found in the Practice Points archive of The Association for Preservation Technology website. **www.apti.org/publications/PP-archive/Friedman-PPs.pdf**

1,000 psi. The use of cinder concrete, however, due to the acidic nature of the clinker (coal cinder) used as the aggregate, resulted in the corrosion of the embedded iron beams and reinforcing mesh. Catenary systems are also vulnerable to collapse as a result of failure of the wire anchorages.

Brick arch floor construction consisted of a single arch of unmortared brick, typically only one wythe or 4 inches thick, capable of spanning 4 to 8 feet with a center rise of approximately ⅛ of the span. The spring line of the arch was constructed on top of the bottom flange of the supporting beams. The space above the arch was filled in with concrete, which sometimes had wood nailer strips embedded in the top of the slab. Tie rods were commonly placed about ⅓ of the height of the beam and were spaced from 4 to 6 feet on center. The entire system had to be built on formwork, which supported the brick. The thrust (T) on the arch, in pounds per linear foot, can be calculated as follows:

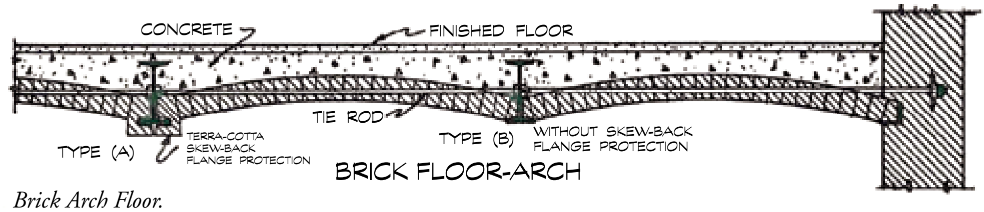
$$T = (1.5 \times W \times L^2)/R$$

Where:
W = load on the arch in PSF
L = span length of the arch in feet
R = rise of the arch in inches

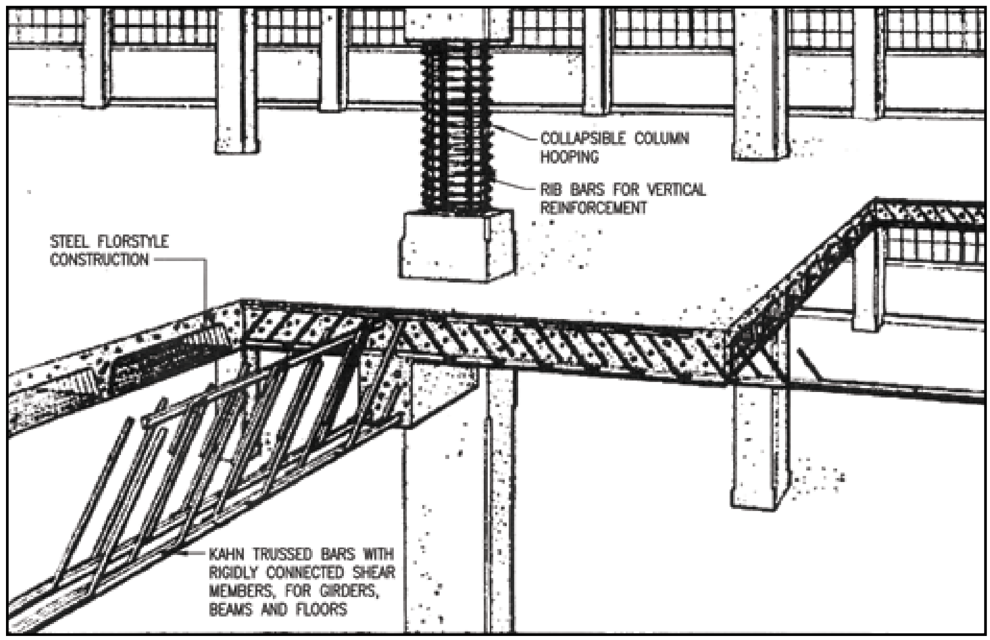
Other common floor systems included:

Fawcett System and Acme Floor-Arch – clay lateral cylindrical tile flat-end construction arch.

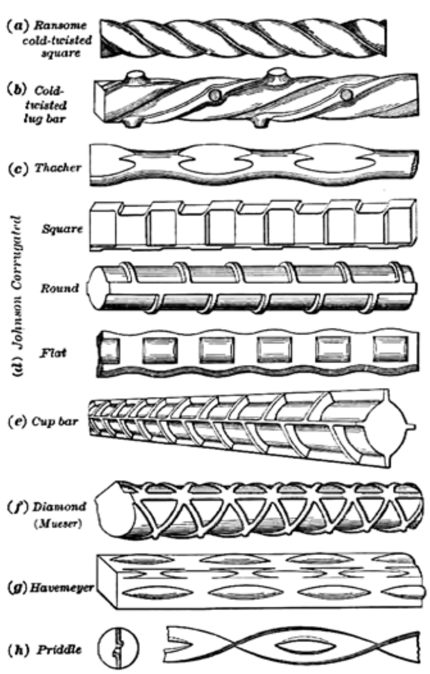
Rapp Floor and McCabe Floor – gauge-steel inverted tees spaced at approximately 8 inches on center, supporting a layer of brick and upper cinder concrete slab spanning 4 feet between supporting beams.



Brick Arch Floor.



The Kahn System.



A series of deformed bars.

Roebling Floor Arch – arch of dense wire mesh supported on the top of the bottom flanges of the beams covered with concrete.

Manhattan System and Expanded Metal Company (EMC) Floor – flat and arched (for EMC) expanded metal mesh covered with concrete.

Multiplex Steel-Plate, Buckeye and Pencoyd Corrugated Floor – Riveted steel plates supporting a concrete slab.

Thompson Floor – Unreinforced concrete slab spanning approximately 3.5 feet between beams connected with tie rods.

Roebling Flat Slab Floor and Columbian Floor System – reinforced concrete slab.

Metropolitan System – early draped mesh floor system.

Plain round and square bars were typically used in reinforced concrete buildings built before 1920. Plain bars began to be phased out during the 1910s and early 1920s in favor of deformed bars. The two types of deformations used at that time included longitudinal and radial deformations. In addition, the Ransome bar included deformations induced by twisting square bars.

Other forms of longitudinally deformed bars included: the Thatcher bar, which was a square bar with cross-shaped deformations on each face; the Lug bar, which was a square bar with small round projections at the corners; the Inland bar, which was a square bar with raised stars on each face; the Herringbone, Monotype and Elcannes bars, which included complex cross-sections similar to radial deformed bars, but with longitudinal deformations; the Havemeyer bar, which included round, square and flat cross-sections with diamond-plate-type deformations; the Rib bar, which included a hexagonal cross-section with cup-shaped deformations; the American bar with square and round cross-sections and low circumferential depressions; the Scofield bar with an oval cross-section and discontinuous circumferential ribs; the Corrugated bar with flat, round and square cross-sections with cup deformations; the Slant bar with a flat cross-section and low projecting diagonal ribs on the flat faces; the Cup bar with a round cross-section and cup deformations; and the Diamond bar with a round cross-section and low circumferential ribs. The modern designation of #3 to #8 round cup or diamond deformed bars was established in 1924.

Reinforcing for concrete beams was also available in prefabricated trussed bar units. A truss bar is essentially a top bar at the ends of a beam that is bent diagonally down to a bottom bar position at midspan. Prefabricated assemblies included the Kahn System, the Cumming System, the Corr System, the Hennebique System, the Pin-Connected System, the Luten Truss and the Xpantruss System.

Conclusions

Engineers involved with renovation and rehabilitation projects need to be aware of the specifics of antiquated structural systems in order to develop non-destructive and unobtrusive solutions. This approach enables the project to be more economically viable because of the extent of structural costs associated with a typical renovation project. In other words, without any knowledge of an existing structural system, it is still possible to develop a structural solution; however, this approach will always be much more intrusive, and therefore more costly, than if the engineer has a sound understanding of the system involved.

Information concerning antiquated structural systems provided by this series of articles, and the referenced source material, has been compiled and made available because the history of structural systems is far less documented than the history of architecture. This lack of documentation can be traced to the general public's lack of awareness about the hidden structural components of a building, which are typically enclosed after erection by the architectural finishes and therefore of less interest to a casual observer.

This general lack of readily available information on antiquated structural systems has occurred despite the fact that most of the methods of analysis and materials used in this country, including steel and concrete, are not much older than 100 years. At the same time that new materials, technologies and methods of analysis have become available and readily embraced by design engineers and the construction industry, previously used systems were, more often than not, quickly discarded and forgotten.

The information that has been presented in this series is intended to represent the knowledge that has been available at various stages of different methods of construction over the past century or so in the United States. However, this information cannot be used from a perspective in which any framing system can be assumed to correspond precisely to a specific system described in the material presented. As is still the case now, the fact that records indicate that a particular structural component should be able to support a given load does not mean that errors were not made during the original construction or as a part of the initial design.

Table 1: Minimum Building Code Thickness of Brick Masonry Walls – Inches.

Total Stories	City	Floor							
		1st	2nd	3rd	4th	5th	6th	7th	8th
2	Boston	12	12						
	New York	12	12						
	Chicago	12	12						
	Philadelphia	13	13						
	Denver	12	12						
	San Francisco	17	13						
3	Boston	12	12	12					
	New York	16	16	12					
	Chicago	16	12	12					
	Philadelphia	18	13	13					
	Denver	16	12	12					
	San Francisco	17	17	13					
4	Boston	16	12	12	12				
	New York	16	16	16	12				
	Chicago	20	16	16	12				
	Philadelphia	18	18	13	13				
	Denver	16	16	12	12				
	San Francisco	17	17	17	13				
5	Boston	16	16	12	12	12			
	New York	20	16	16	16	16			
	Chicago	20	20	16	16	16			
	Philadelphia	22	18	18	13	13			
	Denver	20	20	16	16	12			
	San Francisco	21	17	17	17	13			
6	Boston	16	16	16	12	12	12		
	New York	24	20	20	16	16	16		
	Chicago	20	20	20	16	16	16		
	Philadelphia	22	22	18	18	13	13		
	Denver	20	20	20	16	16	12		
	San Francisco	21	21	17	17	17	13		
7	Boston	20	16	16	16	12	12	12	
	New York	28	24	24	20	20	16	16	
	Chicago	20	20	20	20	16	16	16	
	Philadelphia	26	22	22	18	18	13	13	
	Denver	24	20	20	20	16	16	12	
8	Boston	20	20	16	16	16	12	12	12
	New York	32	28	24	24	20	20	16	16
	Chicago	24	24	20	20	20	16	16	16
	Philadelphia	26	26	22	22	18	18	13	13
	Denver	24	24	20	20	20	16	16	12

19th Century Train Station (Reading Terminal, Philadelphia, PA).

In addition, it is common to encounter some overlap between a previous and more recent method of construction, which has resulted in a blending of two otherwise discrete structural systems. Also, before ASTM began to standardize construction materials in the late 1890s, the quality of irons, steels and cementious products varied greatly. Therefore, when dealing with a building that predates ASTM testing, samples of the existing structural materials should be obtained and tested as a part of the due diligence effort.

In the absence of existing drawings, the methods of evaluating the properties of an existing system include core samples for cementious material strength, depth and/or thickness; coupons to determine iron or steel tensile strength; x-rays to determine internal reinforcement; petrographic analysis to determine the quality, condition and consistency of concrete; ground-penetrating radar (GPR); profometer to determine the location of internal reinforcement; Schmidt hammer to determine in situ concrete compressive strength; exploratory demolition; and in situ load tests.

In some instances, it is not possible or not practical to obtain material strength properties of an existing system in order to complete an analysis using current methods. However, if the past performance of the structure has been good (i.e., no signs of distress or significant deterioration), then it is very likely that the system is adequate for the same use in the future. In such situations, however, it is helpful to try and determine what the likely original live load designation was for comparison to the planned current use.

If the engineer can determine what the likely original use of the building was and has access to copies of older building codes, it is sometimes possible to determine the original live

Table 2.

Minimum Building Code Live Load - PSF						
Building Type	New York	Philadelphia	Boston	Chicago	Denver	San Francisco
	1927	1929	1926	1928	1927	1928
Residential	40	40	50	40	40 & 60	40
Hotels, Hospitals	40	40	50	40	90	40
Office Buildings:						
First Floor	100	100	125	125	125	125
Upper Floors	60	60	60	40	70 & 90	40
Classrooms	75	50	50	75	75	75
Public Seating:						
Fixed Seats	100	60	100	75	90	75
Without Fixed Seats	100	100	100	125	120	125
Garages:						
Public	120	100	150	100	150	100
Private	120	100	75	100	150	100
Warehouses	120	150	125-250	125-250	200	125-250
Manufacturing:						
Heavy	120	200	250	250	250	250
Light	120	120	125	125	120	125
Stores:						
Wholesale	120	110	250	250	120	125
Retail	120	110	125	125	120	100
Sidewalks	300	120	250	150	150	150

Current Day, Jim Thorpe, PA.

Strengthening of existing slab (Slag Block System).

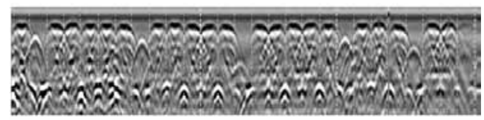
load for comparison to the proposed adaptive reuse. Individual building codes were commonly developed by different cities before the advent of national codes. These local codes often reflected different allowable strengths for the same building materials and varying degrees of minimum live loads. *Table 2 (page 27)* is an example of minimum live loads for a number of major cities.

The original criteria for the design of antiquated structural systems was a performance-based approach grounded in experience, both good and bad (i.e., successes and failures). The transition to the more recent analytical design approach has come about through the development of strength-based formulas derived from scientific experimentation and tests. Structural engineering of buildings as a separate discipline did not exist as late as the 1840s. However, the need for engineers began to grow in the 1850s with the advent of wrought iron beams, which had to be mathematically designed because there was no craft tradition to provide rules of thumb. In addition, the establishment of ASCE in 1852 helped to promote the rapid spread of technical information, such as records of experiments with cast and wrought iron performed in England by Hodgkinson and Fairbairn.

Early 20th Century Retail Arcade (Downtown Nashville Arcade).

It should also be recognized that an existing structural system can often be found to have two different load-carrying capacities – one found using the original codes and methods of analysis, and another using the current codes and methods of analysis. The differences between these two approaches can typically be explained by the expansion of knowledge in the field of structural engineering. More often than not, comparisons between the original and more current methods of analysis will reveal that the older design was conservative. In any case, if the properties of the materials can be substantiated, it is always possible to analyze an older structure using the latest methods of analysis and most current codes. In most cases, in fact, the current building code will mandate such an approach.

In situations in which it is confirmed that the existing structural system does not have sufficient capacity to support the new loads, there are two basic methods that can be used to rectify the condition: adding new framing members, either to support the new loads independently or to provide supplemental support of the existing structure; and/or internally or externally reinforcing the existing system.▪



GPR printout.

D. Matthew Stuart, P.E., S.E., F. ASCE, SECB is licensed in 20 states. Matt currently works as a Senior Project Manager at the main office of CMX located in New Jersey. Mr. Stuart may be contacted at ***mstuart@CMXEngineering.com****.*

Reference Material

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