Antiquated Structural Systems Series

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This article is the first in a series that is intended to provide a resource of information to structural engineers that they can refer to for projects that involve the repair, restoration or adaptive reuse of older buildings for which no drawings exist.

As developable land becomes more difficult to find, particularly in densely populated urban cities or suburban areas in which open space cannot be used, owners and developers are increasingly turning to existing facilities to convert into new uses. If no drawings are available for an older building, a structural engineer will typically first turn to industry resources to try and determine the nature and capacity of the existing structural system. Any available information is then used to confirm that the facility meets the current building code requirements, or determine what strengthening or remediation must occur to accommodate the new use intended by the architect or owner.

If no information is available, the structural engineer must resort to either expensive non-destructive testing or exploratory demolition methods to try and ascertain the nature and capacity of the structure. In some cases, it becomes necessary to abandon parts of the building in place and construct independent structures around the existing one in order to support any new imposed loads or uses safely.

The purpose of this series is to compile and disseminate information that will enable structural engineers to share their knowledge of existing structural systems that may no longer be in use but are capable of being adapted or reanalyzed for safe reuse today and in the future.

The Circumferential or S.M.I System of Reinforced Concrete Flat Slabs

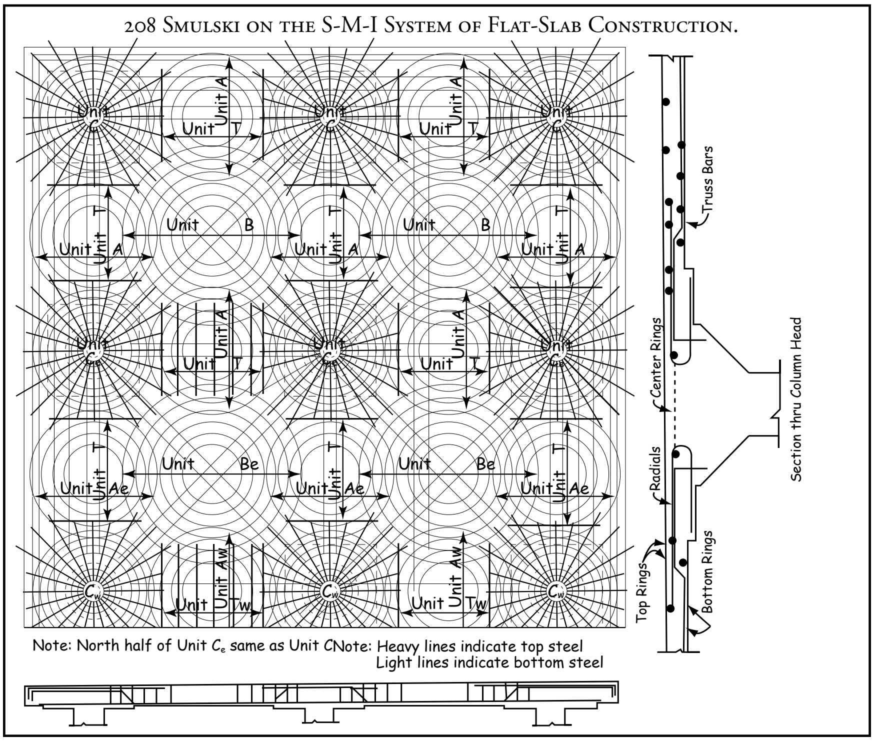
The S.M.I. System of designing reinforced concrete flat plate slabs was developed by Edward Smulski, a consulting engineer from New York City, prior to the 1920s. The system was unique in that the primary flexural reinforcement consisted of concentric rings of smooth reinforcing bars supplemented with diagonal and orthogonal trussed bars placed between the supporting columns and radial hairpin bars located at the columns.

The author first encountered this type of system while evaluating an existing structure in Philadelphia that had at one time been used as an enclosed parking garage, but was being used as an office building in the late 1990s. No drawings were available for the structure, but small openings cut in the slab revealed portions of the internal reinforcement and slab thickness to enable an analysis of the load carrying capacity of the framed floors. However, rather than the typical orthogonal reinforcing bars, the exploratory demolition discovered rings of smooth bars. A subsequent investigation of the available literature on flat plate construction from the approximate time period during which the structure had been built revealed that the slab was very likely designed and constructed using the S.M.I. System.

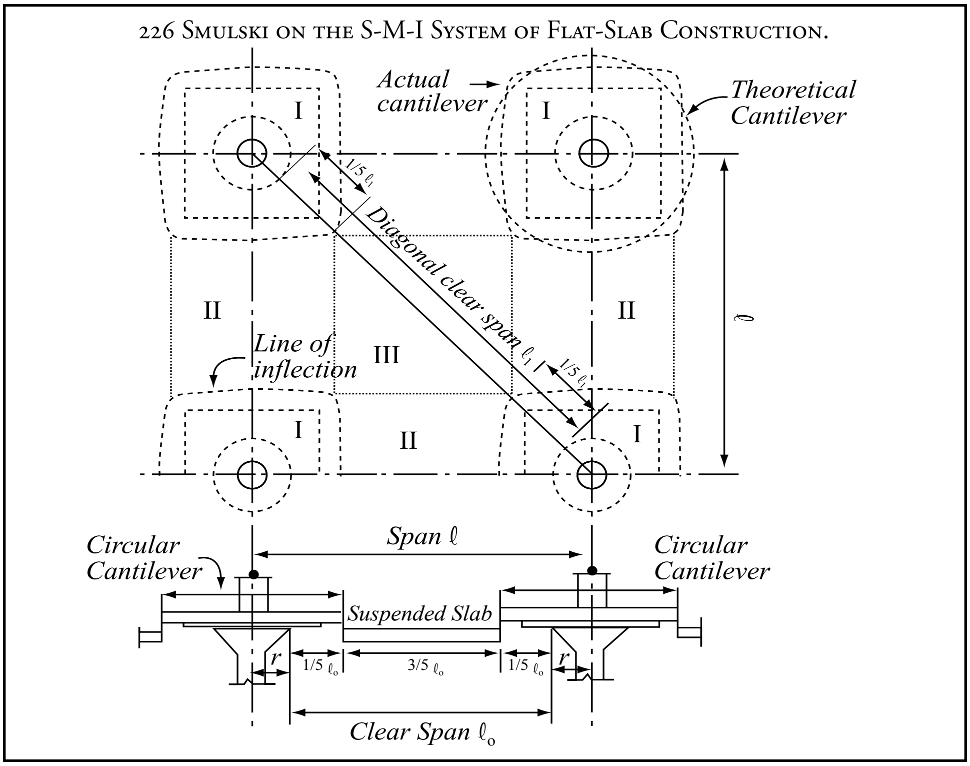
The concentric rings of the S.M.I. System are located in the top of the slab directly above the columns (referred to as Unit C in the available literature), and in the bottom of the slab at the mid-span of what we would now call a column strip (Unit A), as well as in the bottom of the slab at the mid-span of what is now referred to as a middle strip, or centered in the bay formed by the column grid (Unit B). There is typically no top reinforcing provided in the middle strip at the intersection with the column strips, as is now required by the latest building codes. The concentric rings of bottom reinforcement overlap at the interface zones of Units A and B, while the top reinforcement above the column typically overlaps the Unit A bottom bars below.

The slab is separated into three independent sections as a part of the design of the system. These parts include the column head section (Unit C), the slab between the columns (Unit A) and the central portion of the slab (Unit B). The column head is analyzed as if it were a circular cantilever fixed at the column and loaded uniformly around its circumference by reactions transmitted to it by the adjacent surrounding components. The slab between the columns and the central portion of the slab is analyzed for positive bending moments only.

The design of the S.M.I. System is based on the same flexural theory of reinforced concrete used by all other previous methods of analysis, i.e. bending moments are resisted by internal stress in the concrete, compressive on one side of the neutral axis of the section and tension on the other. The primary difference with the S.M.I. System is that the tensile stresses in the structure are offset by the concentric rings of reinforcing bars, which resist the tendency of the concrete within the ring to deform/elongate due to the tensile bending forces. In other words, the rings were subjected to hoop stresses – axial forces acting on the



Section through column head.



Flat Slab Divided into Simple Parts.

rebar perpendicular to the radial direction of the concrete tension. The rings consist of smooth bars. The ends of the rings are lapped to develop their full strength. The laps of the concentric rings are staggered to avoid adjacent laps from occurring at the same radial location within the designated Unit.

Comments by one of the authors of the 4th Edition (1925) of *Plain and Reinforced Concrete Volume 1*, Sanford Thompson, indicates that the S.M.I System required 20 to 24% less reinforcing than comparable two-way and four-way flat slab systems designed during the same historical time period. Comparisons between weights of reinforcing for different two-way and four-way flat slab systems provided in the CRSI publication, *Evaluation of Reinforcing Steel Systems in Old Reinforced Concrete Structures*, does not list the pounds of steel required in a typical interior panel of the S.M.I. System; however, other information concerning this system is provided in the same document.

Professor W. K. Hatt conducted load tests of the S.M.I. System at Purdue University prior to 1920. The results of these tests appeared in the 1918 *ACI Journal Proceedings*. An "extensometer" developed by Professor Claude Berry of the University of Pennsylvania measured stresses within the reinforcing rings. The 41 feet x 36.5 feet, 2x2 bay test frame, with cantilevers on three sides and an upturned spandrel beam on the fourth, was loaded using bricks stacked in such a way to prevent arching action of the masonry units. The center-to-center spacing of the columns was 16 feet. All columns included a capital. The slab thickness was 5½ inches. The test frame was loaded from 150 PSF to 950 PSF until failure occurred.

The following working stress formulas are used to analyze S.M.I. slabs and size the required reinforcement:

(Unit C) *Column Head* $2A_sf_s = 0.64(M/jd)$

Where: M = Bending Moment per ½ of the circumference

A_s = Sum of the cross-section of rings

(*Based on the assumption that the directions of the bending moments are radial. The circumference of the Unit was typically established as the average of the inflection points for the continuous orthogonal and diagonal moment diagrams between the column spacings.*)

(Unit A) *Between the Columns* $2A_sf_s = (M_1/jd)$

Where: M_1 = Bending Moment on portion covered by the rings

A_s = Area of one section of rings

(*Based on the assumption that the principal bending moments act primarily in one direction. Span of Unit was typically established as orthogonal distance between the inflection points of the opposing columns.*)

(Unit B) *Center Portion of Slab* $A_sf_s = ½(M_2/jd)$

Where: M_2 = Bending Moment acting in the distance equal to the diameter of a ring

A_{s1} = Area of one section of the rings

(*Based on the assumption that the bending moments act diagonally. Span of unit was typically based on diagonal clear span between the inflection points of the opposing columns.*)

Additionally, F.E. Turneaure and E.R. Maurer were researching the principles of circumferential and radial bending moment analysis at the University of Wisconsin in the early 1900s. A discussion of their methods of analysis can be found in The Principles of Reinforced Concrete Construction, 3rd Edition (1919).

The available literature that deals directly with the S.M.I. System indicates that the method of construction was patented by Edward Smulski. However, a cursory search through the U.S. Patent Office indicates that there were only two patents granted to Smulski, one for a cast-in-place counterfort system for retaining, reservoir and dam walls, and one for a two-way, orthogonal reinforced slab system that included encased steel beams.

It is not clear how predominant the use of the S.M.I. System was during the early 1900s and later in the century. The number of such structures that were constructed and the number currently remaining are unknown. In the opinion of the author, it is not likely that this system was used to a large degree or was very popular because of the assumed difficulty associated with properly fabricating and placing perfectly round and concentrically positioned bars in overlapping top and bottom layers.▪

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References

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