Of Shells and Their Master

By some of his disciples…

The 1950's and 1960's were exciting years for structural engineers. A post-war generation of young and eager architects and engineers had taken over to satisfy the pent-up demand of the war years. The borders had opened up, and from other parts of the world new ideas and methods were being absorbed and used by willing professionals.

Among these, the field of concrete shell roofs was exciting the structural world. Words and pictures of amazingly thin, wondrously long-span structures aroused the design world, and inevitably some leaders in our profession picked up the challenge and inspired a new generation.

In this article, we would like to memorialize one such leader, and remind ourselves and the profession of a creative period of structural design, of some of its procedures and achievements, and also of its eventual decline.

Milo Ketchum Jr., son of one of the prominent structural engineers of his time, was early-on open to new ideas. In 1934, still a graduate student, he wrote on the innovative bridges of the Swiss engineer Robert Maillart for Engineering News-Record. The newly-developed iterative methods, such as moment distribution recently published by his teacher Hardy Cross, influenced his life-long thinking habits about structural analysis.

In 1945, Ketchum opened his own office in Denver and soon had the opportunity to propose the newly-developed folded-plate roof construction to his architect clients. He wrote much later, under the heading *Care and Feeding of Architects*, " ... because the engineer is essentially a subcontractor, it takes a type of person that can adjust to this secondary role…," and "…play it down. Eventually the idea will become the architect's own...."

Analysis methods proposed for folded plates at that time involved large sets of simultaneous equations, unsuitable for design practice in pre-computer days. Ketchum successfully brought his previously-studied iterative schemes to bear on the problem. More important were his relations with architects and contractors: established 'old timers' were reluctant to embark on strange unknown construction. Luckily, a younger generation was willing to try new things, but much flexibility and cooperation between owner, architect, and engineer was needed for successful construction of new shapes in concrete - qualities that define an "Architectural Engineer". **Figures l and 2** are of some of the folded-plate structures of that time (Fig.2 with Milo Ketchum on an inspection visit), showing clearly the unmistakable Ketchum imprint.

Figure 1

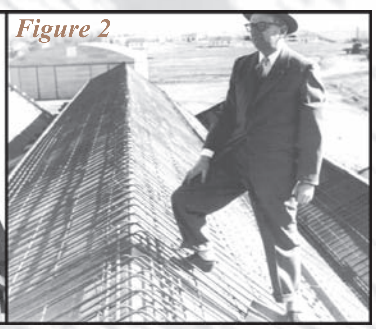
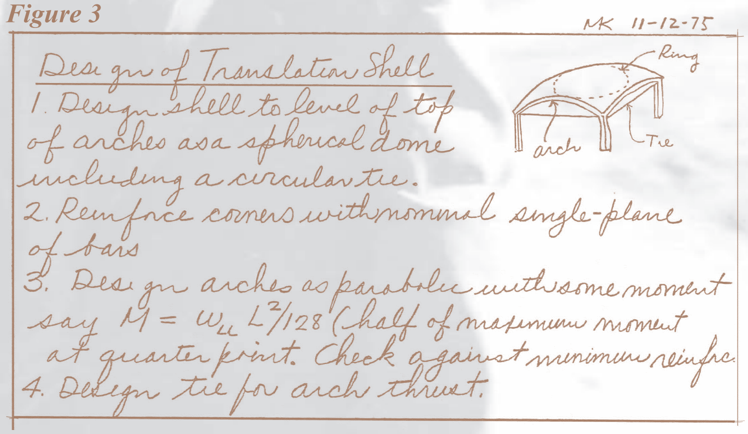


Figure 2

Curved roof shells followed - structures whose strength and stiffness were derived from their shape, so that the shell design process was dominated by geometric considerations. A thorough visualization of the load transfer, confirmed by sketches and models, was needed. **Figure 3** shows a preliminary design outline by Ketchum for a translational shell for a supermarket project, shown completed in **Figure 4** (see next page). Based on these steps, the rest of the preliminary design fills no more than one page. Obviously, more accurate analysis was needed prior to final design - but the conceptual thinking of a master designer is clear. And the sequence from initial concept to final design, from back-of-the-envelope calculations to refined analysis, might be of particular interest in this computer-dominated age.

Figure 3



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Design of Translation Shell
1. Design shell to level of top of arches as a spherical dome including a circular tie.
2. Reinforce corners with nominal single-plane of bars
3. Design arches as parabolic with some moment say $M = w_u L^2/128$ (half of maximum moment at quarter point. Check against minimum reinfc.
4. Design tie for arch thrust.

A variety of shell projects followed: Hyperbolic paraboloids with and without prestressing such as the 180 ft. span column-free space shown in **Figure 5**, single and multiple barrel shells, **Figure 6**, composite shells such as the 340 ft. span hangar of 4 ½ inch thickness, **Figure 7**. Ketchum's preliminary analyses were clear-cut engineering approaches, understood by engineer and structure alike: membrane approaches for HP's, beam methods for folded plates and cylindrical shells.

Figure 5

Figure 6

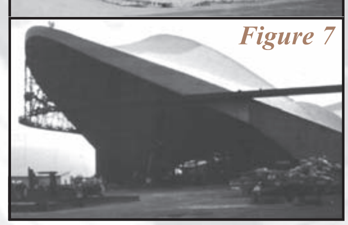

Figure 7

As with other stylistic periods, this one also had to come to an end. Ketchum himself wrote "...shells were built in a time when structural expression was in vogue...", "...it took a good architect to design a shell properly...", and "....engineers were not properly trained or had enough imagination..." - all statements we should take to heart.

Possibly more important was the rise of industrialized components. Catalogue items such as precast, prestressed twin-tees could provide long-span roofs at lower cost and less design effort. Long-span steel joists could be selected from tables. Heavy promotion and first-cost considerations surely tilted the field in their favor. **Figure 8** shows a structure of that time which still retained the favored shell shape, but was simulated by precast twin-tees.

The clock turns, tastes and economics change, and surely, one of these days, the pendulum will swing back toward an elegant, beautiful structure type which we were privileged to share under the guidance of a master.

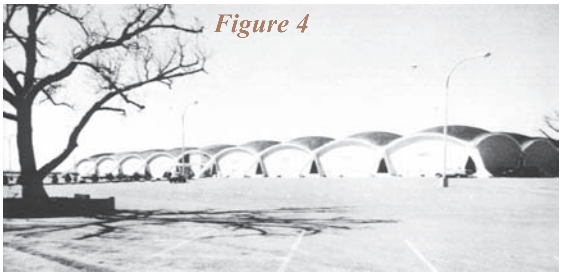

Figure 4

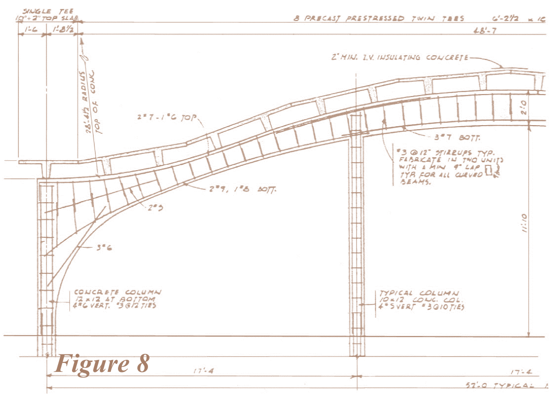

Figure 8

The Ketchum Legacy... Three Generations of Ketchum Engineers

Three generations of Ketchum engineers have made contributions to structural engineering in the United States.

Milo Ketchum Sr. was primarily an educator and author. Born in 1872 in Illinois to a farming family, he was part of the ninth generation of Ketchums born in America. After earning his degree in Civil Engineering at the University of Illinois in 1895, his early career was as Assistant Professor at the University of Illinois, mining engineer in Montana and Idaho, and Contracting Manager for the American Bridge Company.

In 1904 he joined the Civil Engineering faculty at the University of Colorado. A year later he was appointed Dean of Engineering, a position he held until 1917. During this period, he wrote the first editions of his well-known books *Design of Mill Buildings, Design of Walls, Bins and Grain Elevators, Design of Highway Bridges, Design of Mine Structures, and Structural Engineers Handbook*. He also maintained a consulting practice in Denver.

During WWI, he served as Assistant Director of Explosive Plants for the U.S. War Department, in charge of construction of a plant in Nitro, West Virginia. The $70 million project (equivalent to about $3 billion today), including the plant and a complete city, was completed and in production within a year.

After the war, Ketchum served on the faculty of the University of Pennsylvania, and in 1922 was appointed Dean of Engineering and Director of the Engineering Experiment Station at the University of Illinois where he served until his death in 1934, at the age of 62. During this period, he co-authored the first AISC Standard Specification, which appeared in the AISC first edition Steel Construction Manual, and led the University of Illinois to a preeminent position in engineering education in the United States.

Milo Ketchum Jr. was best known for his design practice. Born in 1910 in Colorado, he earned Bachelors and Masters degrees in Civil Engineering at the University of Illinois. An early interest in and training for a career in airship structural engineering was cut short by the demise of the Akron and the Hindenberg.

After leaving the University during the Depression, he worked for the WPA as a surveyor, at the Bureau of Reclamation on dam design, and at the Portland Cement Association as a writer and project consultant. At PCA, he advocated and developed the bridge railing design with a clean rail, offset from the posts, which subsequently became the standard. In 1937, he took a position as an Assistant Professor of Structural Engineering at Case School of Applied Science.

In 1946, he moved to Denver to start an engineering practice. He earned a reputation for innovative and economical designs, and for providing invaluable continuing education for his young engineers. Early on, he designed rigid frame buildings for schools and gymnasiums, and developed a strong rapport with architects and owners. This enabled him to promote the design of concrete shells and folded plates, for which he became a strong advocate with an international reputation.

Ketchum's firm grew in size and stature, and after taking on partners finally became known as KKBNA. Its designs won numerous awards, including the ACEC Grand Conceptor Award and the ASCE Outstanding Achievement Award. After moving to Connecticut to open a branch office, he left the management of the firm to others and accepted a position as Professor at the University of Connecticut. There, he encouraged the creative as well as scientific training of structural engineering students.

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The Ketchum Legacy

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He received many honors based on his work and professional activities, including honorary membership in ASCE and ACI, membership in the Academy of Engineers, and an honorary Doctorate from the University of Colorado. He died in 1999 at the age of 89.

Mark Ketchum is an engineering consultant in San Francisco. Born in 1954 in Colorado, he graduated from the Worcester Polytechnic Institute's innovative "Plan" program, and earned M.S. and Ph.D. degrees at the University of California, Berkeley.

Mentored by Professor Lin at Berkeley, Mark took a position at T.Y. Lin International after completing his M.S degree. He worked there on long span bridges and roofs, including concrete segmental and cable stayed bridges that were gaining popularity in the United States at the time. An FHWA segmental bridge research project lured him back to Berkeley, and led him to participate in the development of the AASHTO segmental bridge guide specification.

A second tenure at T.Y. Lin international, this time as a principal, put Mark in a leadership position in its bridge department. He led a number of projects, including the initial phases of the Golden Gate Bridge seismic evaluation and retrofit project. He left the Lin firm, however, shortly after it was sold to new owners.

Ten years after co-founding OPAC Consulting Engineers, Mark has demonstrated the Ketchum innovation and dedication of his ancestors. OPAC's international practice has included design of bridges on three continents, including the longest span in South America, the first major suspension bridge in the U.S. in 30 years, and the first bridge in China for which design responsibility lies with a foreign firm.guide specification."

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Fig. 1 Casey Middle School, Boulder, CO
Fig. 2 Milo Ketchum on Inspection
Fig. 3 Preliminary Design for Transitional Shell
Fig. 4 Fan Fare Supermarket, Denver, CO
Fig 5. Broadmoor International Center, Colorado Springs, CO
Fig. 6 First National Bank, Boulder, CO
Fig. 7 TWA Hanger, Kansas City, MO
Fig. 8 Colony Supermarket, Boulder CO