PAPER SP 28-1

SHELLS 1970—HISTORY AND OUTLOOK

By ANTON TEDESKO

The history of the development of shells in the United States is reviewed. Current trends and practices are examined. Observations and recommendations are made with respect to the future.

Fewer industrial shell structures are built today than in former years, when the few engineers who designed shells and knew how to build them were active in their promotion. Today's shell designers are too often far removed from the construction and are not sure of construction costs. The author's observations are applicable also to other fields of building construction, as more and more contractors become merely brokers and, lacking extensive concrete experience, prefer solutions which keep their field forces small, and as clients with a limited budget tend to purchase prefabricated structures which can be bought from fixed price lists. The author, therefore, earnestly hopes for greater collaboration, as in the past, between designer and constructor.

Outstanding and monumental structures will be designed and built, and computers, excellent tools in the hands of experienced engineers, will be used. Computers can show us what new shapes are possible, but they are no substitute for engineering judgement. Rationally designed, imaginative, and economical shell structures will result if the abilities of the new generation of talented, esthetics-minded designers are blended with the effective use of computer technology and the experience and know-how of the older generation.

Keywords: history; reinforced concrete; shells (structural forms); structural engineering.

INTRODUCTION

☐ These opening remarks, made at an ACI Symposium on Concrete Thin Shells, are a look back and some reflections on the history of the development of shells in the United States, a look at current trends and practices, and a look forward to what can be expected if present trends continue.

Having been deeply involved in shell design and construction in this country for more than 30 years, my comments are based on personal experiences and my desire to share these experiences with the profession.

The history of shells in this country can be broken down into several distinct periods. Shell theory and standards were of European origin. Names such as Zeiss-Dywidag, Dischinger, Finsterwalder, and Torroja come to mind.

ACI member ANTON TEDESKO, a consulting engineer, operating out of Bronxville, New York, was associated for many years with Roberts and Schaefer as engineer of design, structural manager, and vice president. Dr. Tedesko was involved in the design and construction of 60 major shell structures, also bridges, ground installations for ballistic missiles and space rockets. He was chairman of the first ACI Shell Committee (1957-65), is a member of other ACI committees, and a past director of the ACI. Dr. Tedesko, awarded the Lindau Award of the ACI, was elected a member of the National Academy of Engineering in 1967.

Period 1 First came the introduction and the years of pioneering in the nineteen thirties. (Shells in this country were never copies of designs used abroad.) Almost all the design work, the promotion, and the supervision of construction in this country was done by a single company of engineers (and I am proud to have belonged to that group),* assisted by the promotional staff of the Portland Cement Association. Most architects of those days considered a shell as something to be hidden, just as steel trusses were usually concealed. Shells were not seen as a fresh concept of space enclosure.

As an example, many years ago I designed a flat and what I considered quite an elegant dome for the McAlister Auditorium at Tulane University. This dome is supported at 8 points, but when it was finished one could not see the structural system. A shell was not considered fit to be seen; it had to be covered by an architectural veneer. There are heavy walls, a ceiling underneath the dome, and above, a patterned roof in colored tile.

The architects of those days chose shells only when they could be built for less money than the conventional steel structure, and especially when the owner could be persuaded that in using a shell there was some advantage from the standpoint of fire safety, although insurance companies at that time were too conservative to look into the question of lowering insurance rates.

Economical use of shell materials and efficient use of labor did not mix. Labor-material cost relationships in America were different from those in Europe. Low cost labor, which makes possible economical construction of thin shells in Mexico, is simply not available in New York. As a result, American shells are different from their foreign counterparts, with the designs emphasizing labor savings at the expense of additional material. Ingenious contractors contributed new ideas and new job applications, as the design of forming and the handling of labor were of much greater importance here than they were in Europe. These

---

*Roberts and Schaefer Company, Engineers, founded in 1903 as an Illinois corporation, performed more than 3000 engineering assignments during the first half of the century. Beginning in 1954 the company went through several corporate mergers and became a subsidiary of Thompson-Starrett and other publicly-owned corporations. After 1968, only the Chicago branch, active in the design and construction of plants for the mining industry, continued under the Roberts & Schaefer name as a division of Elgin National Industries.

improvements in construction technique made possible the success of American shells, which were the product of resourceful designers who visualized the construction job as it would be built while the structure was still in the design stage.

Many shells were built during World War II, including industrial plants, military installations, and airplane hangars. They required less strategic materials, did not use much steel. Structural efficiency and performance were the important requirements during these years, with the architect playing a minor role. There was no emphasis on appearance, but the structures built turned out to be clean and simple, based on function and not on architectural dreams (Fig. 1-1).[1] Corbetta* built a shell structure, 180 by 1560 ft in 34 calendar days (still a record), his price being less than the price of temporary wood construction.

The shell boom continued after the war. At this point a second firm of engineers† entered the field and by the end of this first period shells were the domain of two recognized engineering firms who at times associated themselves with local engineers (Fig. 1-2).

By now modern architects had been installed as heads of all prestige schools of architecture in the United States, giving rise to a new generation of architects. This had its influence on the shape of shells in Period 2.

Period 2 This period was initiated with the publication in 1952 of the ASCE Manual 31 on Shell Design,[2] ‡ which ended the technical domination by the two firms and, with the help of the Portland Cement Association, enabled more engineers to design cylindrical shells. Other firms of engineers entered the field and the purity of the shell form became more generally appreciated. The Portland Cement Association's promotional support shifted from the two pioneering firms to small, local engineers; this brought on some unexpected economic side effects which will be mentioned later. Some of the new men in the field erroneously assumed that the design of shells would cost no more than the design of any other type of construction.

In this Period 2, there should be mentioned a variety of shells built for the Space Program and our national defense: underground installations, such as missile launching facilities, launching control centers, often designed for very substantial loads as may be produced by misfiring space vehicles or nuclear explosions. Many thousands of cubic yards of concrete were used in these shells (Fig. 1-3, 1-4, 1-5, and 1-6).[3,4,5,6]

Period 3 The third, current stage was initiated by the 1964 report of the shell committee.[7] By this time, many engineers and architects were at work, often competing with each other. The results were a great variety of new ideas and designs and better looking shells in the hands of creative architects (Fig. 1-7).[8] Unfortunately, there were a number of poor shells and of failures when men with insufficient knowledge did the designing. As in the medical field, there were many good practitioners around, and some who are not so good.

---

*Corbetta Construction Company, New York.
†Ammann & Whitney, Engineers, New York
‡Primarily based on the work of Alfred L. Parme.

ECONOMICS OF DESIGN

Using the medical field for another comparison; the firm of shell designers of the first period (no longer operating in this field of engineering) might be compared with the Mayo Clinic. Doing their own testing, sponsoring university research, keeping labor cost records, they maintained a competent staff of shell experts and construction advisors. They helped interested contractors plan and estimate a shell job, showed films of the construction of shells (taken at their own expense), and planned jobs in cooperation with ingenious contractors. Engineering fees were ample, with money allowed for extensive engineering-design services during the construction phase. These consultants could afford to maintain a competent organization. The result was fully-engineered shell projects constructed on a planned manufacturing cycle, which were successful in competing with other types of framing on large projects. Millions of square feet of shells built for industrial use were the result. These engineers in a sense paid back to the P.C.A. the debt for its past promotional efforts by opening up the market for shells. Many large jobs which had been designed for wood or steel were converted into concrete. This firm, of course, spent thousands of dollars on the design of structures which for various reasons did not reach the construction stage or did not go ahead as shells. Some may remember that in New York, many years ago, I was part of a team designing a shell roof, column-free over spans of 540 by 580 ft, for a convention hall to be built in the New Jersey meadows; Walter Ahlschlager was the architect. More than 5000 pre-war dollars were invested, but due to political changes in New Jersey the job never went ahead and the engineers were never paid. During this period fees had to be higher than conventional fees. Engineers furnished more than just the minimal design drawings. This helped the contractor, brought down his costs, ultimately benefiting the client.

Engineering fees have decreased during the last 20 years (Periods 2 and 3) as the field became more competitive. Costs to design a shell are higher than to design a comparable conventional structure. The completeness of the designs suffered in this squeeze. The pioneering companies could no longer afford to keep their all-around experienced staffs and to make available the construction advice of earlier days. Films which previously were shown during pre-bid conferences to create a fuller understanding of problems and costs were not shown anymore. Fewer competent contractors were induced to bid. Contractors who did not have shell experience came in with high prices and few engineers knew whether their cost estimates would be met during actual bidding; as a matter of fact, hardly any shell designs were made from then on for competitive bidding with other types of construction.

Today there are fewer shells for big industrial installations than there were 20 years ago. Shells are being designed by engineers who are inexperienced in the field and although the number of shell designers increased under this policy, the total area covered by shell structures built must have decreased.

It is ironic that in earlier days the design fee could be paid out of savings over other forms of construction made by the owner. Assuming for the purpose of this comparison that all costs remain relatively constant, the owner now pays more for a shell job, and the engineer gets less, due to greater competition. Of course, labor prices have not remained constant; great advances have been made in prestressing techniques; these are other reasons that the number of shell jobs has not attained the promise of the late fifties and early sixties at which time there was great enthusiasm for shells and their future possibilities.

CURRENT TRENDS

More and more of the general contractors who turn in low bids on public jobs are merely brokers who do not have extensive concrete experience. Where these men have influence on decisions, the decisions are in favor of solutions requiring fewer men on the job. In this age of demonstrations, stoppages, and interruptions of all kinds, a cast-in-place shell is more vulnerable to unforeseen events and to pressure tactics than is a pre-cast job. If concrete finishers on a shell structure walk off at 4 p.m. because they do not want to work overtime, the final product is affected. If all workers are on the job for an early start in concreting a large shell on a hot summer day, and if the concrete supplier sends a fleet of trucks delivering concrete which is not of the type specified for hot-weather concreting, a loss in time and dollars will result. The contractor who handles merely precast parts of concrete, avoids this problem.

With the mass market for shells fading, there is a tendency to go to plant-produced structures, made of precast, prestressed elements for which firm prices can be obtained. This type of construction requires fewer men, is easier to design and takes some of the guesswork out of estimating.

In America, shells for single-story industrial buildings are not utilized unless aesthetic considerations play a dominant role, or unless an enlightened owner assembles a competent team, pays a competent engineer a sufficient fee to enable him to do a complete planning job, inclusive of model testing if deemed advisable (design of centering, etc.), and a competent contractor can be interested in the construction. Shells particularly benefit by joint planning of design and construction.

> (Thinking of competent engineer-contractor teams, names like Candela and Arthur Anderson come to mind; unfortunately, there are not many such teams in existence. Abroad, Finsterwalder, Nervi, and Esquillan have great teams.)

It is the separation of design and construction which has worked against shells in our economy. Unfortunately, because of our economic system, too many engineers are far removed from the construction, exert no control, and feel their job is done when their drawings are finished; they do not get paid for supervision of construction and their attitude if the contractor gets into trouble is: that's his own business. Such engineers are co-responsible for ending up with delays, a patched job, and with shell projects which do not come up to their full potential.

Those designing shells are usually unable to tell a client accurately what the job will cost, as they are dependent on whether a contractor with or without previous shell experience happens to bid the job.

On moderately-sized shells which are part of a larger contract, it does not make much difference whether these shells cost more or less, the shell cost usually is hidden. On larger jobs I would recommend that we follow the original concept of Period 1, as much as possible, that is, maximum engineer-contractor collaboration; if you want progress, this is one way of getting it, although it is not the American practice at this time. The ultimate goal is to get a building, not a design! I also recommend making use of precast parts in cast-in-place shell structures. Such jobs in which the contractor had appreciable influence on the design have recently been built abroad and are well suited to American conditions. The larger the job the greater the possibility that an on-the-job plant producing monolithic shells will do the job better and more economically than a plant manufacturing prefabricated parts which have to be shipped to the site and then erected.

Let us learn from the past that there is no substitute for competence. It pays to design a job right in the first place and to avoid correcting deficiencies later, after things have gone wrong. The costs of corrective measures usually are a multiple of the costs of items not taken care of at the beginning. The average practitioner in the medical field calls in a specialist; why can not the average engineer do the same? In this day of specialization no one has to be ashamed of not knowing everything. Would anyone encourage a medical practitioner to perform major surgery in a field in which he lacks experience? Not likely! So let us drop the idea that every engineer is competent to design shells.

In the interest of better shells and of making the designer aware of the construction aspects, I would rather consult with an engineer at the beginning of a significant job as to what he should do with his shells, than to be called in by the contractor later, and placed in the position of having to protect the public, help the contractor, and bail out the engineer.

THE FUTURE

What does the future hold?

There is a field for shell roofs of moderate size for churches and other eye-catching buildings where a shell adds an attractive or unusual element and gives an air of elegance. For long spans where the saving in weight is an important factor, shells must be seriously considered.

What constitutes a pleasing shell structure?

Flat surfaces are easier to form than most curved surfaces; some people thereby justify their preference for folded plates. Some types of shells were used until they became boring architecturally; then the pendulum swung back as architects tried to build something different. Too often an architectural designer thinks he has to incorporate something new, even though the new is not necessarily good. I have seen streamlined shapes with good aerodynamic properties which might be more appropriate for flying saucers. I, personally, do not believe that a "free form shape" is the solution, even though a computer might be able to calculate the stresses. Nature builds simply and with economy and I believe that our shells would be more pleasing to the eye if they followed some geometrical law, in the manner of snow flakes or a rainbow. Countless combinations of cylinders, cones, and simple doubly-curved shapes have not been utilized and would produce logical and attractive solutions. It is an exception if complicated or far-fetched solutions turn out to be good. Good designers can produce excellent effects with simple shapes. Consider the outstanding shells of men like Finsterwalder, Nervi, Torroja, and Candela. These men refined in a subtle way simple shapes; the refinements had structural meaning and resulted in elegant solutions.

Questions of cost and re-use of forms may have influence on the solution to be adopted. In many cases, however, the architect and the engineer are picked to do the job as an artist is commissioned to do a painting. Economy in the execution and the final price of the work are seldom criteria in the award.

Outstanding and monumental shell structures will be built. Prestige architects will be involved, some of them without a particularly well-developed sense of the practical elements of construction. Shell structures in the past were built with the construction cost occasionally going much higher than anticipated. A high price can be justified in our complex economy when added attractiveness is achieved, a cost which in a sense represents a form of advertising. TWA did not "lose" by erecting a costly and beautiful terminal at J. F. Kennedy Airport. The terminal is a piece of sculpture and should not really be called a shell. Political aspects have influenced decisions in favor of expensive solutions which an engineer would not have recommended. The history of cost increases due to naiveté and inexperience is not limited to this country. Very well-known structures are examples of cost multiplication. The Sidney Opera House is an illustration of what may happen when shape comes first and design comes later. When funds are not limited, there need be no limit to new shape, the scope, and size of our shell structures.

There is no generation gap when it comes to shells and shell designers. There is no gap between the good designers of earlier days and good engineers of today. Progress in shells is in the hands of forward-looking men, the young and the more mature, those who make optimum use of good practice, old and new, using the powerful weapons of today: the computers. Some of our younger men know more of shell analysis and computer solutions; the older men may know more of practical problems and the cost of construction. In the interest of progress this great talent and experience which are available must be blended.

Having been involved in many shells, I know that none of the great classic shells of the past would have become a better shell by the use of any one of the computer solutions available today. Computers cannot replace engineering judgement and are no substitute for good design. Computers can show us what new shapes are possible; they opened up new opportunities and are a wonderful tool in the hands of experienced engineers for speeding up calculations and replacing the tedious work of former days. They make it easier to cope with complicated shapes.

Computer solutions should not be misused for mathematical exercise. The purpose of calculations is not to keep us in trim intellectually. Their purpose is "to build"!

CONCLUSIONS

This brief look at the history of the development of shells, and the examination of current trends in the United States, lead me to the conclusion that while in present design practice there are some misguided applications of shell structures and lost opportunities for using shells, there is also strong hope for the future. A new generation of shell designers has grown up in the United States. They add the gift of imaginative, artistic sensibility, and greater computer technology to the practical knowledge, understanding, and intuition of the older generation. These younger men are more structural sculptors than mass-producers of shells, more partners in the architectural team than engineer-workers producing, as in former days, an inexpensive structural system to carry the architect's loads. Shell design has been advanced as a result of this development.

Rationally-designed shell structures will have the greatest promise whenever there is cross-fertilization between the minds of the designer and the constructor.

REFERENCES

1. Joedicke, J., "Shell Architecture," Reinhold Publishing Corporation, New York, 1963, 304 pp. (A bibliography of publications describing American shell structures built during Periods 1 and 2, pp. 295 and 297, lists more than 70 items, many of these articles by the author of this paper.)
2. "Design of Cylindrical Concrete Shell Roofs," *Manual* No. 31, American Society of Civil Engineers, New York, 1952, 177 pp.
3. Tedesko, Anton, "Shell at Denver–Hyperbolic Paraboloidal Structure of Wide Span," ACI JOURNAL, *Proceedings* V. 57, No. 4, Oct. 1960, pp. 403-412.
4. Tedesko, Anton, "Multiple Ribless Shells," *Proceedings,* ASCE, V. 87, ST7, Oct. 1961, pp. 107-124.
5. Gensert, R. M., "Hyperbolic Paraboloidal Roof for a Grandstand," *Civil Engineering–ASCE,* V. 30, No. 5, May 1960, pp. 49-53.
6. "Assembly Hall, University of Illinois," *Engineering News-Record,* V. 166, June 1, 1961, p. 32; V. 167, Oct. 5, 1961, p. 30; and V. 168, May 24, 1962, p. 44.
7. ACI Committee 334, "Concrete Shell Structures–Practice and Commentary," ACI JOURNAL, *Proceedings,* V. 61, No. 9, Sept. 1964, pp. 1091-1108.
8. Obata, Gyo, "The Priory of St. Mary and St. Louis–St. Louis County," *Architectural Record,* V. 138, No. 8, Aug. 1965, pp. 144-145.

Fig. 1-1—Ellipsoidal shell domes for trickling filters, Hibbing, Minn., 150 ft span (author's photograph)

Fig. 1-2—Shell units for aircraft hangar of US Air Force, clear span of 340 ft was longest at that time, stiffening arches restrained by heavy buttresses follow catenary (photographed by author) (similar hangars for American Airlines of 260 ft span, engineered by Ammann and Whitney, followed the same year)

Fig. 1-3—Shell at Denver was longest span hyperbolic paraboloid (author's project)

Fig. 1-4–Cast-in-place shells for US Government installation proved competitive with precast concrete structure (author's project)

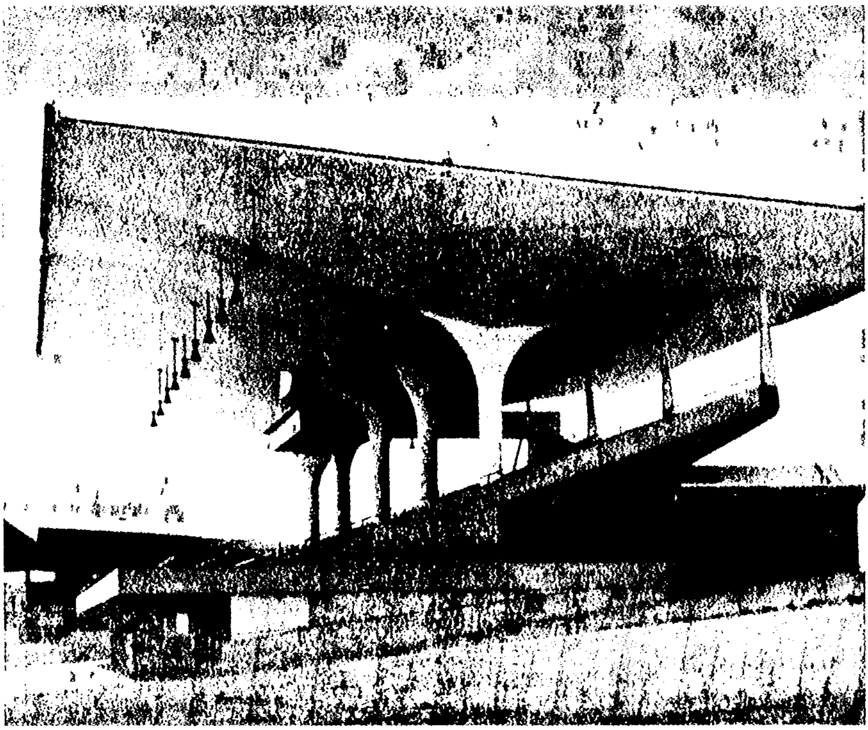

Fig. 1-5–Grandstand at Columbus, Ohio (R. M. Gensert Associates, Engineers)