COVER STORY

IF IT'S BUILT, THEY WILL COME

By Teresa Verbout

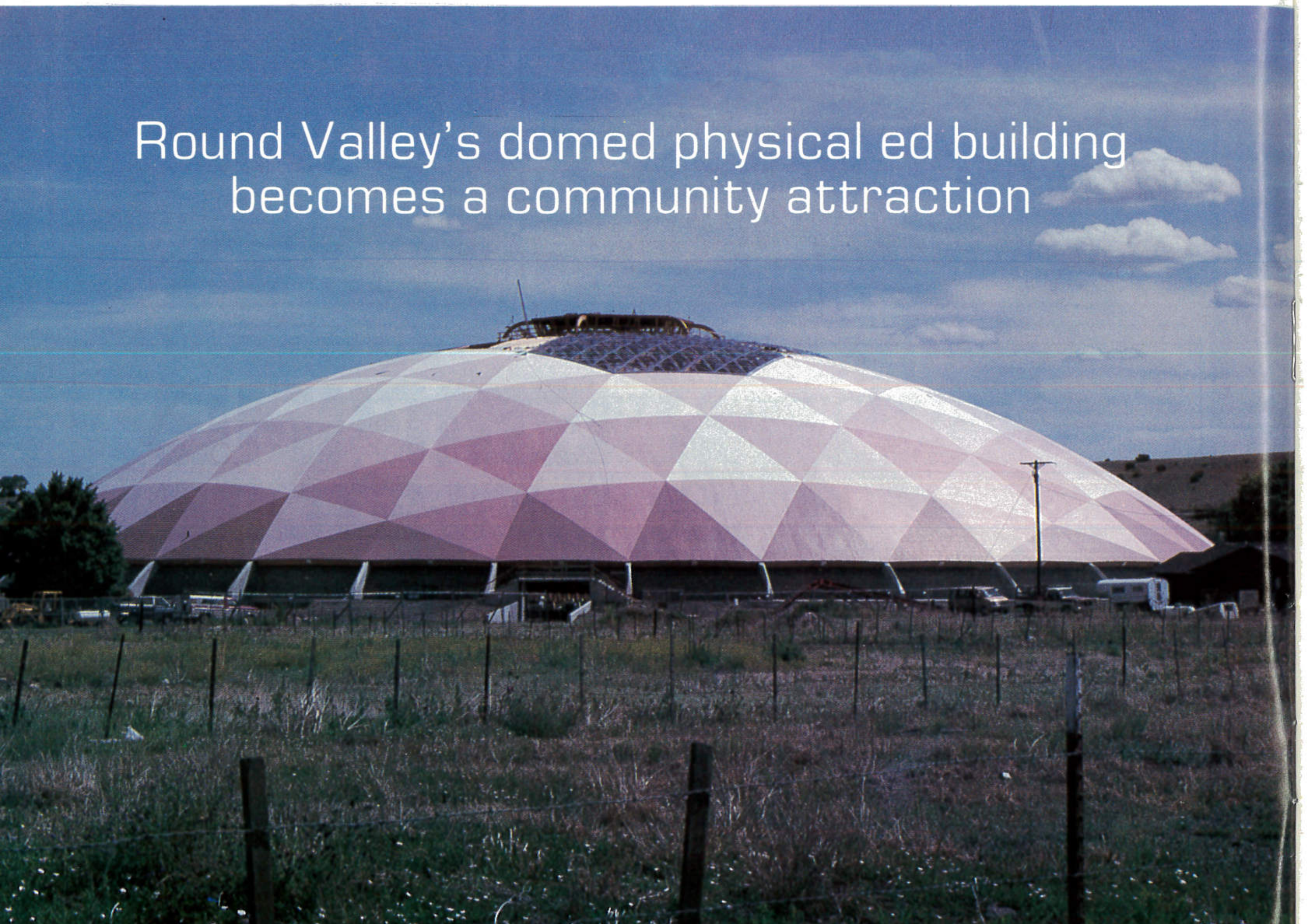

Photo courtesy of Sletten Construction

Out-of-towners going to a sports event at Eagar won't have trouble finding the gym. The school's new facility can be seen from all angles in the rural Arizona community.

Photo by Teresa Verbout

An aerial shot shows how masive the ensphere is. Next fall, Round Valley High School will start football season in the new facility. Outdoor baseball fields will still be used.

In a way, Arizona has its own "Field of Dreams" unfolding in Eagar.

In the movie "Field of Dreams", a farmer, who listens to a voice, builds a baseball diamond in his cornfield and people from all over are drawn to it.

Since July, more than 2,000 people have been drawn to the Round Valley Ensphere, a domed physical education and multi-purpose facility.

While the architects and contractors realize they are building what is considered the first domed high school football field in the country, they didn't anticipate the overwhelming interest from the community, and even out-of-state tourists.

Daily tours and weekly radio construction updates are as much a part of the job as pouring concrete.

For Sletten Construction, general contractors, daily tours and weekly construction updates on the radio are as much a part of the job as pouring concrete or installing more than 800 wood beams.

Robb Ellis, Sletten project engineer, said so many people started hanging around the construction site that the contractors decided to start daily construction tours. Ellis said an average of 20 people show up for the afternoon tour. Art Eagar, Round Valley Unified School District #10 project director and mayor of Eagar, said various newspaper articles and a story carried by Associated Press has prompted visitors from throughout the Southwest. One man from Michigan

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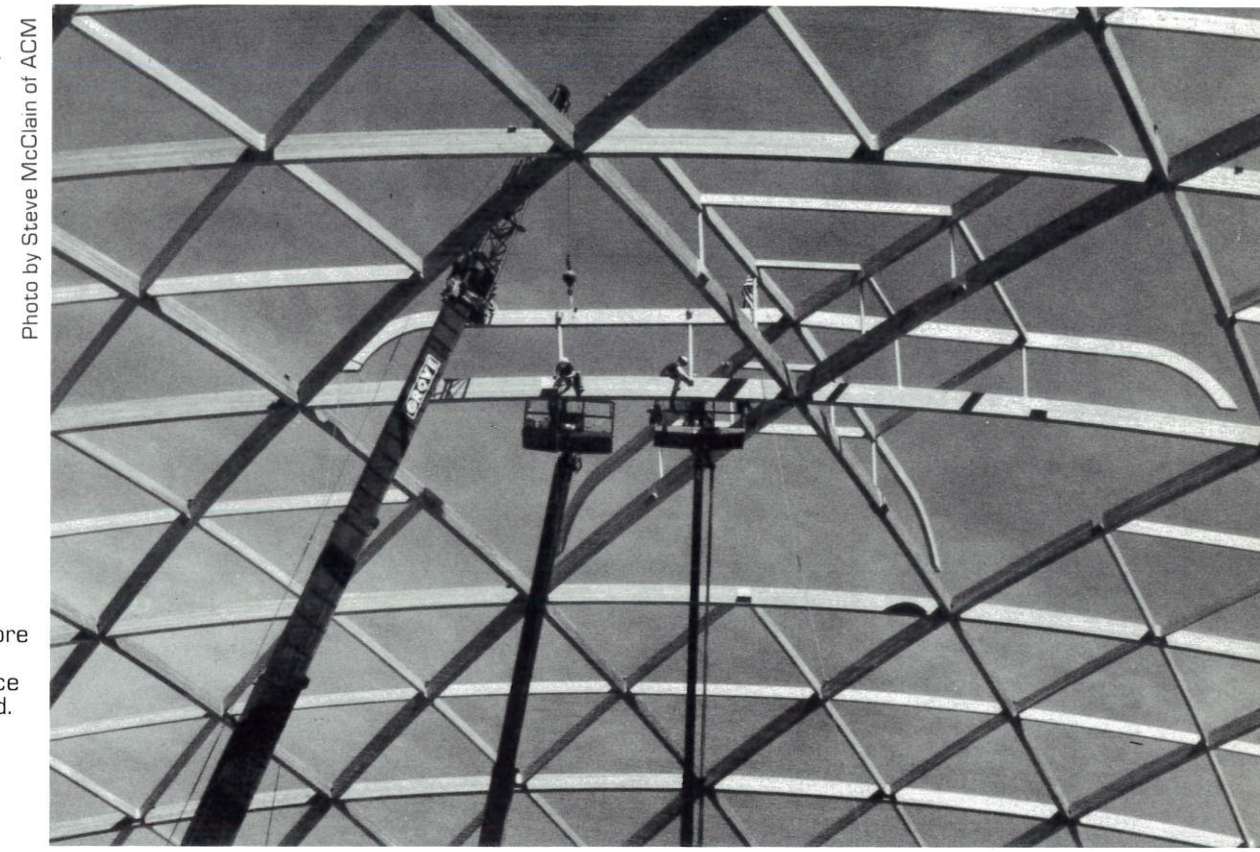

Photo by Steve McClain of ACM

Sletten erected more than 850 glue-lam beams in a sequence that they developed.

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made a detour on his vacation to see the dome.

Other members in the community can tune in to the local radio station and catch the weekly "dome report," which is hosted by Ben DeLeo, Sletten Construction project superintendent.

And the community has a lot to be curious about. The ensphere is by far the largest structure in Eagar and adjoining Springerville. Not only will it serve as a physical education facility for 504 high school students, but also as a center that will benefit the whole community by possibly hosting concerts, carnivals and state high school sporting events.

Flexibility was one of the school district's needs for a physical education facility. Eagar said the school's current facility wasn't adequate. The school was opening at 5 a.m. and staying open until 10 p.m. just to fit in all the different athletic practices. If the school built a multi-court gymnasium, then various teams could practice simultaneously.

Enter a Phoenix architecture firm that specializes in the ensphere concept. Now known as Rossman, Schneider, Gadberry, Shay Architects, the Scottsdale firm created the first large-scale ensphere in the world when they designed the J. Lawrence Walkup Skydome at Northern Arizona University in Flagstaff. An ensphere uses a different structural system than traditional wall-restraining ring-domes. The concept of an ensphere is similar to a bowl resting on the ground. The entire dome is supported by the ground. The structure can be built large enough to rise above anything inside. While walls and dome support columns are not needed for an ensphere, the restraining ring is lowered to a sub-grade level, thus increasing the floor area by 25 percent over a traditional dome. Plummer Hasan and Associates, Scottsdale, were consulting structural engineers.

The concept of an ensphere is similar to a bowl resting on the ground. The entire dome is supported by the ground.

Dr. Wendell E. Rossman, AIA and RSGS partner, said the school district's desire to have an indoor football field required the building to have a 440-foot clear span.

Rossman said there are two ways to design a building with that large of a clear span. One is post and beam construction and the other is thin shell, which Rossman chose. Rossman explained that a thin shell structure is similar to an egg, which is uncrushable in the palm of one's hand. While both construction methods do the same job, the price tag differs by nearly 50 percent. Rossman quotes post and beam construction expenses at $55 per square foot, while thin shell construction costs are $28 per square foot.

Using 170,000 square feet of floor area, Rossman said the facility could have an indoor football field, or remove the field to use a synthetic rubber eight-lane, 200 meter track that lies underneath. Other track features include an eight-lane 100 meter straightaway with run-out, high jump and pole vault areas,

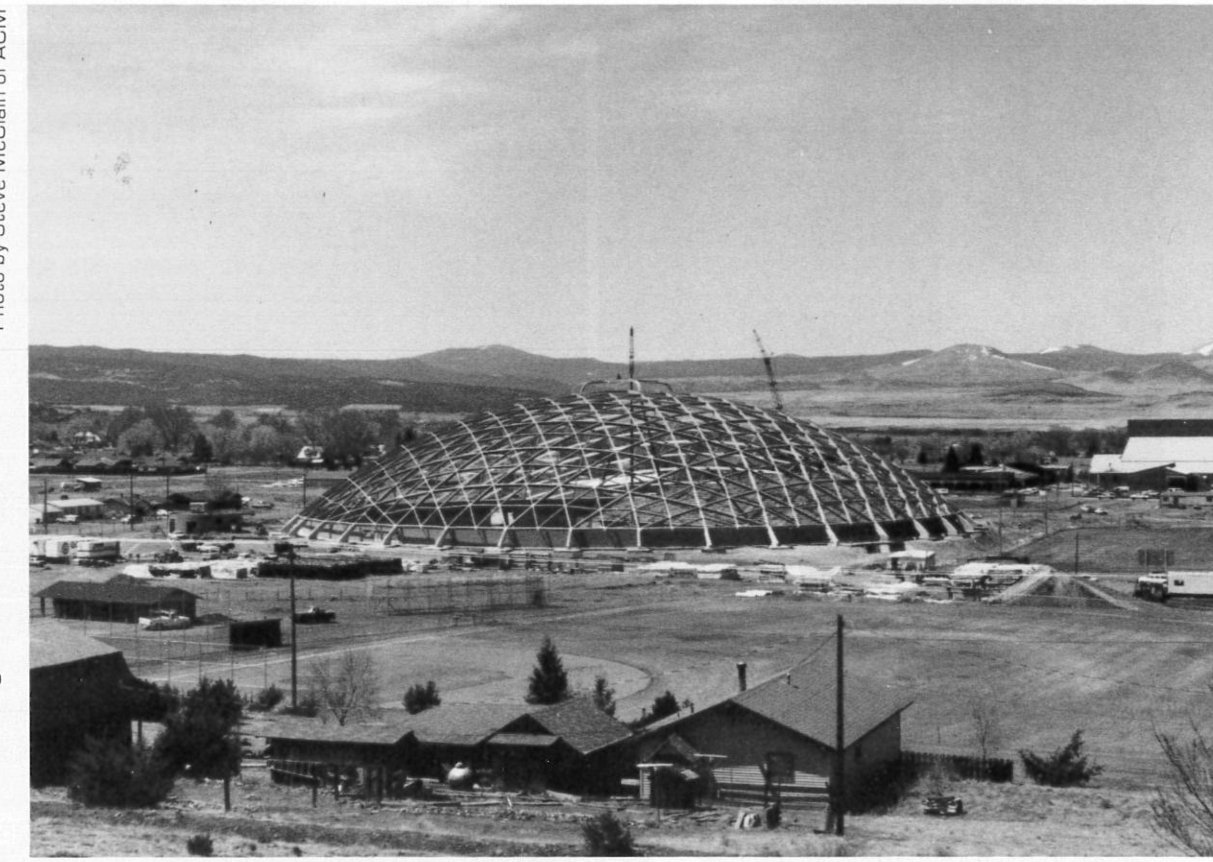

Photo by Steve McClain of ACM

Buttresses, cast in place every 10 degrees, are tied into the facility's, tension ring and are used to support the roof.

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and triple and long jump areas. The floor also has seven courts, which can be used for basketball, tennis, or volleyball, or two competition basketball courts. Also the facility can accommodate a softball field.

At the north concourse on the field level are two large blocks of locker rooms and showers for students and home teams and two smaller facilities for visiting teams, two officials' quarters, coaches' quarters and an equipment storage room.

Underneath the stands, which accommodate 3,500 seats on concrete risers, are restrooms, classrooms and an elevator.

The south concourse has 8,000 square feet of storage for portable bleachers.

DeLeo said construction started May 1990. First, the project was excavated to the field level. Carmean Contracting, Tempe, removed 25,000 cubic yards of soil, which was stockpiled on site for later use as backfill.

Footings were also excavated for a poured-in-place concrete, 1,500 linear foot perimeter wall which, when backfilled, acts as a retaining wall. On top of the 10-foot high perimeter wall is a two-foot high concrete tension ring, which contains 15 miles of post-tension cables. Fifty-six post-tension cables, tensioned at 7,000 pounds per square inch, act as a belt and hold the building together. Footings for 36 buttresses were then poured. The buttresses, which are cast-in-place concrete, were set every 10 degrees and tied into a tension ring in six different locations. The buttresses are used to support the roof.

On top of the tension ring is a 10-foot high wall made of concrete masonry units. From the exterior, one only sees the block wall. From the interior, both the retaining wall and block wall are clearly visible, giving the facility a "sunken" look.

Fifty-six post-tension cables, tensioned at 7,000 pounds per square inch, act as a belt and hold the building together.

Other concrete work included pouring 32 caissions, which were three feet wide and 25 feet deep, for the permanent seating. Poured-in-place riser beams sit on the caissions and hold precast double Ts to which the seating is attached. Sletten did all concrete work.

More than 850 wood glue-laminated beams form the ensphere's skeleton. Besides being lighter and cheaper, Rossman said wood beams have greater resistance to fire than steel. Insurance is lower since wood can be refurbished and steel, which buckles, must be replaced.

RSGS has been pioneers in the development of the reticulated glue-lam timber domes. The firm has a patent on Ensphere Connector, the hub that joins radiating timbers.

Ellis said he used a computer software program and trigonometry to pinpoint the exact elevation for each point and developed a sequence in which to erect the beams.

Using a Grove RT760 rough terrain crane, two Grove MZ90 84-foot manlifts, and a 50-ton Lima crane with a 150-foot

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Photos by Teresa Verbout

The field holds a track, football field and seven courts for basketball, volleyball or tennis. Above left, poured-in-place riser beams hold precast double Ts. Nearly 3,500 seats will be attached to the double Ts.

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boom, the beams were set from September 1990 through last May.

Ellis adds the last six beams were erected in just five hours. "They just slipped in like they were perfectly made."

While the beams are exposed on the inside, several layers cover the exterior to make the shell. The first layer is 164,000 square feet of two and a quarter-inch thick pieces of tongue and groove decking, which is then covered by a 5/8-inch thick sheet of firecode sheetrock. The outside is shielded by single membrane roofing in four colors — rust, dusty rose, pink and white.

Ten percent of the dome is translucent to allow light onto the field. Skylights are made of Lexan, an improved plexiglass strong enough to handle the snow and ice that Eagar experiences.

In the center of the dome, which is 10 stories high, is a low-rise cupola to exhaust air.

One of the advantages of an ensphere is its energy efficiency. The roof shell acts as a thermal barrier, enclosing space from the ground up and making the interior insensitive to outside temperature variations. Rossman explains the skylights will provide adequate lighting during the day and help heat the interior during the winter. For additional heating, a hot water heat loop runs through the building. In the summer, large quantities of fresh night air are drawn into the building to cool it.

Although construction costs for the project are $10 million, Eagar said the price tag will run closer to $13 million after furnishing is complete.

Although the Round Valley Ensphere is not scheduled for completion until April 1992, DeLeo said the facility should be substantially completed this month. By completing their own concrete work and developing a formula for setting the beams, Sletten shaved six months off the project.

Karen Hales, depository administrator, said the depository will handle public work buildings more than $250,000.

Open for deposit

Arizona bid depository organizers hope to ease bidding chaos

By Teresa Verbout

Organizers of a new bid depository are hoping to change the way Arizona contractors currently bid projects.

If accepted by contractors, the depository will increase bidding time, reduce bid shopping and, hopefully, raise contractors' profit margins.

Nine months of planning have resulted in a bid depository that initially will handle only structural public work projects $250,000 and over according to Karen Hales, depository administrator.

Hales, the executive director of the Air Conditioning Contractors of Arizona and the Sheet Metal and Air Conditioning Industry Program, was appointed administrator in August by the depository's board of directors. Hales was appointed administrator since she had been organizing the depository from its inception.

Hales said ACCA's board of directors started plans for the depository in January. After talking with and receiving support from other trades, a subcommittee was formed to begin organizing the depository. Three major subcontracting trades are supporting the depository — the mechanical contractors, electrical contractors and masons. A group of general contractors has also added its backing. A depository board of directors, which has a representative from each of the four groups, was appointed in June.

At press time, Hales said the depository had hoped to bid its first job toward the end of September or the beginning of October. If the depository is well received, commercial work may be included.

The depository, which is incorporated and not for profit, is modeled after Las Vegas's bid depository. Hales said the Arizona group adopted the same rules and regulations. While the Las Vegas depository handles three projects a week, Hales said the Arizona office will start off slowly "to get the bugs worked out."

"The bid depository is going to provide us with a more stable field when we're bidding on projects."

Mike Kearney

The use of a depository could affect the way contractors bid projects. General contractors will have more time to put bids together. Subcontractors will bid within a uniformed scope of work and don't have to worry about bid shopping.

Currently, bidding is a race to beat the clock. Subcontractors send in bids as late as possible to dissuade generals from bid shopping. Thus, generals draw up bids within minutes of the bid opening.

"Contractors are looking for a remedy to the chaotic way jobs are bid," Hales said. "And this gives them a way."

Jim Hari, vice president of Vickers/Hari Contracting, represents the masons on the depository's board of directors. He explained that generals will get bids early enough to sit and analyze each bid while putting together their own package.

"It gives the general time to call up the low bidder with questions," Hari said.

Bid forms with a general scope of work will be printed for each trade. Hari said since the work will be standardized, there will be less chance for error.

"The bid depository is going to provide us with a more stable field when we're bidding on projects," agrees Mike Kearney, president of Kearney Electric and depository board representative for electrical contractors.

Bob Feger, senior vice president of

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The Institute for Professional Practice: a big factor in reducing liability exposure

A key to dramatically lowering a firm's vulnerability to liability claims is proper training of engineers concerning liability and ways to avoid it. The Institute for Professional Practice, a two-day seminar program, has been successful in providing such training. There are some lessons here, for practitioners and educators, on how to organize a highly effective short course.

THE ASSOCIATION of Soil and Foundation Engineers recently launched its Institute of Professional Practice and now is making the course available to all interested firms and persons. According to ASFE's IPP Chairman, George Hervert, of Woodward-Clyde Consultants: "ASFE has spent more than $100,000 to develop the Institute of Professional Practice. To date, some 250 students—primarily middle management employees of member firms—have participated in the IPP course, including a series of seven seminars."

The program was initially established to provide soil and foundation engineering firms' personnel with an awareness of what it means to be a professional. In theory, this training should be provided by key firm members in a position to share wealth of professional experience. In reality, these people seldom have the time.

The Institute of Professional Practice was created to fill the gap. A truly significant side benefit of IPP: many firms sending people to the course have lessened their exposure to liability. Says Hervert: "the overview provided by IPP gives participants an in-depth awareness of the nontechnical aspects of consulting engineering and geotechnical or soil and foundation engineering. As such, they are far more aware of the ramifications of everything they do as members of professional organizations."

Unique aspects of course

The course is divided into two elements: home study, research, and testing; and a two-day seminar. Once enrolled, students receive a variety of books—one prepared exclusively for IPP use and supplemental works covering 12 specific subjects. They are: history of civil/soil and foundation engineering; professionalism; economics of the firm; communication; the individual; group behavior; motivational theories; conflict resolution; client development; tort law; contracts and evidence; and insurance.

These are subjects not covered in formal college and post-graduate engineering courses. Yet they are essential if an individual is to act as a professional. "It's a sad fact of life," observes Hervert, that some professionals will go through their careers without full knowledge of many of these subjects."

Students are given standard reading assignments encompassing all 12 subjects. Assignments completed, they take an open-book examination, which is sent into ASFE for grading. Those passing can participate in an IPP seminar; those failing—very few do—are encouraged to re-read materials and take the examination again.

Next, a student is given a specific subject—one of the 12—for comprehensive research. The student may use any reference materials, including interviews and questionnaires, to develop a 30- to 45-minute talk to be presented at the seminar. Although presentation by students at a seminar may seem unusual, this is exactly what a seminar is supposed to do. According to Webster's, a seminar is: "A group of advanced students studying under a professor with each doing original research and all exchanging results through reports and discussions." In the case of ASFE's Institute, professors are "facilitators," individuals with extensive backgrounds in the 12 subjects.

Seminars stress student participation

Seminars last for two days and are held at isolated locations, minimizing the distractions of in-town and resort locations. Seminars are divided into classes of 12 students, each responsible for one of the 12 areas; a facilitator is assigned to each class. In the first class session, facilitators present an overview of the 12 subjects. Following this, attendees make their presentation on a given subject. Facilitators and students then comment and question.

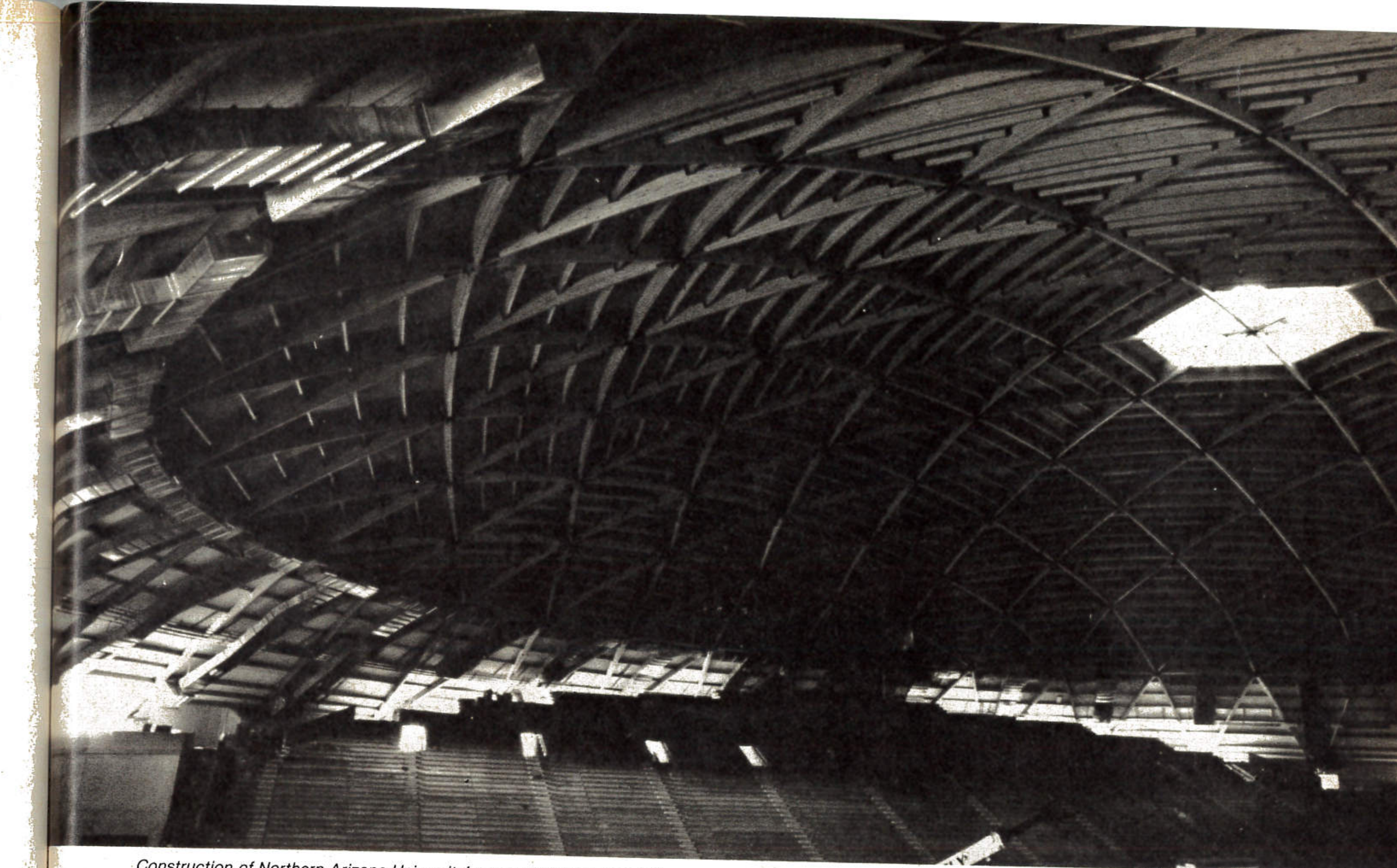
Students study case histories of actual problems in consulting firms. They analyze these cases to identify why problems occurred and what could have been done to prevent them. For example, was there a failure to communicate well? If so, what should have been said by whom, and when? Were personnel policies inappropriate? If so, how should they have been restructured? In fact, it is analysis of these case histories that brings all the experience of seminar students to bear, examining problems from 12 or more points of view.

During the seminar, students are also involved in role playing using actual case histories. Each student is assigned a specific role and participants are given information pertinent to that role that others involved do not have. Thus, one will play owner, another principal, etc. According to Mr. Hervert, himself an IPP graduate: "The role playing aspects are among the most significant. There's no better way to learn what empathy is all about than by putting yourself in the other guy's shoes. Role playing does just that. By being empathetic, by knowing how someone else is apt to be thinking by virtue of his position, an individual is more capable of conducting himself in a manner conducive to a successful outcome for all parties concerned."

ASFE is optimistic about the future of IPP. According to ASFE President Walter Lum, "The entire concept of IPP was to make it modular. There are 12 basic subjects: some relate to virtually all engineering disciplines; some to civil engineering in general; and some to soil and foundation engineering in particular. By changing a few of these modules, the program could be made applicable to other disciplines easily. And other organizations, of course, would have the benefit of our own experience, testing, research, and development."

The cost of the program to representatives of ASFE member firms is $450: $200 for the home study materials and testing; $250 for the seminar. Attendees or their firms must also bear the cost of transportation, lodging, meals, etc.

For more information on the Institute of Professional Practice, contact ASFE at 8811 Colesville Road, Suite 225, Silver Spring, Maryland 20910. ▽



Construction of Northern Arizona University's new multi-purpose stadium nears completion. With a span of 502 ft, the dome is the largest wood dome in the U.S.

Timber Dome roof over stadium spans record 502 ft

Varax Dome, a 502 ft (153m) diameter engineering marvel of glue laminated timber, was built in record six months erection time. This dome shell structure forms both walls and roof for the new $8.3 million Northern Arizona University multipurpose stadium, to be completed next month. Careful architectural planning provided the University with substantial enclosed floor space for a bargain basement price. Additional future savings will be realized from advanced thermal design, which keeps energy consumption very low.

MARSHALL R. TURNER, President
Western Wood Structures, Inc.
Portland, Oregon

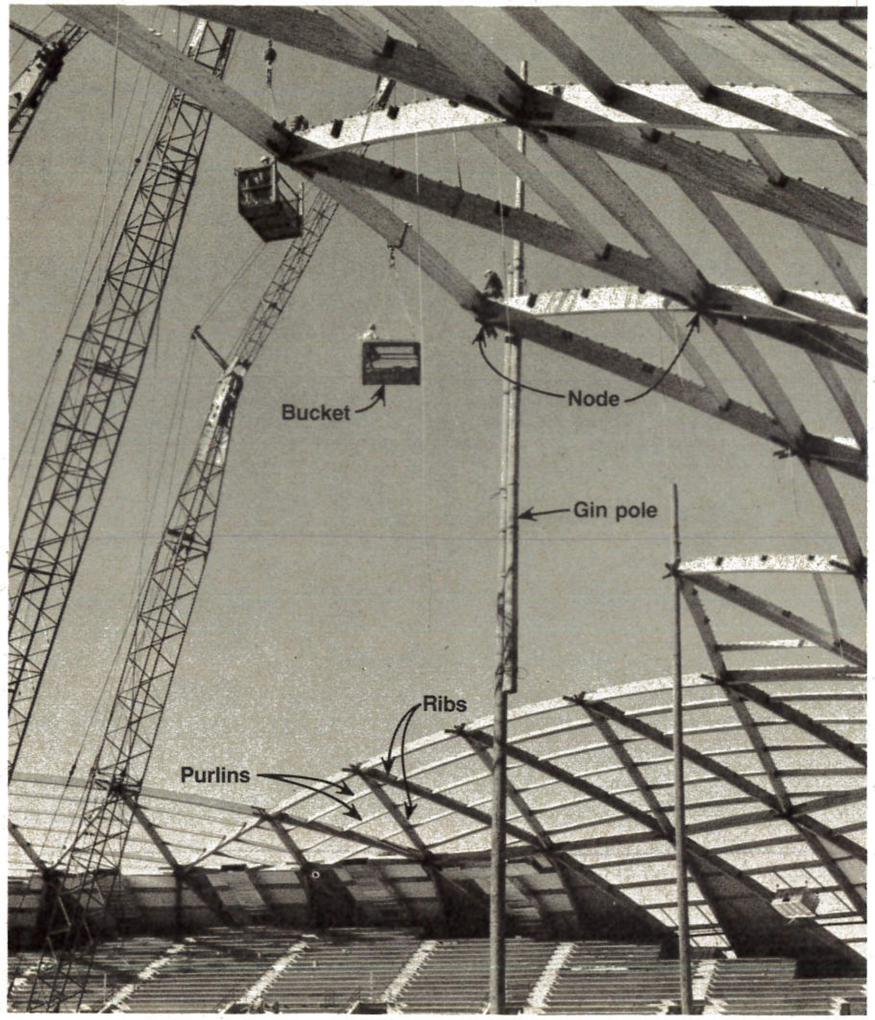
CLIMATE, EXCEPT FOR THOSE rare days in June, is usually not welcome by a large audience attending today's sporting events. To the owner, "it looks like rain" causes lost ticket sales and income, and the term "rain check" is as old as baseball. The black and blue Central Division of the National Football League means blue with cold as well as bruises in the late November and December games.

A desire and a need does exist among cities and universities to provide enclosed facilities for the protection of ever larger spectator crowds and sport contests. Today there are fewer than a dozen covered stadiums in the United States large enough for a football game. High construction costs and completion times that overrun contract dates have combined to convince many planners that large covered multipurpose buildings are not practical.

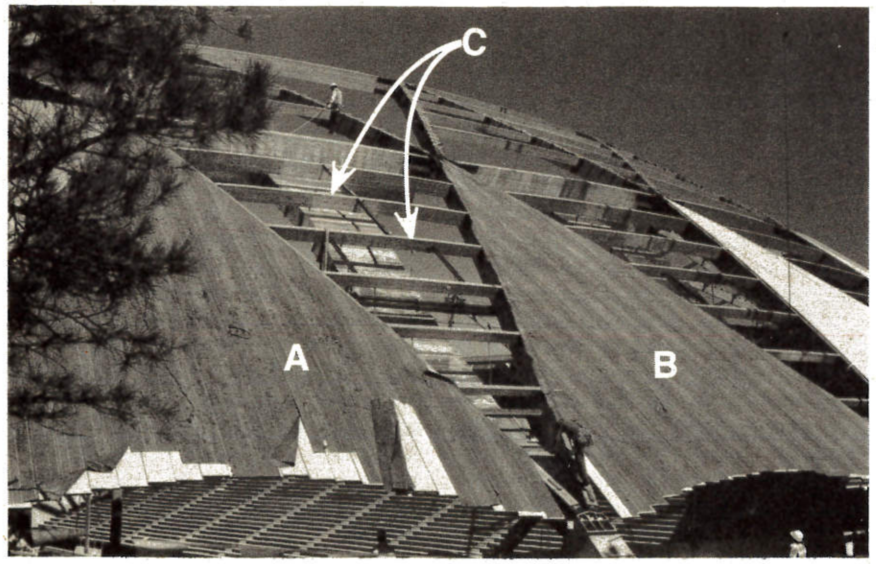
Well, the Board of Regents of the University of Arizona may have changed that thinking. Their Northern Arizona University of Flagstaff is 7000 ft (2289 m) above sea level. Flagstaff has 96 in. (2.4 m) average snowfall to consider, and winter comes early in November and below freezing nights continue well into May. The Board has responded to this need by authorizing construction of the ENSPHERE, a major size multipurpose sports, cultural and recreation stadium to provide a warm, quiet indoor atmosphere for many outdoor sports. The ENSPHERE is based on the simplest concept of a dome resting on ground level and spanning 502 ft (153 m) to cover 6.2 acres (25090 m^2) or 270072 ft^2. The Houston Astro-Dome, by comparison, is 504 ft (153.6 m) in diameter.

This remarkable new university building, contracted for a slim 8.3 million dollar price, is an answer to today's tax payer demand that college facilities be for all students. It will make all sports, sports for all seasons. Also, the ENSPHERE will permit a big range of local community sponsored activities, from musical performances to rodeos and motorcycle shows.

The university physical education department will be allowed flexible scheduling of non-varsity sports activities in intramural and exercise classes, all in



1. Workers erecting the wood dome. A rope hanging from the top of the gin pole helps support the node near center of photo. As soon as the bottom-most ring of triangles has been erected, and the decking nailed down, workers begin installing HVAC ductwork—saves time. The crane helps position purlins, most of which are bolted in place after the triangles have been erected. Note the use of the bucket to position men to bolt components together. Prior to OSHA, it was common practice for erectors to walk up on the top surface of the ribs to do the bolting.



2. Erection procedure was this: erect prefabricated triangle (a), erect triangle (b), then bolt purlins (c) in place. Triangles were decked almost at once to: help stabilize the structure; allow HVAC work to proceed on inside of structure (see photo); and to promote safety—e.g. no hammers dropping on workers below. Note buttress providing support for the node.

combination with varsity athletics. This is possible because the ENSPHERE has a 212 x 457.5 ft (64.6 x 139.4 m) level concrete play field, covered with a continuous resilent flooring for various court sports. This flooring is marked permanently with all lines for 10 basketball or tennis courts, and special applied tapes will be used to mark other games such as volleyball and badminton.

The architectural plans provided inserts with capped flush covers set in the concrete floor to hold tennis net standards and such necessary accessories as take-off boards for the long jump. A national league size hockey rink has been built in one corner of the floor, and it is complete with inserts for the dashers. The ice making equipment is designed to freeze either 1/3 or all the rink surface, depending on the intended ice use.

And finally, a five lane 1/5 mile (322 m) running track with a permanent synthetic surface and lane markings encircles the field. For the field sports such as football or soccer, the entire concrete play field and running track will be covered with a rolled in place artificial turn and impact pad.

Ensphere design firm

This beautiful new ENSPHERE stadium concept was developed by Rossman & Partners, a Phoenix, Az. architectural firm. They departed from the conventional high cylindrical wall approach to stadium design when their preliminary cost analysis indicated that one construction dollar out of every three would be spent for the walls. By contrast, only a small part of large savings generated by eliminating the walls would be needed to pay the cost of field excavation to a depth of 30 ft (9.1 m) (see photo 8). This allowed one-half the seating system, two opposing parallel single slope precast concrete grandstands, to be built in the excavation. The grandstands accommodate 15,200 plastic seats in 43 vertical seating rows, with the first seating seven ft (2.1 m) above the field level. Spectator sight lines permit free view of all field activities in the direct down slope direction to within 15 ft (4.6 m) of the first row. Twenty vomitories, at about half height of the grandstands and 30 ft (9.1 m) above the play floor level, lead to the concourse spaces. Each of the two large concourse areas behind the grandstands has 17,000 square ft (1580 m^2) of public space, interconnected through balcony walks. The general offices and concession rooms are located here, together with ticket sales booths, sound control rooms, public rest rooms and telephones.

The concourse areas open directly to the outside through 128 exit doors at 16 exits, and in addition the field level has 14 more doors to the outside. This public concourse space will serve both the college and the community for open meeting and display area.

The ENSPHERE will be heated and cooled using 36 hot water heating units suspended from the glulam roof framing above the concourse areas. Thirty of these units are designed to pull in outside air, so that cool night summer air can be stored to air condition the building for day use, and air warmed by the winter noon sun can be utilized for evening heat. This design extra will keep the estimated total energy costs including field lighting to under $4,000 a month, based on 1975 rates for electricity. This is an important factor in reducing the total life cycle costs of a building.

The VARAX timber dome is easy to climate control because semi-rigid insulation is applied to the exposed inside face of the two-inch deck (51 mm). This single material provided four instant advantages:

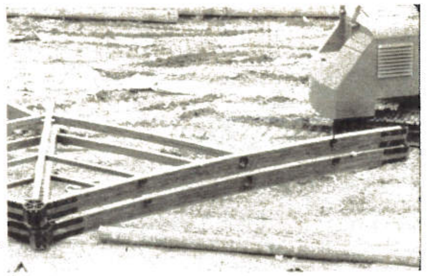
- A .09 U-factor (R-11), even more reduced in combination with the excellent insulation properties of the two-inch (51 mm) wood deck. This makes the storage of outside air feasible.
- A 0.65 noise control coefficient, which reduces reverberation time within the dome to $3\frac{1}{2}$ seconds. This approaches the sound control present in concert halls.
- A white vinyl plastic face, which saved the cost of painting and provided a beautiful light reflective ceiling.
- A 25 flame spread rating, which reduces the danger of fire. The heavy glulam sections act as draft curtains to further minimize this potential.

General description of roof structural system

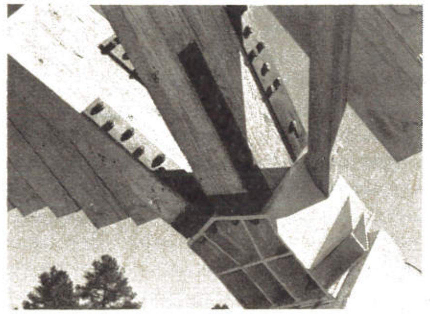
The ENSPHERE shell is a computer engineered VARAX dome, developed by Western Wood Structures, Inc., of Portland, OR. The VARAX dome structural system is a true spherical framework of glue laminated timber ribs on intermeshing great circle arcs. The glulam ribs form triangles, connected by 127 unique patented steel hubs. Each triangle contains simple span purlins set at 8′0″ (2.4 m) on center maximum spacing. This framework is covered with 2-inch (51 mm) thick tongue and groove wood deck, in specified lengths so the end joints are on supports.

The VARAX dome was designed to meet these physical measurements:

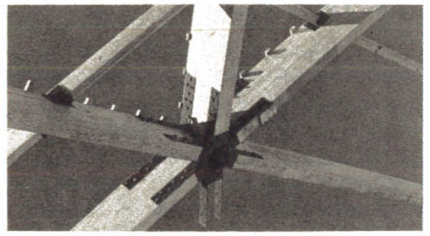
Number of Buttress Supports = 36; Dome Span, C to C opposing buttress faces = 502 ft (153.0 m); Spring Angle @ Buttress = 40° 18 ft 32 in.; Dome Rise = 92 ft $4\frac{11}{16}$ in. (28.16 m); Spherical Radius = 389 ft $1\frac{1}{2}$ in. (118.6 m); Dome Base Area = 198,000 ft^2 (18,395m^2); Dome Surface Area = 225,900 ft^2.



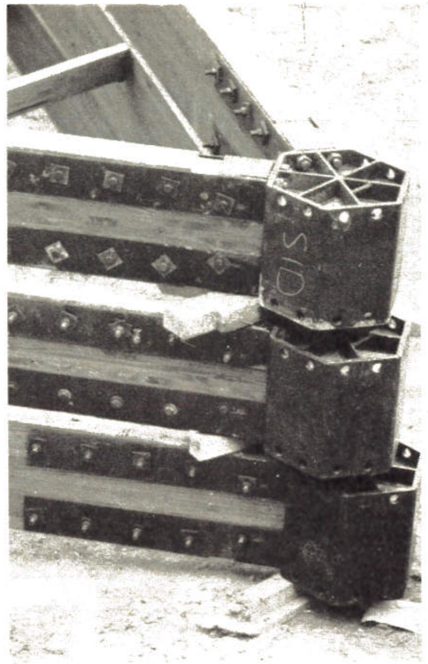
3. The first step in erecting the wooden dome is to assemble the triangles (See photo). Carpenters bolt together prefabricated triangle components. The idea is to assemble as much as possible on the ground—much faster and cheaper than aerial assembly.



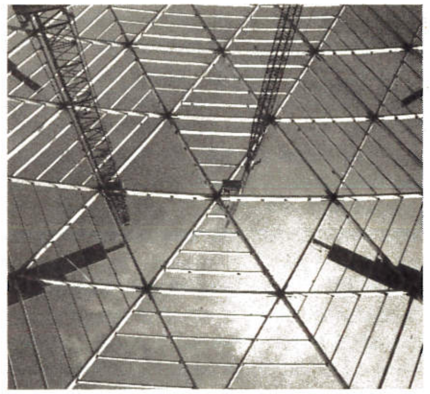
5. Details of a node at a buttress. If you look closely, you can see the laminations on far-left rib. 27 in.-deep rib consists of 2 in. deep X 8 in. wide boards stacked on top of one another and glued. Why use laminated ribs? Without laminating, it would be impossible to get members this large.



6. Connection details at one of the nodes in the wooden dome. Under normal dead and live loads, all main rib members are in compression. With unbalanced loading conditions (e.g. snow or wind on only one side of the roof), though, some members may go into tension. Thus, node connections must be able to take both compression and tension.



4. Connecting hardware at a node. The wood is Southern Yellow Pine. Why pine? It grows fast, is readily available, is strong structurally, has good bending and modulus of elasticity.



7. Here is the most crucial step in the entire roof-erection process: installing the last hub (node). If everything has been done precisely, it will fit. If not, well . . . Note that sheathing is being nailed down on all dome sections simultaneously. Such prevents dome distortions and speeds the project.

All glulam main grid members and purlins are curved to the spherical radius (photos 0 & 1). The length along the top is different from the length along the bottom because the steel hubs set at varying angles of inclination. The grid members range from 19 ft 4 in. (5.9 m) to 61 ft 9 in. (18.2 m) in length, and vary from $8\frac{3}{4}$ x 27 in. to (222 mm x 686 mm) $12\frac{1}{4}$ x 27 in. (311 mm x 686 mm) in size. The Southern Pine glulam members were fabricated by Unadilla Laminated Products, of Unadilla, N.Y.

Forces are distributed from the wood deck to purlins and grid member triangles, to the 36 reinforced concrete buttress supports, which are 5 ft (1.53 m) high. Horizontal thrusts are resisted through a cast-in-place post tensioned concrete ring beam 1580 ft (481.6 m) in circumference. All but 175 ft (53.3 m) of this ring beam is earth covered (see photo 2).

The buttresses were poured in stages with the tension ring and the 8-in (203 mm) thick concourse slab. Each is supported on two 3 ft (.92 m) in diameter caissons drilled up to 35 ft (10.7 m) deep.

Method of force & design analysis

A dome 450 ft (137.2 m) in diameter with 36 supports was first planned by the architectural firm. This would have

8. Section through stadium. Note that dome goes all the way to the ground, eliminating costly vertical walls often used with many stadiums. To do this, the playing field must be below ground. Thus, the expensive wall and aerial compression ring of a conventional stadium is replaced by the far more economical shell surface and ground-level compression ring. Some of the horizontal force exerted on each buttress by roof ribs is taken up by a tension ring linking all the buttresses together. Of course, each buttress could be designed large enough to take the entire horizontal force. But it is more economical to go with moderate-sized buttresses and a tension ring.

9. Northern Arizona University wooden dome nearing completion. With a diameter of 502 ft, this dome is the largest such wooden structure in the U.S. In the future, there are likely to be many more stadiums covered with wood. For wood has numerous advantages: it's readily available; takes less energy to transform the raw material into a finished product than either concrete, steel, or aluminum; it's a good insulator and doesn't provide a surface for moisture to condense on and cause dripping on the inside; wood is a renewable resource; it can't be attacked by chemicals; and it is very attractive economically. (CE thanks Mr. Thomas W. Jones, Unadilla Laminated Products (Unadilla, N.Y.), for providing most of the photos in this article. Captions are based on an interview with Unadilla's Mr. Raymond C. Haag by CE staff.

required a VARAX dome pattern of six repeating 60° sectors, each with six points of support and 5.75 equal zones or frequencies of great circle grids measured from the center hub along a sector line. When the ENSPHERE diameter was established at 502 ft (153 m), the great circle grid was reduced to 5.67 equal frequencies 402 ft (123 m) in diameter and a perimeter ring zone 50′ (15.3 m) wide was added.

The geometry coordinates for main member lengths, dihedral angles at tri-corners, and triangle areas determined with a computer program. The dome loading conditions, established by the architects and John K. Parsons, Consulting Engineer, were: 40 psf (195.3 kg/sq m), snow load; 17.4 psf (85 kg/sq m), actual dead load; 37.5 psf (183.1 kg/sq m), wind load.

Additional asymmetric hanging loads, consisting of a 16 x 60 ft (4.9 x 18.3 m) press box platform and two lighting bridge catwalks, were added. A total of 15 elementary loadings and 24 combined loading sets were investigated to find the loading combination that produced critical design stresses.

Nine months of computer engineering skills and technical planning were needed to analyze the VARAX dome. The VARAX geometry, material member properties, along with each loading case, were key punched onto computer cards and fed into GENSAP, a TRW Systems Group licensed computer program. This program solves for forces and joint displacements using the direct stiffness finite element method and matrix decomposition.

The printed data obtained was used to draw force maps of each combined loading case. Member forces were indicated as line widths, scaled to represent the force size and colored red for tension or black for compression. These maps helped to eliminate the redundant members and to find the set of sub-critically loaded members.

Each sub-critical member was then reloaded with actual purlin loads, plus combined uniform loads and axial forces. Calculations for shear and bending moments were listed in table form, so previously assumed member sizes could be calculated and checked for adequacy. Member sizes were checked for combined bending and axial stresses using maximum bending moments produced from an assumed 50% end fixity and full axial force. Member end condition was checked, using forces produced assuming full end fixity.

Computer routines were used again to produce the moments tables, and the members analysis.

Varax hub connections

The VARAX dome system uses steel connectors to pull six glulams into a patented steel hub or node (patent 4,005,561). The hub transfers the moments into a system that approximates a continuous or diaphrymetric dome, thus creating similar moments of inertia at every point in the system. This enables the dome to work as a unit and not a series of small individual triangles.

The steel connectors are made up of the hub itself, or S1 assembly, plus the glulam-to-hub connectors, or S2 assemblies (photos 4, 5, 6). The S2 assemblies consist of two steel side plates which transfer forces from glulam to steel using $1\frac{1}{8}$ in. (29 mm) diameter machine bolts and two large $1\frac{3}{4}$ in. (44 mm) diameter stud bolts welded to a heavy steel bridge plate, which transfers tension forces to the hubs.

Generally, the steel hub (S1 assembly) is a 27 in. (686 mm) hexagonal box formed by 1 in. (254 mm) face plates and $\frac{1}{2}$ in. to $\frac{5}{8}$ in. (13-16 mm) thick interior reinforcing and stiffening plates. A glulam member connection is made by inserting the stud bolts on the S2 assembly through holes in the hub face plate. Stud bolt nuts are torqued to specification, which pulls the glulam end bearing surface tight against the face plate and develops the moments connection.

Erection

The concrete buttress supports are rigid and would allow no tolerance for either fabrication or erection errors. The general contractor, Mardian Construction Co. of Phoenix, AZ., used laser beam instruments to set the buttress locations. The VARAX dome erection began with installing the heavy base hubs to proper elevation on the buttresses, so the 72 triangular sections in the outer ring zone could be erected. The glulam ribs in the ring zone were 61 ft (18.6m) long. All purlins for the ring zone were installed, and the 2 in. (51 mm) deck was placed before any interior glulams were raised.

This procedure permitted the general contractor to continue with other subcontracted work at the concourse. The hot water piping, along with the air exchange units and sheet metal duct work, was installed and hooked up. A start was made in the installation of the acoustical material, and a roof dry sheet was placed.

Meanwhile, Western Wood Structures erection crews were pre-assembling great circle arc glulams and hubs. These assemblies, usually two or three main grid members with purlins, were lifted by a single crane. Two other cranes were used to lift workmen in cages to secure the hub connections. The hub connections were self supporting, and gin poles were used only to provide a means of jacking members for ease in bolt installation.

Hub elevations were monitored on a regular basis and the glulam plant fabrications were so accurate that the final main member slipped easily into place, and the bolts were hand inserted. ▽

Rebar splices: cutting costs, avoiding errors

Information on splicing rebars is among the most-often requested by those using *CE's* Engineers Information Service. Here, a specialist with the Concrete Reinforcing Steel Institute tells how to minimize splicing costs, and gives do's and don'ts of welding splices.

PAUL F. RICE, M. ASCE
Vice President, Engineering
Concrete Reinforcing Steel Institute
Chicago, Illinois

THE ORIGINAL STRUCTURAL analysis and the preliminary selection of reinforcing steel areas required, are performed as if the entire concrete structure were built in one piece and the bars were full length, also in one piece. The next step in design is to consider how the concrete structure and construction joints can be built to fit in sequence with real bar sizes, spacings, and lengths to suit. At this point the designer leaves the world of science and theory and enters the real world where he really has to use judgment. The art of design consists of matching the requirements of science to the realities of splices, anchorage, and fitting together all elements at the least cost. As soon as cost is considered, the ccontractor's input is needed. An ideal design is probably impossible, but it would be one practical to build in several ways according to the ingenuity of the lowest bidder. Sometimes the contractor is brought into the picture in the design stage ("fast track"), but then the design is created to suit only one contractor and it is only as economical as the contractor selected. In the usual case, the engineer and contractor should confer immediately after the contract is awarded to work out the most economical solutions satisfying the design.

Holding down the cost

The theme of this presentation is to show the wide variety of solutions they can consider for splicing and anchoring reinforcing bars to perform as needed. Our interest is simply to help hold down the cost of reinforced concrete.

Any help we can suggest to avoid costly delays in field time for construction should help hold down costs. Most complications in reinforced concrete occur in the columns and their connection to roof, floors and footings where vertical and horizontal reinforcement must fit. These are the natural joint locations between placements and where splices of vertical bars, anchorage of horizontal bars, and design needs for confining ties and stirrups all meet.

It is difficult and costly for the designer to show really complete typical details here, and so the details are usually incomplete. Incomplete details are difficult to estimate, yet the contractor must complete estimates in a short time. The more acceptable choices the contractor has, the more likely he can pick the most economical solution for whatever conditions appear in the design. Under our latest Code using higher strength concretes and rebars, design requirements have proliferated. The engineer can no longer draw column verticals as one piece from the footing up, and the estimator can no longer read such a design as 24 bar diameters lap length at footing and each floor. At least, it should not be taken for granted by either engineer or contractor that the other party automatically wants the same detail.

Usually, the engineer shows some acceptable system of splices to fit his design needs and hopes it will be the most practicable and economical. The contractor estimates the cost, and hopes he was right. Ideally, the engineer originally considered several possible solutions, showed one, and gave specifications open to as many as possible. Ideally, the contractor considers alternate methods, and offers in his bid some reduction if he has a preferred alternate. This could be as simple as the contractor proposing two-story lengths with Class B tension lap splices instead of one-story length bars with Class C lap splices. (Some Class C tension lap splices become almost one story height in length.)

Compression lap splice

The compression lap splice is generally most economical. As tension lap splices go from Class A to B to C to D, they become progressively longer. By the time we reach Class C for Grade 60, #11 bars, the lap length in 3,000 psi (21,000 kN/m^2) columns becomes 116 in. (3000 mm) and finally at Class D, they are prohibitive for use since they require 18 per cent more lap, plus hooked ends and enclosing spirals. Lap lengths can be reduced if splices are staggered, or if splices are located in the center half of the column as required in seismic zones (see Figure 1). Lap splices are not permitted for #14 and #18 bars. These Code requirements, plus the high cost of hand welding larger bars, led to development of tension couplers, and for large bars, end-bearing splices to transmit compression.

Most columns are designed for compression stress in the vertical bars as this is critical. Tension, due to bending, usually increases the compression on one face and reduces the compression on the other. Sometimes low net tension can result. Compression lap splices usually are good for these low tensions (see Figure 2). Under these conditions for #14 and #18 bars, end bearing splices can be used by staggering somewhat to keep a few bars continuous throughout. End bearing splices represent substantial savings with the large bars as alternates to welding or couplers.

Typically vertical bars in such a column might be designed for 60,000 psi (414,000 kN/m^2) maximum compression and 10,000 psi (69,000 kN/m^2) maximum tension. In this case compression lap splices would be specified for bars up to #11. Since a compression lap splice (30 bar dia.) is one half to one third as long as a Class C tension splice, the compression splices would be more than adequate for the smaller tension stress. Suppose the lower stories required 8 to 16 verticals per column with up to six ties per set. If the tonnage involved made #14 and #18 bars available, the con-

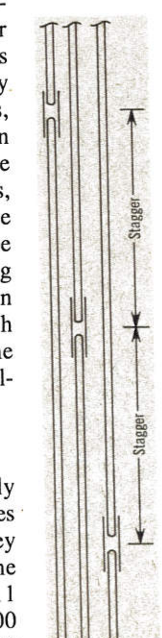


Figure 1. In bundles splices for compression only some stagger is provided, usually 2 or 3 in., as an erection convenience to avoid bunching splice devices all at one point. Compressive capacity for this arrangement is taken as 100%. If the stagger is made equal to the tension lap length required, this arrangement is assumed to provide a 50% tensile capacity for a 2-bar bundle, 66% for a 3-bar bundle, or 75% for a 4-bar bundle.

C L E A R - S P A N

TIMBER DOMES

BY WESTERN WOOD STRUCTURES

The Tacoma Dome, Tacoma, WA

multi-purpose entertainment arena • major sports stadium • ice rink • swimming pool • church • civic coliseum • gymnasium • equestrian center • convention hall • museum • industrial storage facility

...timber domes provide versatility of clear span design...for less money...

Yesterday's domed stadiums were massive concrete and steel structures, or large tents. They were expensive to build and maintain and limited in terms of function. They lacked intimacy and they overlooked the importance of good acoustics, pleasing aesthetics and multi-purpose programming.

Today a Western Wood Structures timber dome can match the size and strength of yesterday's superdomes for less money, while providing the true multi-purpose flexibility needed to maintain a profitable bottom line.

The Western Wood Structures designed dome incorporates the versatility of clear-span construction with wood's strength, beauty, economy and energy-efficiency.

Tacoma city skyline is now dominated by the Tacoma Dome.

...dome structure of tremendous strength...suitable for all climates...

Computer Technology. Western Wood Structures uses a computer program developed to analyze a timber structure for all possible loading conditions. This program performs rapid calculations of member forces, greatly reducing costly engineering time.

Design. The Western Wood Structures dome is a true spehérical shape which

Steel (VARAX) hub provides continuity in transfer of member forces.

uses curved glue-laminated (glulam) timber ribs connected by patented steel hubs. These VARAX™ hubs allow tension and compression forces within each rib to be shared by adjoining ribs. The result is a dome structure of tremendous strength. It is suitable for all climates and any combination of snow, wind or seismic loads. Interior concentrated loads from suspended scoreboards, speakers, field lighting, HVAC plenums, and press boxes can be easily accomodated.

Materials. A Western Wood Structures dome uses plant fabricated,

Ground level assembly eases construction.

Weyerhaeuser First Choice™ glulam beams trimmed and drilled to within 1/16" dimensional accuracy. A two-inch thick timber roof deck provides natural insulation and complete environmental control. Fiberglas, applied as a white, vinyl-faced blanket to the interior surface of the deck provides additional insulation, acoustical enhancement, light reflection and reduced flame spread.

Erection. Accurate pre-fabrication facilitates the ground-level assembly of glulam into triangular shaped elements. This safe, cost-effective construction technique allows Western Wood Structures' supervisors to use all local labor. The triangular elements are lifted into place and connected at the steel hubs. Since each element is self supporting, interior scaffolding is eliminated, and other work can proceed during dome erection.

NBA action at the Tacoma Dome.

...cost effective construction technique...can lower costs by 20%...

Construction Savings. A Western Wood Structures timber dome allows designers to utilize one of the building's least expensive components, the roof, to supplant one of its most expensive

Wide concourse a benefit of dome shape.

elements, the supporting wall system. A Western Wood Structures dome over an excavated area can lower overall construction costs by as much as 20%.

Energy Savings. Wood is a natural insulator. A Western Wood Structures dome combined with applied synthetics delivers R-values of 30 or more. As a thermal barrier over an excavated area, a Western Wood Structures dome can lower utility costs by up to 75%.

Flexible seating arrangement allows facility to be used for sports as well as meetings. (Chiles Center, University of Portland)

Increased Revenues/multi-use. Concert-hall quality acoustics (reverberation time 3.2 seconds) are achieved, even within stadium spans. Also, more types of events can be scheduled within a fully controlled environment which allows shadow-free television lighting or a darkened house—any time of day. In addition, the dome's great structural strength can be used to suspend lighting and sound equipment, to attract artistic events as well as sports contests.

Safety. The Western Wood Structures dome will perform well in protecting life and property in the event of a fire. Its heavy timber members have excellent fire resistive qualities. Timber retains its strength

Chiles Center, University of Portland.

under fire longer than unprotected metals, which soften and collapse suddenly under extreme heat. Heavy timbers resist heat penetration by the formation of self-insulating char.

Further, the Western Wood Structures dome is designed to expel noxious gases through a cupola opening at the apex of the roof.

Aesthetics. People relate positively to the inverted bowl shape of a dome. It is a wonderful reflection of nature.

The exterior makes a friendly statement, displaying balance and perfection of line. This contrasts nicely with the squares and rectangles of modern cities. The dome is a setting sun when seen through the canyons of a city block.

...concert hall acoustics in a stadium span...

Inside, a Western Wood Structures dome is both warm and bright. The absence of columns affords open, cathedral-like aesthetics and excellent sight lines from any seat. The curved timber ribs arch gracefully above the arena imparting a feeling of intimacy which harmonizes with any event.

ENGINEERING DATA

Diameter: 80 to 800 feet
Height: Diameter x 0.15 to 0.18
Shape: Spherical, ellipsoidal or non-spherical (curved rectangle)
Support: Columns or buttresses, below intersection of glulam members at perimeter. Five to nine segments with two to eight columns per segment.

Data required for pricing

1. Proposed building use
2. Span/Rise: Desired diameter and rise
3. Wall construction: Height, material and required number of supports.
4. Building code*, live load, dead load and suspended loads.

*Note: Timber domes are permitted under the requirements set forth in the UNIFORM, BASIC/NATIONAL and STANDARD model codes. Western Wood Structure domes are classified as "heavy timber" construction, designed to be in compliance with the three model codes. Specific requirements may vary with code, and local codes should be checked.

For questions and help with preliminary pricing contact Marshall Turner or Barton Eberwein **800/482-4004.**

CLEAR-SPAN **TIMBER DOMES**

- ***Safe and Strong***
- ***Low Construction Cost***
- ***Low Maintenance Costs***
- ***Multi-Use Capability***
- ***Aesthetic Beauty***
- ***Suitable for All Climates***

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