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SDC
SOLENOIDAL DETECTOR NOTES

FEASIBILITY OF LARGE BLOCK DESIGN FOR THE SDC MUON BARREL

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0.1 Introduction

The steel in the muon barrel for the SDC will weigh about 16,000 tons. Piece size is one of the important design issues. Large pieces have several important advantages. The flatness and thickness variations inherent in steel plate can be easily dealt with as the plates are "pre-assembled" into large blocks at a machine shop or shipyard. Subsequent machining of the blocks insures good tolerances. Assembly of the large machined blocks is relatively easy because the tolerances are good and the number of pieces is small. The amount of bolting required is also low. The final tolerance of the assembly is good because the tolerance of each piece can be controlled and the stack-up of tolerances is limited by the small number of pieces. The difficulty in working with large blocks is their weight. The machining, transportation, and assembly of pieces over 50 tons requires special tools and people. An important step in considering a large block design is the investigation of the resources available (in the U.S. especially) for heavy fabrication. This report is a feasibility study for an early large block design. It includes company names and contacts for plate production, welding, machining, transportation, and assembly of 290 ton pieces.

0.2 Design Concept

The proposed geometry for the barrel steel is a "cylinder"with an axis along the beamline. However, the "cylinder"has an octagonal cross section instead of a circular cross section. The length of the steel is 24.09 m (948.5 in) centered on the interaction point (IP). The radius from the IP to the closest surface of the steel is 7.07 m (278.2 in). The thickness of the steel wall is 1.50 m (59.1 in).

It is best if the steel plates are approximately perpendicular to the particles leaving the IP. This way the particles will not travel along any gaps in the steel. This arrangement of plates also insures the magnetic field will travel along the length of the steel plates and jump a minimum number of air gaps. Since plate comes in straight sections, it is logical to split the steel at the corners of the octagon. To keep the plates and blocks to a manageable size, there must also be some splits along the axis of the steel.

The drawings in Appendix A show one possibility for a large block design. Looking at the steel from along the beam axis eight pieces are visible. One of these pieces forms each side of the octagon. Looking at the steel perpendicular to the beam axis seven divisions can be seen. There are a total of 56 - 290 ton pieces (note: one ton is 2000 pounds). Each piece is 1.50 m (59.1 in) thick by 3.44 m (135.5 in) wide with a length that varies from 7.10 m (279.4 in) to 5.85 m (230.4 in). The pieces are built up by laminating plates that are 135 in wide and between 230 to 279 in long. The thickness of these plates depends on the steel mills production capabilities.

The blocks must be bolted or welded together at the corners to overcome the large moment trying to separate them. There are many ways to attach the blocks. Hand calculations show that a two inch diameter bolt every six inches along the tension side of a joint will carry the moment. By threading half of the clamp bolts into one block and the other half into the other block the bolt heads can be spaced twelve inches apart. There are many possible bolting solutions that should be explored for cost and reliability in the final design process. Welding could also be used to hold the blocks together, but difficulties with distortion, welding position, and in place inspection make a bolted design more appealing. Some bolts should also be used to attach the blocks axially and on the compression side of corner joints. These bolts will add safety while insuring good magnetic contact at the joints.

There are many possible variations to this basic design. The height could be increased to allow more room for calorimeter support. The corners could be adjusted so the joints do not point at the IP. Special corner pieces could be used to allow keying the joints or special bolting. Small step could be added to the blocks to facilitate assembly and improve alignment. Holes and pockets could be added to the surfaces of the steel for mounting muon chambers or their support structures.

0.3 Experience from the Zeus Detector at DESY

The steel for the muon system for the Zeus Detector at DESY has a weight of 2262 tons (note: one ton is 2000 pounds). This steel yoke also has the shape of an octagonal cylinder, but it has caps on both ends. The yoke is made up of 25 pieces weighing between 47 and 170 tons. The yoke was designed by the U.W. Physical Sciences Lab (UWPSL), fabricated by Bremer Vulkan, and assembled by Lastra. Some drawings of the Zeus iron yoke are included in Appendix B.

This steel system has enough similarities to the proposed large block design outlined above to be instructive. The octagonal shape was chosen because it reduced the steel required by about 30%, provided a more uniform magnetic field with less amp turns, and simplified particle mapping. The large piece design was chosen over a small piece (all pieces less than 40 tons) due to reductions in cost and assembly time. Tolerances of the final steel assembly were also an issue. A survey of the completed yoke showed that the largest deviation from the nominal position was 1.5 mm (0.059 in). The cost of the steel with energizing coils was about $0.80 per pound. This number is rough since the actual cost was in german DM and the exchange rate bounces around. The order for the steel was placed in December 1986. Bremer Vulkan received the steel as 73 mm (2.87in) plate, welded the blocks together, machined the blocks and did a test assembly at their factory. The test assembly was made between March and May of 1988. Lastra transported the blocks over the road with heavy haul trucks, erected portable gantry systems above the access shaft and in the hall, and assembled the blocks using these gantries. The assembly was started May

19th 1988 and completed June 28th 1988.

The zeus detector demonstrates that steel detector components up to 150 tons can be machined, hauled, and assembled in a cost effective and timely manner. Further, the good tolerances and short assembly time suggest this is an attractive method.

0.4 Steel Plate Production

The thickness of steel plates used for the laminations is determined by steel mill capacities. Two steel mills in the united states were consulted.

- U.S. steel
  - Phone: 1-800-882-4019
  - Contacts: Ann Hobbs (sales), Bob Lumberg (Metallurgy)
  - Capacity: 135 wide x 279 long x 3.5 thick is possible (inches)
  - Rough cost estimate (not a quote): $ 550.00 per ton
  - Tolerances: Thickness +0.15/-0.01 inch, Flatness 0.88 T.I.R., Half standard flatness 0.44 T.I.R. available for about $10.00 per ton. The flatness numbers are for a 12 foot wavelength, but Bob expects only one wave per plate (no ripple).
- Bethlehem steel
  - Phone: 215-694-2424
  - Contacts: Tom Kovacs (sales)
  - Capacity: 135 wide x 279 long x 4 thick is possible (inches)
  - Rough cost estimate (not a quote): $ 581.00 per ton
  - Tolerances: Thickness +0.15/-0.01 inch, Flatness 0.88 T.I.R., No information yet on half standard tolerances

Laminating the blocks out of plates about four inches thick is reasonable. Two of the large steel mills in the U.S. can produce the plate. There are many other steel mills in the world with larger capacities. Each block would contain 15 to 17 pieces. The largest piece would weigh about 21 tons. To deflect a four inch thick plate simply supported with a twelve foot span 0.88 inch requires only 20,000 pounds. The plates could easily be pressed flat with hydraulics or dead weight. The plates would be held flat by welds. The worst case thickness build up is 2.55 inches, but plate sorting and machining can be used to improve this number. It would be a good idea to design for plates close to the maximum thickness and shim if the plates end up stacking thinner than this. The extra thickness also allows for some flatness variation. These plates are small enough that they can be readily shipped by standard rail or oversized truck. This plate size is a practical upper limit because of both mill capacity and transportation width. Two thicker plates half as long may be used for the outer and/or inner layers to improve bolting possibilities.

0.5 Fabrication and Machining of Large Blocks

Working on fabrication and machining of very heavy pieces requires large cranes, machines with extra large load capacity, and access to transportation by rail and boat. The following companies have all of these things.

- Babcock Willcox
  - Phone: 812-838-1213 FAX:812-838-1210
  - Contacts: Paul W Maurer
  - Comments: 1000 ton crane. Talked about plug welds in plate center. 4 inch thick laminates are good for them if thick enough for bolts. Very interested.
- National Machine and Hydraulic Co.
  - Phone: 201-499-9800 FAX: 291-499-9573
  - Contacts: Pauline Balogh
  - Comments: Size no problem. Port Elizabeth
- CBI Industries (Chicago Bridge and Iron)
  - Phone: 708-572-7000 FAX: 708-572-7405
  - Contacts: Don Coors
  - Comments: 2-600 ton gantry cranes. Very interested in the politics. Would want to consider setting up and machining in the field with their portable mills.
- Marathon LeTourneau Marine Co.
  - Phone: 601-636-4132 FAX: 601-636-1291
  - Contacts: George Williams (production), John Wallace (purchasing)
  - Comments: Can straighten plates. 400 man shop crew. Have a portable boring mill large enough to do the job. Build their own cranes. Have specialty steel mill. Very helpful with help to contact steel mills. Very interested.

- Avondale Industries
  - Phone: 504-436-2121 FAX: 504-436-5375
  - Contacts: Jake Kaul (Shop)
  - Comments: Can handle and machine the pieces in their shop Can do the welding.

0.6 Transportation

The steel can be transported from the mill by train to the shop that will do the work. All the shops have rail access. The individual plates are not oversized load for the rail system. Once the pieces are assembled into blocks, the transportation becomes more difficult. The load is too heavy for a standard rail car, but a special car can take it. These cars can be rented. The blocks can be transported by rail to the rail head that is closest to the hall. Heavy transport trucks can then take the blocks by road or off road (depending on terrain) to the hall. These trucks have 13 to 17 axles that are hydraulically attached to the truck bed to insure load sharing. It will most likely be necessary to rent a crane to unload the blocks from the rail car and place them on the truck. Railroad contacts are listed below, but the trucking would be handled by the rigging contractors listed in the assembly section.

- Railway Equipment Corp
  - Phone: 1-800-334-2166
  - Contacts: Brian William
  - Comments: They have found a long car that can handle 450 ton. This car is not ideal, so they are looking for a better one. They can modify existing cars at their shop.
- Union Pacific
  - Phone: 1-800-272-8777 (ask for high and wide team)
  - Contacts: Julie Brown (Account Rep.), Robert Sherwin (High and Wide)
  - Comments: A normal Heavy Flat car is 10 ft - 6 in wide and 61 ft long. This car has a interior load section that is 35 ft - 11 in long. Cars like these are available and can handle the 290 ton load. Light cars would be placed before and after this car to prevent overload on bridges and and sections with soft bed. The block would be set on the car so that the 59 in by 279 in surface rests on the car. The rail car height of 5 ft - 2 in plus the 135 in block height comes to 197 inches. This is not a problem for the railroad since some standard box cars are 210 in tall.

- AAR (Association of American Railroad)
    - Phone: 1-202-639-2100 (switchboard) 202-639-2396 (heavy car assign)
    - Contacts: Jim Pearsall
    - Comments: Jim suggests a FM-12 axle car. They have a net load capacity from 300 tons to 370 tons. The height above rail is 48 to 52 in. There are 12 of these cars that Jim can access. AAR acts as a car clearing house for the U.S., Canada, and Mexico.

0.7 Assembly in the Hall

The assembly of the large block design can be accomplished in many ways. The most straight forward idea is to assemble the steel with large boom cranes before the hall roof is constructed. This is unlikely to happen due to schedule constraints. The standard idea is to use two cranes after the hall is completed. The above ground crane would lower the blocks down the access shaft. This crane could be a gantry, boom, or more permanent overhead installation. The crane in the hall that would be used to move the pieces to their final positions would need to be either a gantry or an overhead crane. A unique idea proposed by Mammoet Transport is to build the hall with an extra strong crane rail that their company could use for a portable bridge. This bridge is the upper half of the gantry without the legs. A third method would use long stroke jacks (20 to 40 ft) and cribbing to move the blocks into position. This is not very attractive due to the shape of the steel.

There is equipment available from U.S. heavy haul firms for all of these methods. The cost and convenience of renting crane equipment versus installing permanent equipment should be looked at carefully. To do this job with permanent overhead cranes would require a minimum of two 150 ton cranes or one 300 ton crane in the hall. Buying a 100 ton crane and renting a 300 ton bridge to ride on an extra strong crane rail may be more cost effective. A gantry system that rides on the floor requires floor space, but it may be more versatile for assembly of detector components in other parts of the hall. It may even be possible to mount the upper rail of a gantry system to the upper inside blocks of the steel for installation of central tracking and calorimetry components.

The large block design will take less time to assemble than projections for small piece designs. The 56 pieces could be installed in 6 months or less. The 25 pieces in the Zeus yoke were assembled in one and a half months. The pieces were installed at about one piece per day. The remainder of the time was used for coil installation, set up, and removal of equipment. Allowing two days per piece for the SDC due to the extra weight and increased dimensions, 112 days of block rigging would be required. Allowing two weeks for set up and two weeks for equipment removal brings the total time to 27 weeks or six months.

- Jakes
  - Phone: 1-800-553-5253 FAX: 702-736-1562
  - Contacts: Kent Goodman
  - Trucking Comments: JXS super heavy haul system. Over road or land
  - Crane Comments: American 11320. Big in to boom cranes
- Bigge
  - Phone: 1-800-388-4244 FAX: 415-639-4053
  - Contacts: John Tolivasa
  - Trucking Comments: Scheuerle platform trailers
  - Crane Comments: Many Gantries including 80 ft span 450 ton gantry use for moving Mark II at SLAC. This job won the 1986 rigging job of the year from the Specialized Carriers and Rigging Association.
- Mammoet Transport
  - Phone: 713-431-2573 FAX: 713-431-0984
  - Contacts: Al Slikker
  - Trucking Comments: Goldhofer trucks. Load no problem.
  - Crane Comments: Sliding Gantries like Lastra up to 2000 tons. They made the suggestion that the hall could incorporate a ledge for the gantry bridge to travel on. This would allow the used of a very large rented bridge instead of the purchase of a large overhead crane. The bridge would essentially be a legless gantry. This would avoid interference problems with floor space near the steel erection.
- Bragg Crane and Rigging Inc
  - Phone: 213-422-1237 FAX: 213-630-8791
  - Contacts: Bob Murray or Keith Trommler
  - Trucking Comments: Goldhofer trucks. Load no problem.
  - Crane Comments: Hydraulic jack units 27-28 ft of lift for up to 800 tons.

0.8 Conclusion

This feasibility study shows that it is possible to design, fabricate and assemble a muon barrel of 290 ton blocks with companies in the U.S. This statement is supported be multiple contacts in industry for each of the phases of the project.

Further support is provided by the successful fabrication of a large block design at Zeus. The upper limit of block size is based on steel mill capacities and transportation width. Both of these limit one block dimension to less than 12 feet. Weight is not a limitation at this level.

In a large block design most of the work is done outside of the hall and offsite. This helps decouple the hall fabrication and the site work from the steel fabrication. The assembly time for a large block design is realistically six months or less. Rental equipment can be used for almost all aspects of transportation and rigging. The final tolerances expected would be 1-5 mm from the nominal positions. By careful work with the muon chamber group support points and fiducials can be included in the steel blocks.

The feasibility and attractive features of a large block design show that a careful preliminary design should be pursued. This work is underway at UWPSL.

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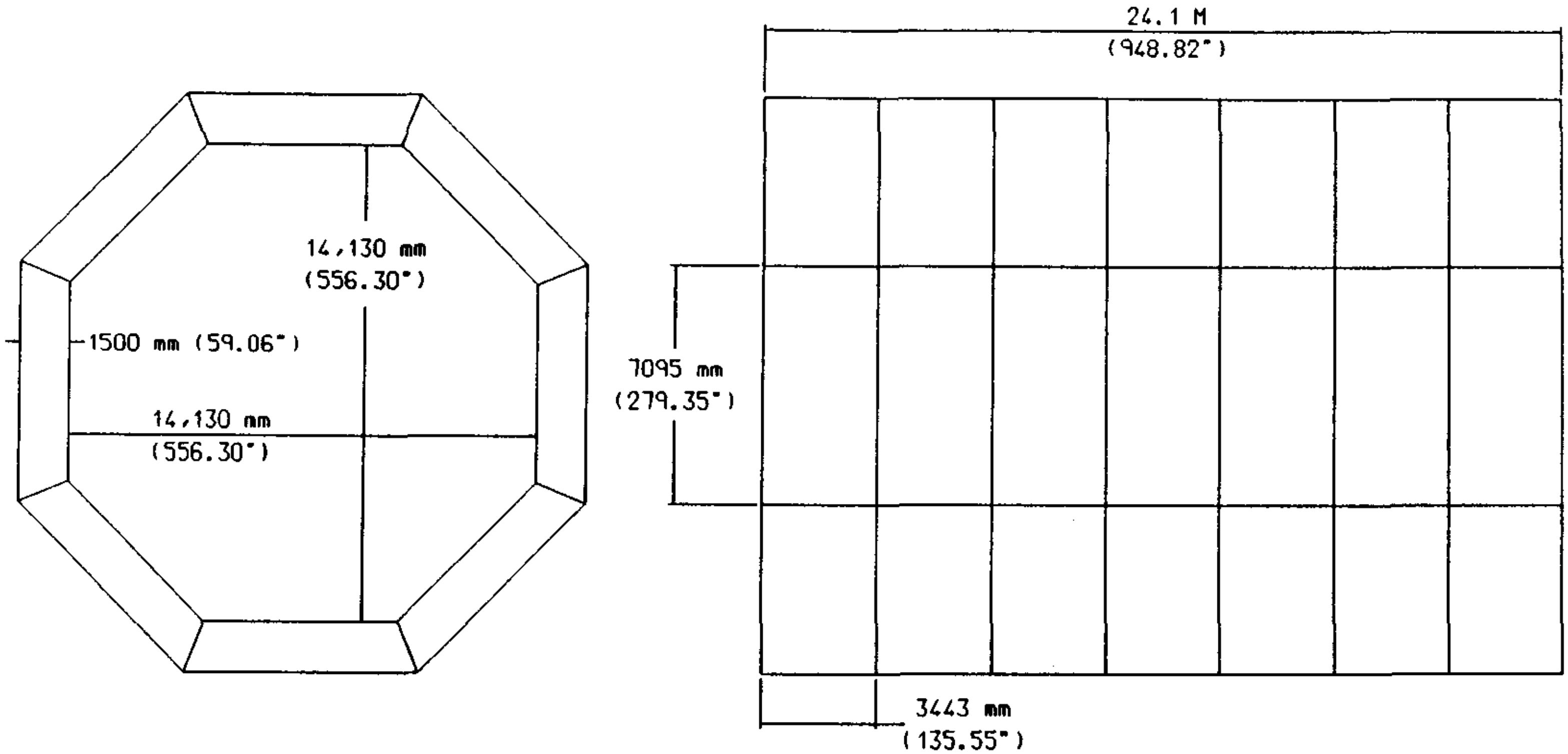
0.9 Appendix A - Design Concept Drawings



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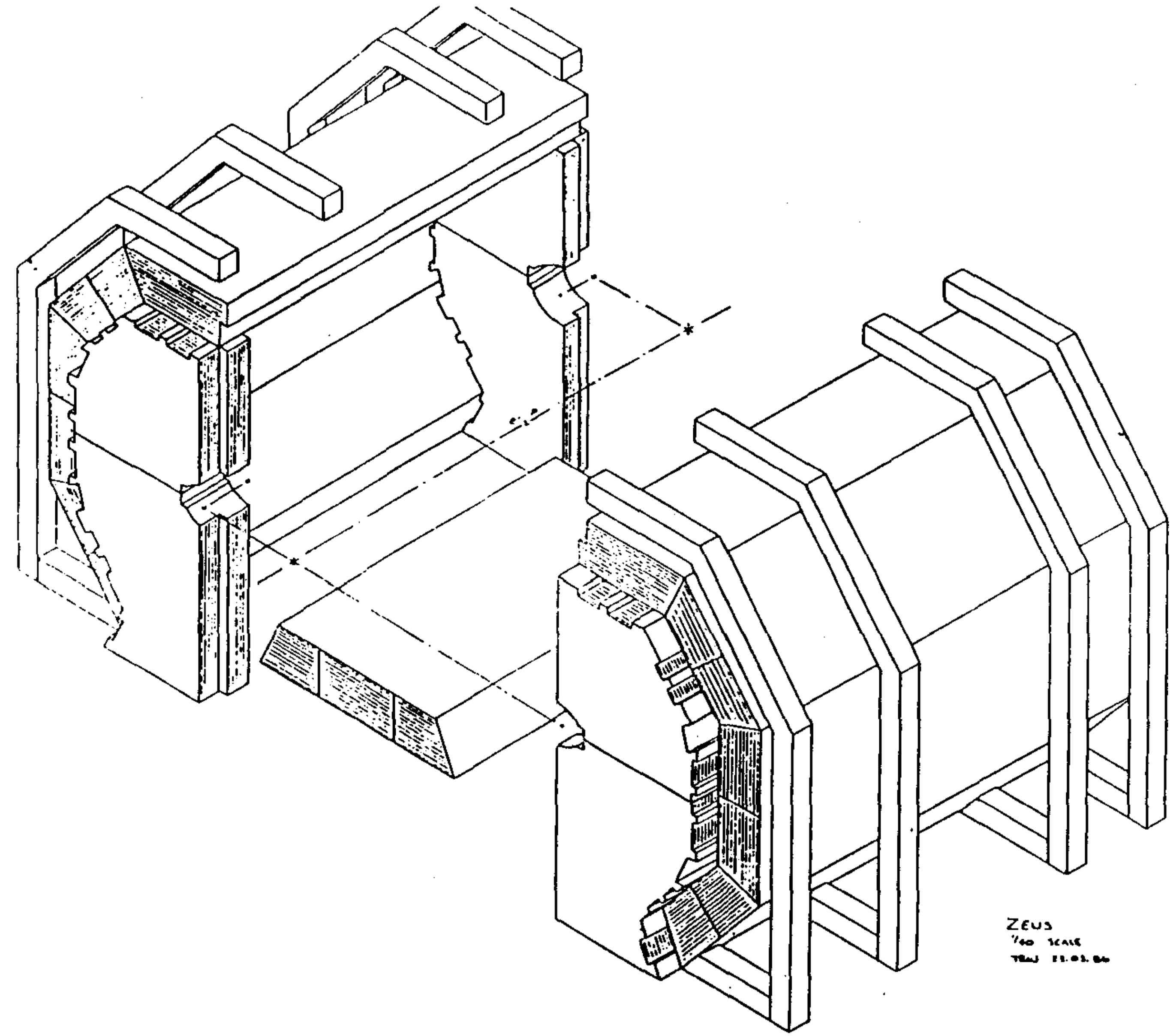
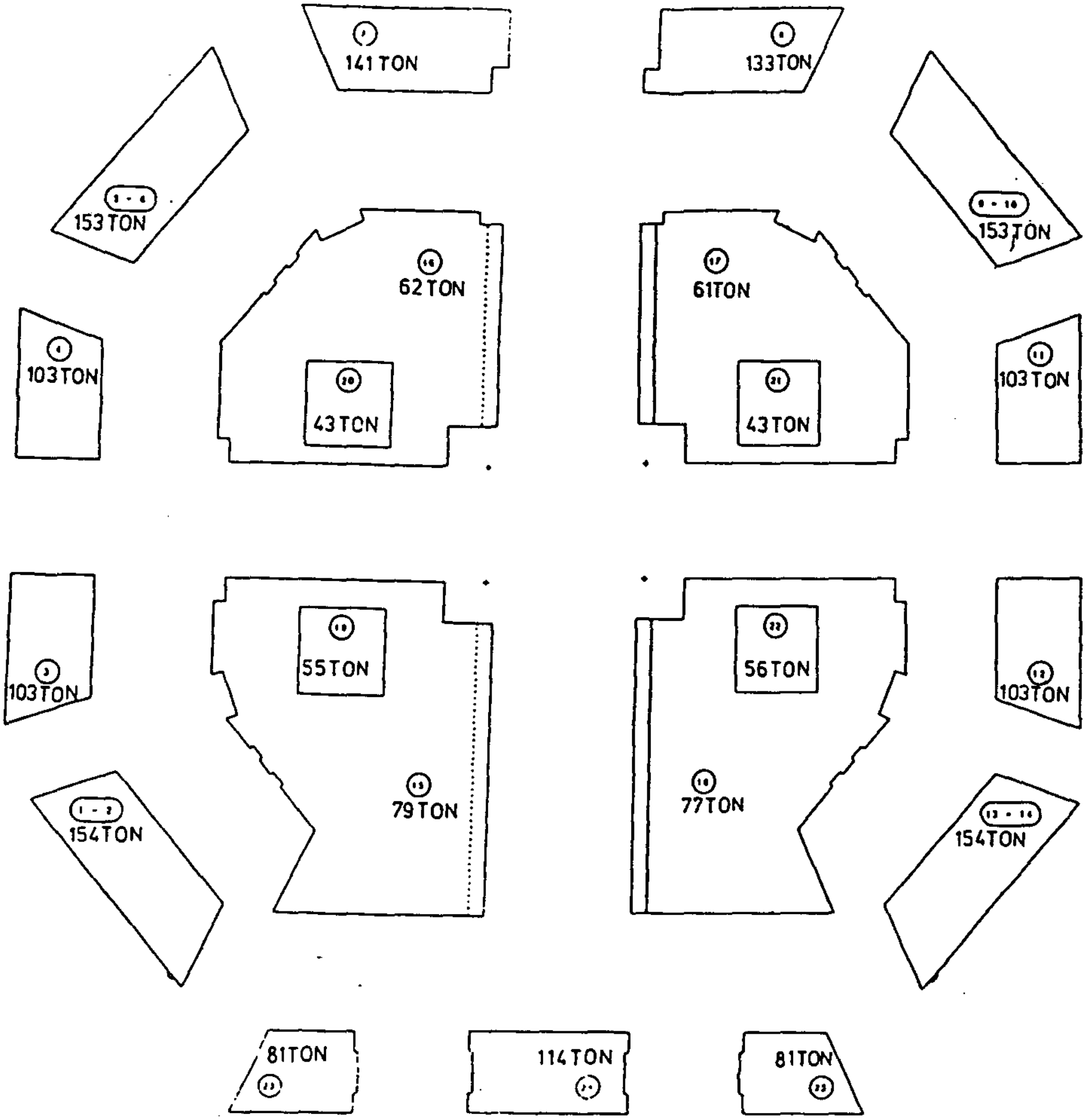
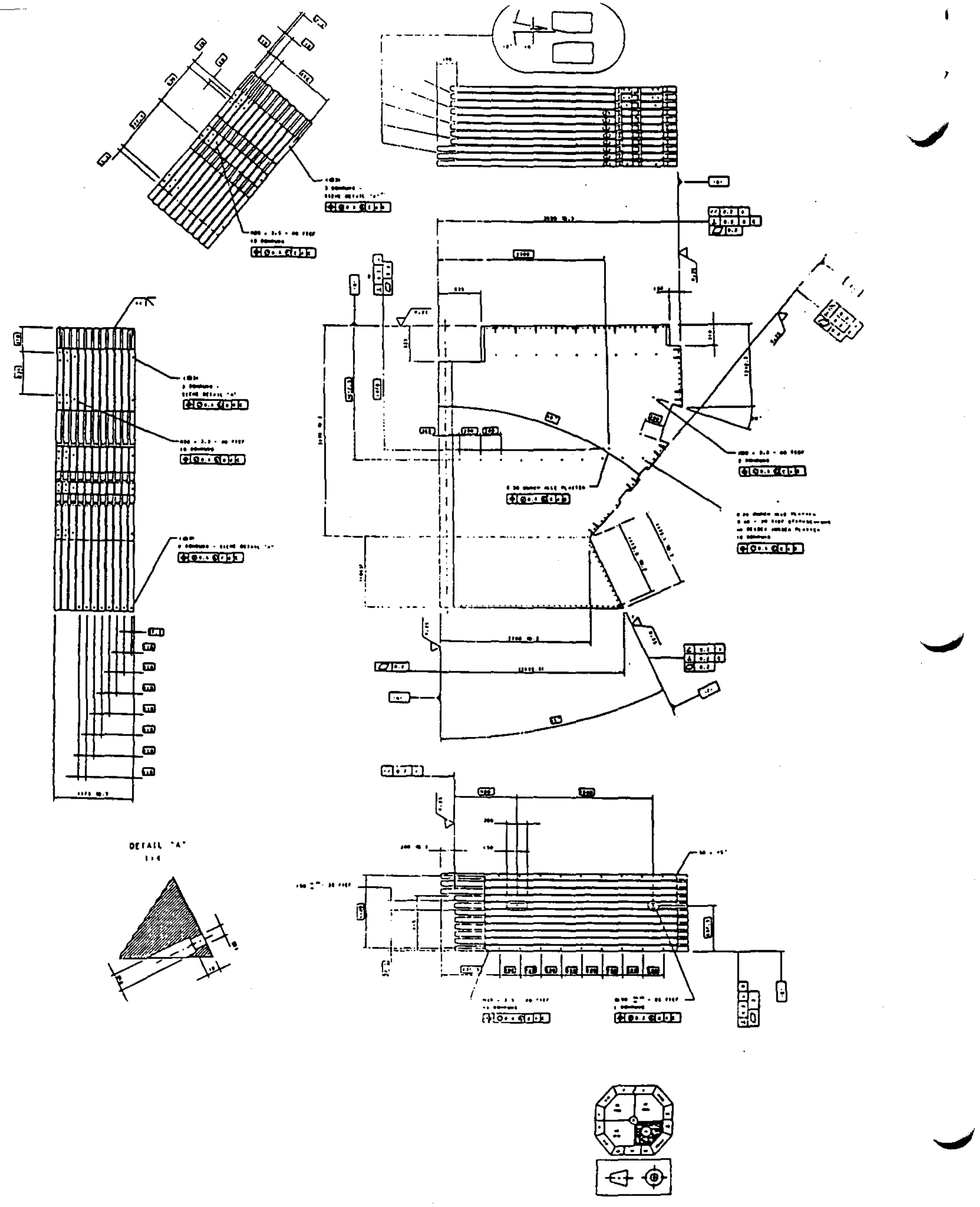


The Iron Yoke in open position.

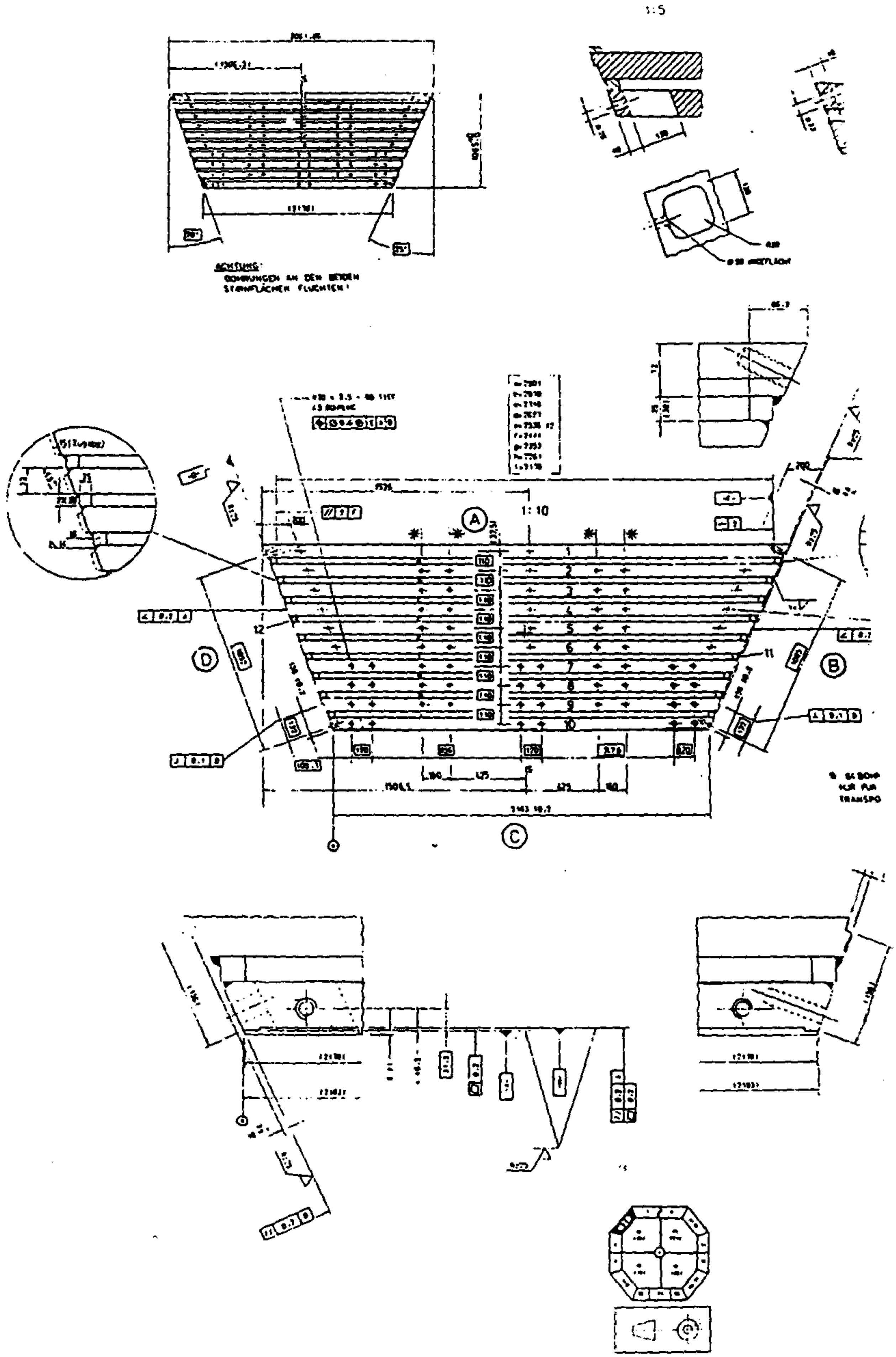


1 – 14 Octagon modules
15 – 18 Front endcap modules
19 – 22 Rear endcap modules
23 – 25 Bottom yoke modules

Weights of the iron yoke modules.



Design of an endcap module of the iron yoke.



Design of an octagon module of the iron yoke.