

# Aerated Autoclaved Concrete (AAC) for Masonry Vaulting

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## REPORT

### AAC Material Properties

AAC is a foamed concrete produced in the factory and delivered to the building site as blocks. AAC is readily cut with woodworking tools (using carbide blades) and can take any shape. This research used 24" x 8" x 6" blocks cut into thicknesses of 1" and 2". For vault building the sheets were cut down further to a variety of sizes, including 16" x 8", 12" x 6", 8"x4", and for tight radiuses 4" square. As a foamed ceramic, AAC is lighter than water. The lightweight is a great advantage, allowing larger tiles to be used for time and material efficiency. The cellular nature is advantageous for good mortar adhesion and gives the tiles insulating value. An 8" thickness of AAC has an R-value of about 15.

Thinset mortar is used in standard AAC construction, although typical bricklayer's mortar can also be used. Catalan vaulting, however, relies on the quick setting time (less than 20 seconds) of gypsum-based mortar, typically Plaster of Paris. I experimented with a spectrum of mortars, including Plaster of Paris, USG HydroCal, USG HydroStone, thinset mortar and 3M Concrete Repair epoxy. In previous work I have also used gauging plaster. Working with AAC differs from typical bricks in that it is extremely porous, and unless completely soaked in water will suck the moisture out of any mortar applied and cause flash setting. There is a delicate balance between sufficiently damp to work with and slippery wet bricks from which the mortar slides off.

### QUALITATIVE RESEARCH

Conventional wisdom suggests that structural masonry spans have fallen out of favor in part due to their high labor cost. Because bricks are small and many spans are relatively large, it stands to reason that labor is one of the limiting factors. AAC allows the economy of masonry spans to be reconsidered. By using larger unit sizes, the labor costs are lessened while the constructive and formal benefits of Catalan vaulting can be exploited. This research demonstrates that the largest reasonable size for construction is a 16" x 8" x 2" thick tile. As long as the curvature of a given span can be accommodated with this modulus, great economy in construction can be achieved.

Two domes recently finished in England stand as an example of possible economy. I managed the construction of two 40' domes in St. Margaret's Bay, near Dover, Kent, using the Catalan technique but built with typical 12" x 6" x 1" thick brick tile. Averaged over the whole construction, one mason could lay about 10 tiles per hour. At this rate, it took about 220 man-hours to complete a single layer of the 4-layer dome. Had we been working with the larger size possible using AAC, we would have been able to not only complete a single layer of the dome in 154 hours (a time savings of 30%), but also to build the required structural thickness in only 3 layers of masonry. This would have afforded us a savings of 416 man-hours on each dome, shaving more than £12,000 (\$20,800) (at prevailing rates of £15/hr) off the construction cost.

In addition to economy, the versatility of form-making with AAC allows greater freedom in design and construction. Bearing conditions are really easy to create, as it requires only a close approximation in cut and good mortar contact. One simple 4" wide vault I built spans across a

corner and can easily support 200 pounds. It took about 10 minutes to construct. The light weight also allows the possibility of cantilevered vaults during construction, making a wide variety of forms available to the designer and the craftsman.

## QUANTITATIVE RESEARCH

The goal of the quantitative research was to determine bond strength, whether AAC fails like typical masonry under load, and the failure patterns of an AAC dome under concentrated crown load. The material tests were carried out in collaboration with MIT Building Technology Masters candidate Wanda W. Lau, and conducted under the direction of Prof John A. Ochsendorf, Prof John E Fernandez, Dr. John T. Germaine, and Stephen Rudolph.

Using HydroCal as a mortar, the AAC-mortar joint can only take about 10 psi in direct tension. We plan further tests of a variety of mortars, but initial load tests show that this is about as high as we can expect using typical gypsum-based mortars.

We built a 7 foot diameter dome to load it to failure to determine both the behavior of an AAC structure under load and the failure patterns. We loaded the crown of the 1 ¼" thick dome with a concentrated load over a 24" diameter circle (~3 sf), adding weight and measuring the load and the deflection until the dome collapsed. We found that the dome was extremely stiff, deflecting less than 0.05" before yielding at a load of almost 1,000 pounds. The characteristics of load and failure were exactly as one would expect for a typical masonry structure indicating that solid ceramic and foamed ceramic materials perform similarly at the scale of a building.

## CONCLUSION

AAC offers significant advantages to the designer and to the craftsman for the construction of structural masonry spans. Merging the Catalan construction technique with modern material technology allows the advantages of each to support the other. The application of this research will come with the design of buildings using both, which will offer the opportunity to educate both designers and masons in the advantages of a contemporary approach to compressive form.

## END NOTES

<sup>1</sup>Material for this research was generously provided by Trustone America, Providence, RI

<sup>2</sup>Trustone America website: <http://www.trustoneamerica.com/thermal.html>

<sup>3</sup>Dome load testing is attached as Appendix A; tension testing proposal as Appendix B.

**Aerated Autoclaved Concrete (AAC) for Masonry Vaulting**  
Boston Society of Architects research grant



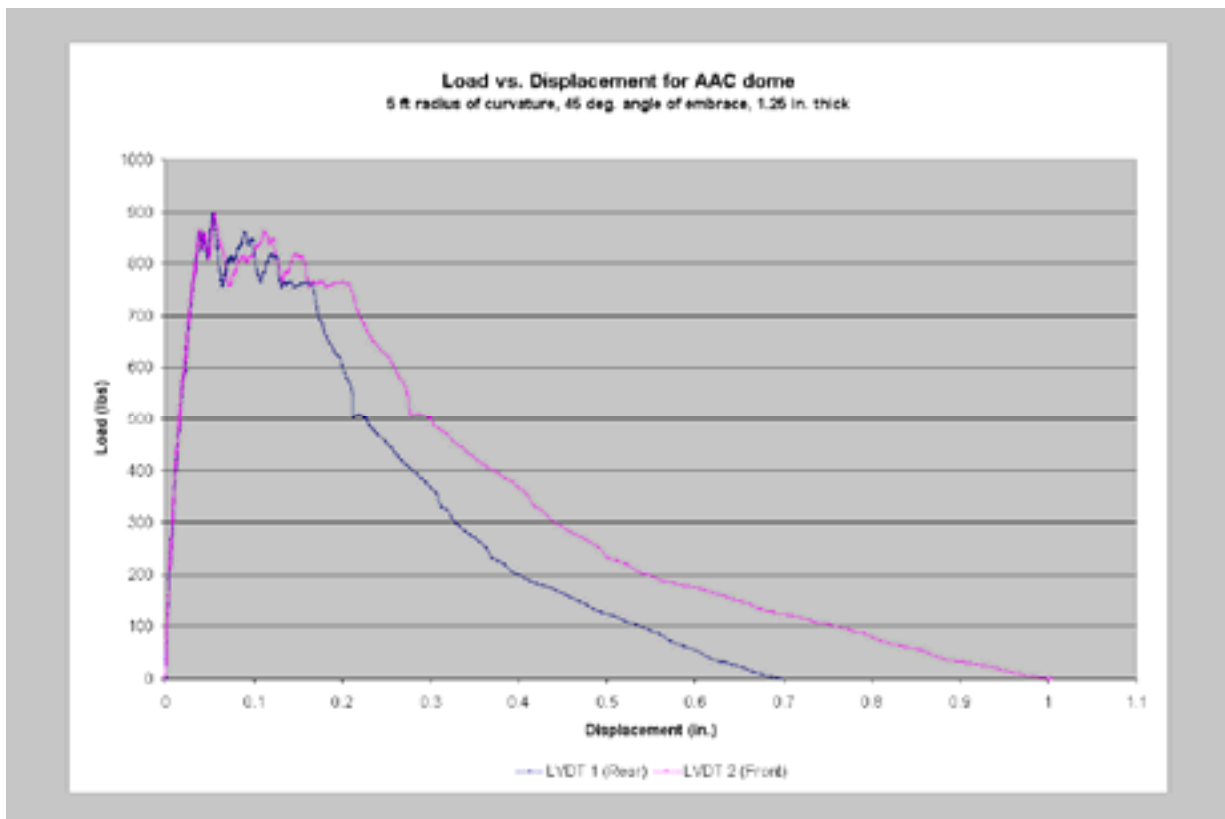
**The 7 foot diameter AAC dome ready for testing to failure in the structural lab at MIT**



**A 4" wide and 2" thick arch of AAC spanning 48" will support over 200 pounds**



Light weight, good mortar adhesion, and workability make AAC ideal for innovative masonry form.



The load/displacement curve for destruction of the dome show performance typical of standard masonry construction

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## APPENDIX A

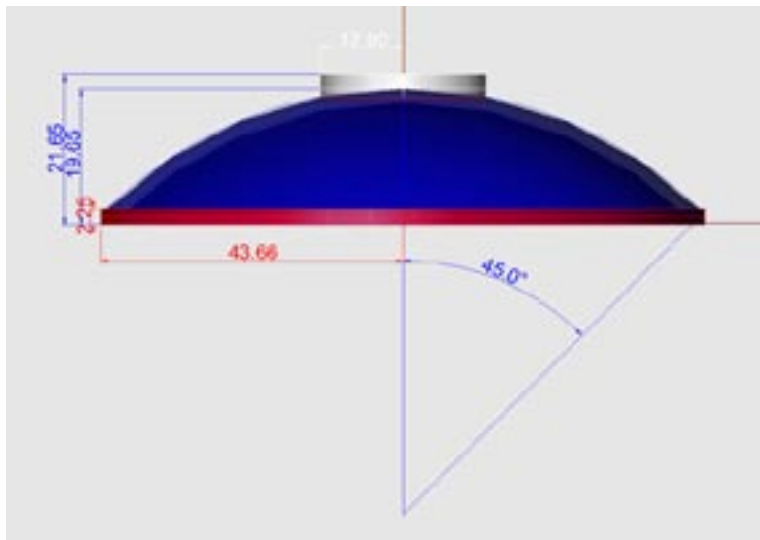
### STRUCTURAL LOAD TEST OF AN AERATED AUTOCLAVED CONCRETE (AAC) DOME

#### CONTACT INFORMATION

This proposal outlines a structural test to failure of a thin shell masonry dome. The goals of the test are to determine the collapse load and the failure mechanism for a masonry dome with an applied point-load at its crown.

#### GEOMETRY (all text dimensions are to the intrados)

Radius of curvature:	59.4 inches
Span at base:	84 inches
Rise above springing:	17.4 inches
Angle of embrace:	45 degrees or 0.79 radians
Thickness:	1 inch
Material unit weight	
Tile Geometry:	4"x8"x1", cut smaller for tighter curves



## DOMES CONSTRUCTION

The test dome will be built using traditional methods for timber vault construction, with a change in the typical material of brick or terracotta tile to AAC tile. The tiles will be laid in fast-setting gypsum plaster mortar. Structural formwork will not be used in the construction, but guides to ensure the correct curvature will be employed. A 24" diameter concrete cylinder 4" thick will be poured at the crown to provide a loading pad.

The tension ring at the base will be rolled steel 2 1/2x2 1/2 x 1/4 " angle with an inside diameter of 87 inches.

## SAFETY

The primary concern during the load test will be the safety of personnel involved. All participants must wear appropriate safety gear, including heavy long sleeves and pants and safety glasses.

The tension ring has been designed with a safety factor of over 4 times the expected maximum tension at the base of 3400 pounds so that it will not yield during the loading, making sure the test will be relevant. The dome has been designed to fail at approximately 3000 pounds, so that the failure load on the structure does not exceed the capacity of the instrumentation.

All CEE testing equipment not directly involved in the test will be moved away from the testing area, and sensitive equipment will either be moved to another room temporarily or covered.

## ULTIMATE LOAD CAPACITY ESTIMATES

AAC Material strength properties (e.g., compression, tensile, bending)

Compression: 600 psi

Tension:

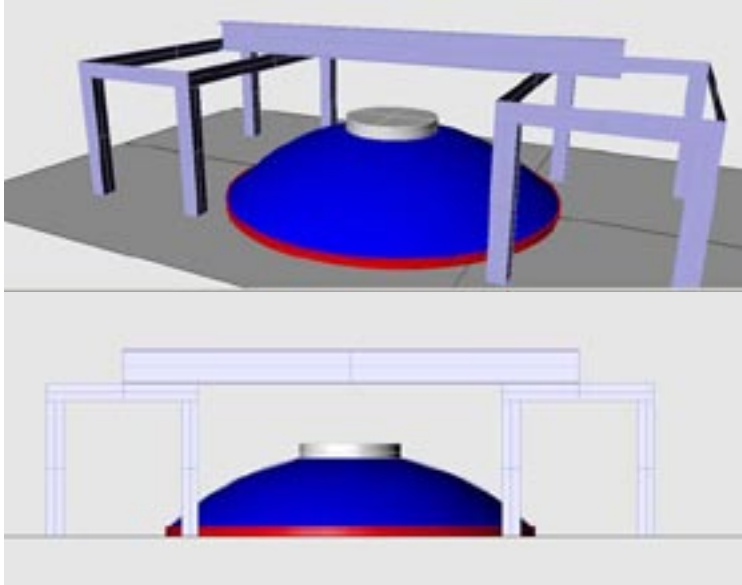
Manufacturer ~ 120 psi

Assumed 0 psi

Expected point failure load: 1900 lbs

## TESTING PROCEDURE

The load test will be carried out in the CEE testing lab, 1-034. We will use two 1,200 lb tables with the load cell on an I-beam between them. The vertical reaction from the loading will be resisted by the weight of the tables and the floor of the testing lab, plus perhaps additional weight on the table to provide sufficient reaction load. The horizontal thrust of the loaded dome will be restrained by the welded steel band.



Loading rate: approximately 200 lbs / minute

Measurements:

- Deflection at the crown of the dome
- Deflection at the surface of the dome at midpoint
- Deflection at the base of the dome
- Load

Documentation:

- Video
- Time-lapse photography every 5 seconds
- Data collection from load cell and displacement measurements

## PREDICTIONS

### COLLAPSE LOAD AND HINGE LOCATIONS AND PATTERN

Assuming absolutely zero tensile capacity, the modified membrane theory predicts failure at 100 lbs with hinges at 8 and 22 degrees from the centerline. The membrane graphical solution predicts failure prior to 50 lbs with a hinge at 21 degrees (the other would occur at 77 degrees). The membrane analytical solution predicts failure at about 5 lbs

If the AAC can take 50 psi tension, the membrane analytical solution jumps to 1000 psi. For 100 psi tension, the membrane analytical solution jumps further to 2100 lbs. From the modified membrane theory, P values go to 1900 and about 4000 lbs, respectively.

<sup>1</sup>Data from the Aerated Concrete Corporation of America website [http://www.accoaac.com/ACCO\\_Prop\\_Load\\_Bearing.html](http://www.accoaac.com/ACCO_Prop_Load_Bearing.html):  
"The direct tensile strength is somewhat less than the flexural tensile strength of the material. It is estimated at about 1/5 of the compressive strength. Very limited test data is available on the direct tensile strength of AAC, and direct tension is typically not allowed in the design of unreinforced construction."

## APPENDIX B LOAD TESTS OF AERATED AUTOCLAVED CONCRETE (AAC) MORTAR BONDS

This proposal outlines tests of AAC mortar bonds in tension and compression. The compression test will consist of loading two blocks of AAC that have been mortared together to test the effect of various mortars on the compressive strength of AAC assemblies. The tension test will be a four-point load test to determine the tensile capacity of various combinations of mortar with AAC.

### COMPRESSION TEST

#### Geometry

The blocks in compression will be 4" cubes of AAC mortared together with gypsum plaster, 3M DP600 epoxy, and thinset cement

#### Testing procedure

The load test will be carried out in the CEE testing lab, 1-034. Each AAC/Mortar combination will test three identical samples.

Loading rate:                      Approximately 2000 lbs/min

Measurements:                      Stress

Strain

Documentation:                      Still photography

Data for load-displacement during each test

### FOUR-POINT LOAD TEST

#### Geometry

The AAC four-point load test will use a modified version of the CEE setup for ASTM 4-point load testing, designed in conjunction with Steve Rudolph and Dr. Jack Germaine. The modification will accommodate 6" wide sample materials and allow a 6" spread between the internal loading points.

I estimate the minimum load capacity of the specimen is 10 pounds, so the test setup should weigh less than this. The maximum load I anticipate applying in the test is 160 lb, so the test setup should be able to withstand at least twice that load.

#### Testing procedure

The load test will be carried out in the CEE testing lab, 1-034.

I will use the same three mortar types as in the compression test, applied to 6"x12" tiles that are 1", 2", and 4" thick. Again, there will be three identical samples for each size.

Loading rate:	Approximately 50 lbs/min
Measurements:	Deflection at joint Load
Documentation:	Still photography Data for load-displacement during each test