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MAKER: Design and Build a New Concrete Block to Make the Curved Roofs

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Abstract

This paper presents a senior design project that students worked on it over a year. The project is about design and building a new mold to produce the concrete blocks which they can make the curved roofs. The traditional concrete blocks can make vertical walls but this new concrete block can make the curved roofs. There were 3 senior undergraduate students with Mechanical Engineering Major and 1 senior undergraduate student from Material Science were involved in this senior design project. A local concrete block company was part of this collaboration. In phase I of this project, the students worked on the design of the mold. It took almost 4 months to come out with final design drawings. On second phase, the mold was ordered to be built based on the design. BESSER Company in Michigan built the mold for this project then the concrete blocks produced by using this mold. On phase III, the students construct a building by using this new concrete blocks. One patent was filed and approved for this design. The project is still going forward with the new groups of students.

Introduction

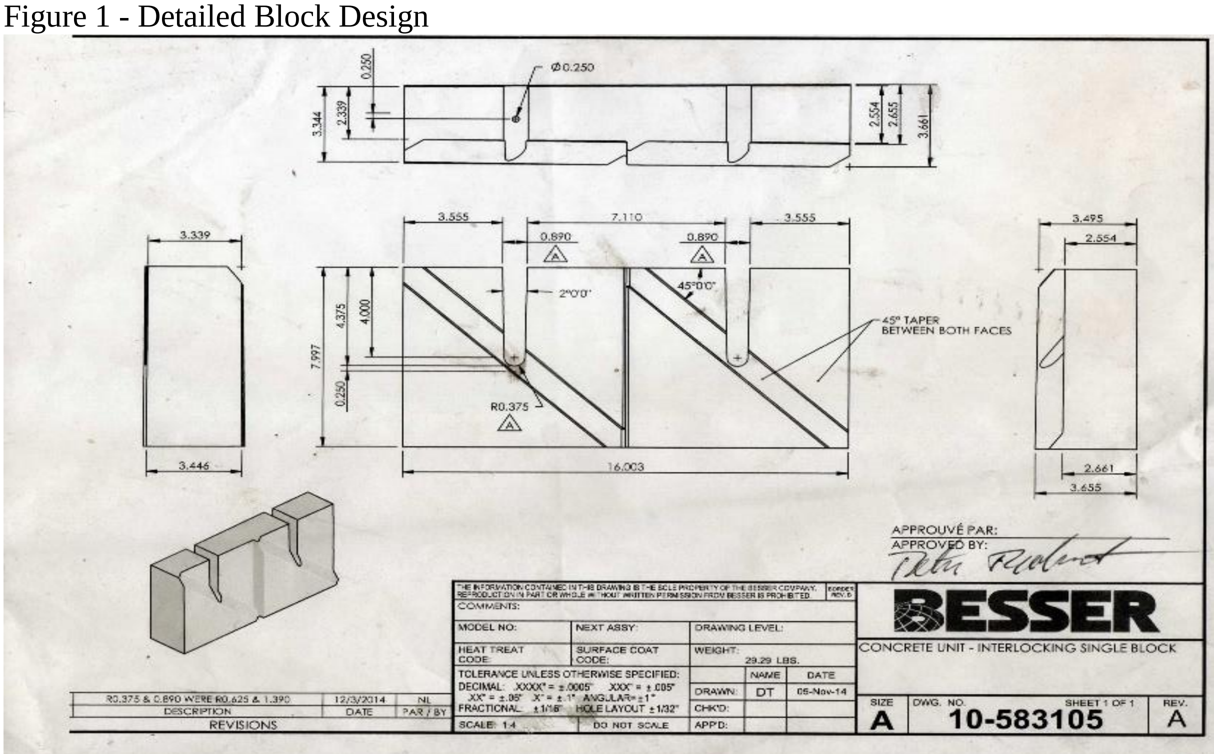
Spherical Block LLC is a local company with the vision of recreating the masonry industry. With the help of the 3-D modeling software, SolidWorks, the group was able create an innovated concrete block design. The block will be used to create arc like structures. These structures will be easy to assemble, cheap to produce, and incredibly strong when enduring structural requirements and environmental factors. With different arrangements the blocks could be potentially used for bridge construction, reservoirs, domes, catenaries, gothic or other similar style of art designs, and much more.

The group has used many different programs to help design and create the block. The first the group used was Microsoft Excel. The group used excel to help find the compound angle create by the blocks design and to set up a spreadsheet that would give the group the correct dimensions based on how big the intended arch was designed to be. The next program used by the group was SolidWorks. With SolidWorks the model could be tested to see if the blocks were able to create the intended structures. SolidWorks was also able to provide us with the mechanical properties of the individual block, such as weight, density and volume. The other program used was Abaqus. Abaqus help in the FEA on the intended purposes of the blocks; bridges, natural disaster shelters, etc. The group was able to apply specific conditions to the arches to simulate hurricane winds and the force of two fully sized tractor trailers. Along with computer software models, a 3-D printer was used to create scaled models of the blocks.

Block Design:

The final design of the block was derived from brainstorming ideas to create a geometry that will construct corrugated features while remaining under 30 pounds. The corrugations will create a stronger feature in the direction along the corrugations. The deeper the corrugations the stronger the structure, this is true because the deeper corrugations will create a larger moment therefore a stronger truss structure. The group selected a weight of 30 pounds due to the fact that a standard concrete masonry unit (cinder block) has a weight of 35 pounds. The lighter block will prevent injury and fatigue to the mason. Using the volume and density estimations the group concluded that a block with a 3 inch center will yield a 29.5 pound block. The block is constructed from a rectangular prism with two u-grooves, which will be where the reinforcement bar will be inserted. In addition, the u-grooves are tapered outward to allow for the reinforcement bar to be inserted with ease. Another feature of the block is two angles that work to create a compound angle that runs at a 45 degree angle along the face of the block. This naturally creates a thin and thick side of the block. To easily locate the thin side, a cylinder was extruded from the radius of the u-groove. The block also contains a “lock in keyway” feature. This feature will allow for a greater interlock between two mating blocks. The way which the group achieved the “lock in keyway” is by a series of intrusions and extrusions that are present on one face of the block. An engineering challenge which the group encountered during the design process was to calculate the angles which would create the desired compound angle and diameter. A diameter of 25 feet was determined to be best. Factors when considering the diameter were what the ceiling height would be as well as the structural strength. Once the diameter was determined the group generated equations using trigonometry to calculate the number of block which would be needed, as well as the required angles. The group then created the block in SolidWorks using the numbers generated from the excel spread sheet. After completing an assembly in SolidWorks software the group was able to verify the trigonometry calculations performed earlier. With the design of the block geometry complete the next engineering challenge was to make production of the block feasible and efficient. The group was able to successfully orientate the blocks in a matter which would allow a mold to create 6 blocks per cycle (appx. 1 block per second). Difficulties faced while orientating the blocks included not creating an undercut, an undercut would prevent the machine from indexing properly. This block design is the strongest and most feasible for production.

Figure 1 - Detailed Block Design



Procedure:

The group set forth small achievable goals to be sure their full attention was on a specific piece of work at a time. Over the first semester as the group was being formed and the objectives were laid out it became clear of how much work would need to be done. The first task was to take the conceptual design of the blocks and find the actual numbers needed to create a working model of the blocks. Once the dimensions and necessary angels were calculated, the group created the models of the blocks using SolidWorks. Once a working model was finished it could easily be tweaked for assembly purposes as well as if any updated features were needed to be added to the block. Many different models were created to find the optimal design that could be used to create the desired arc span of twenty five feet. With the final design settled upon, the group used Abaqus to run FEA on the block to see how it will theoretically preform under applied forces. The group then gathered all of the data found and organized it into a formal report. Once the models were tested, the SolidWorks files were sent to Besser Concrete Industry to get molds created to produce the concrete blocks. While all of this was taking place the group also met with a Patent attorney to apply for a US Patent for the block design.

The group planed to run additional tests on the blocks to better refine our data. The mold for the blocks should arrive shortly so that the concrete block production process could begin. With the concrete blocks in hand, the plan is to create a structure on Spherical LLc property. The group can then run tests on the structure and see how it compares to the FEA testing. With this comparative study, a proper analysis can be completed to test the blocks for their feasibility in numerous types of structures.

Below are a few of the figures generated through the assembly process using SolidWorks.

Figure 2 - Typical Arc (25 ft. span)

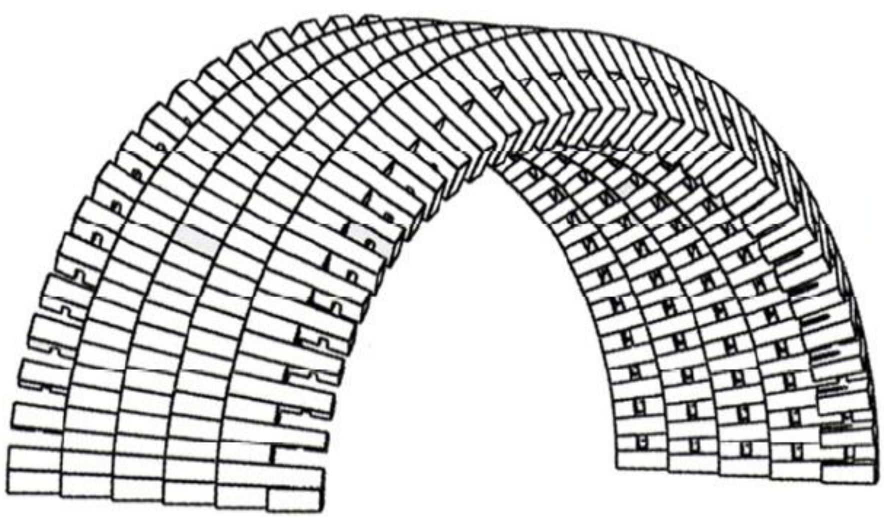


Figure 3 - Multicenter arc (~37ft)

Figure 4 - 25 ft. diameter cylinder (reservoir)

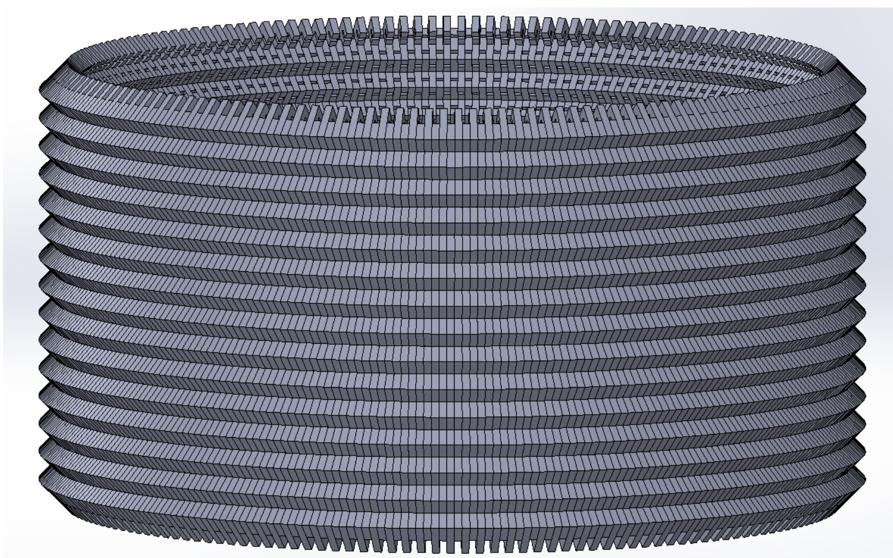
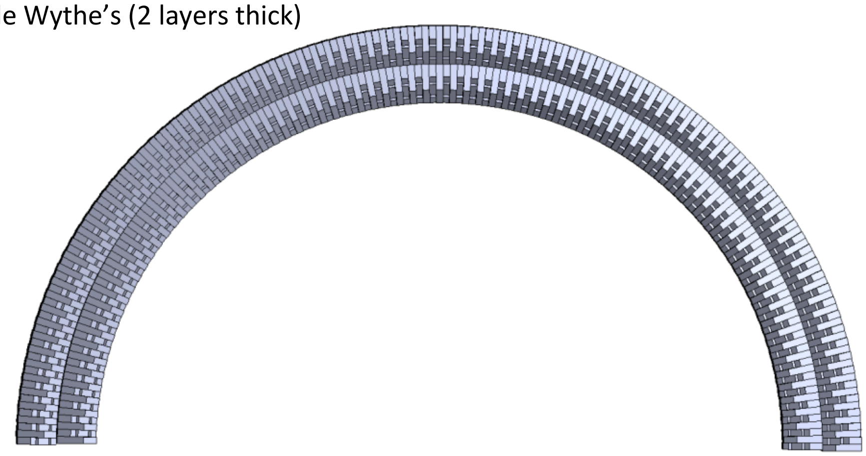


Figure 5 - Multiple Wythe's (2 layers thick)



Tested Structures:

As stated earlier, the program Abaqus was used to study the FEA of the possible structures that could be assembled from the blocks. With bridges and shelters as the primary purpose of the creation, both were tested. Two extreme case scenarios were used, hurricane like conditions and an enormous load applied directly at the apex of the arc. With the steel reinforced concrete block assembly, little to no structural damage occurred when either the pressurized or concentrated force. Below are two figures showing an arc assembly and where the forces were applied during the tests. Red Arrows denote Boundary Conditions:

Green Arrows denote Load locations:

Figure 6 - Hurricane wind simulation: Pressurized load of 2293 Pa

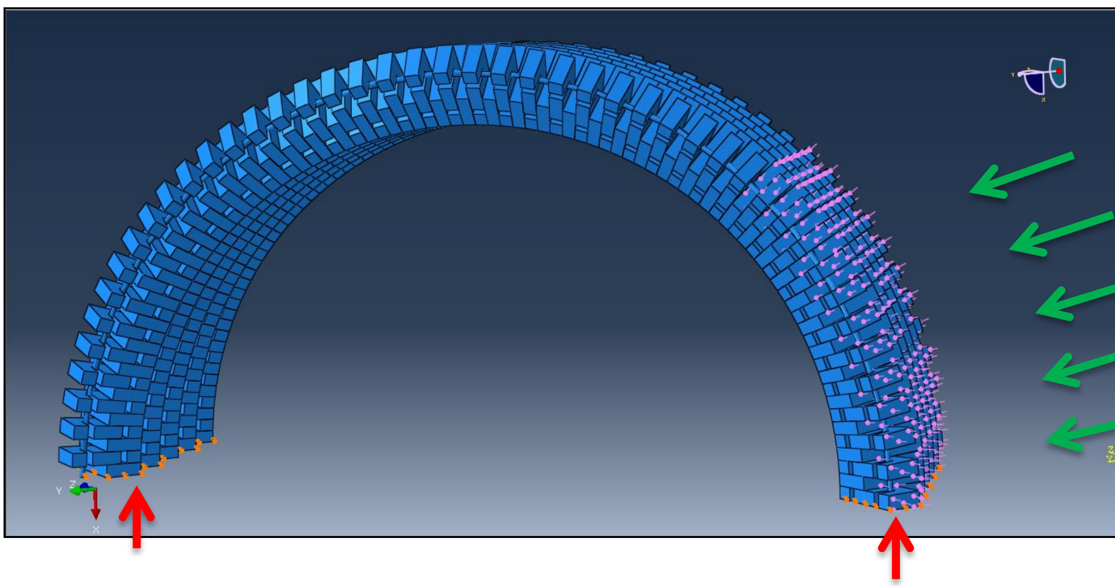


Figure 7 - Stress when the pressurized force was applied

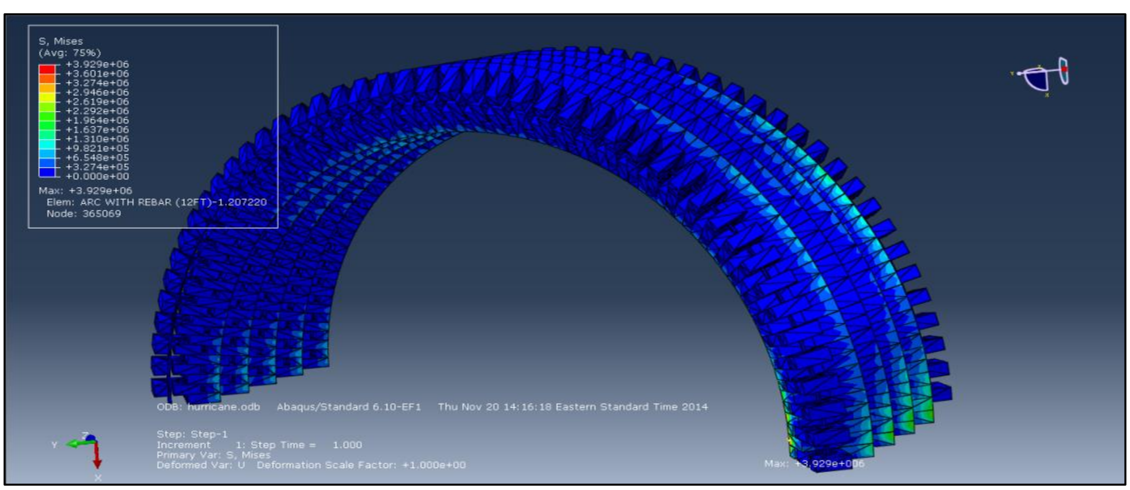


Figure 8 - Truck simulation: 711,715 Newtons

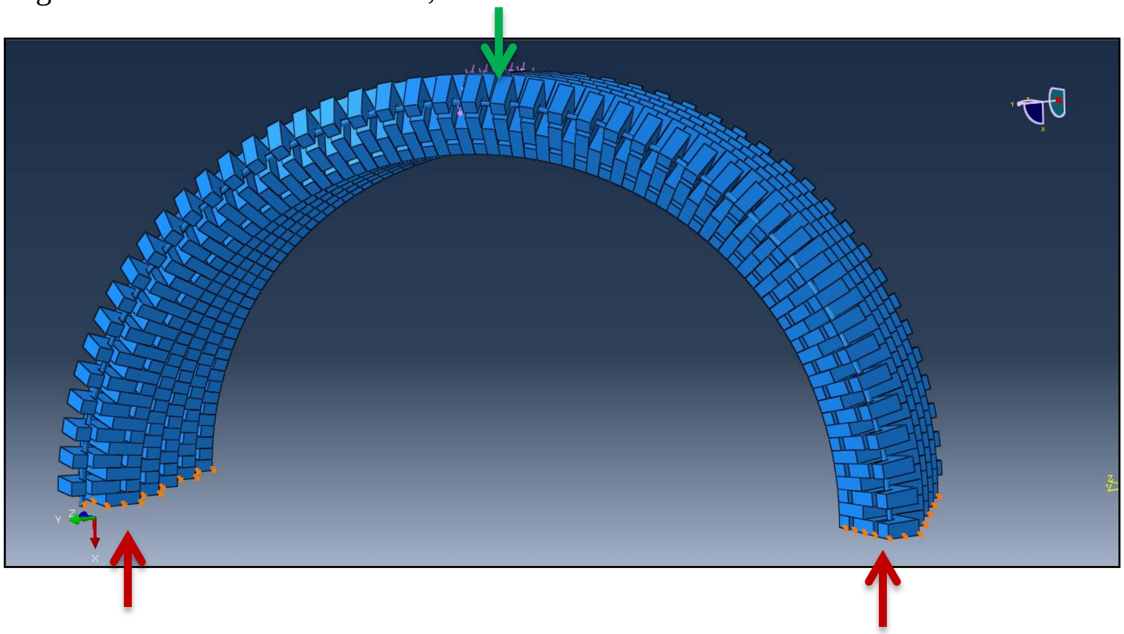
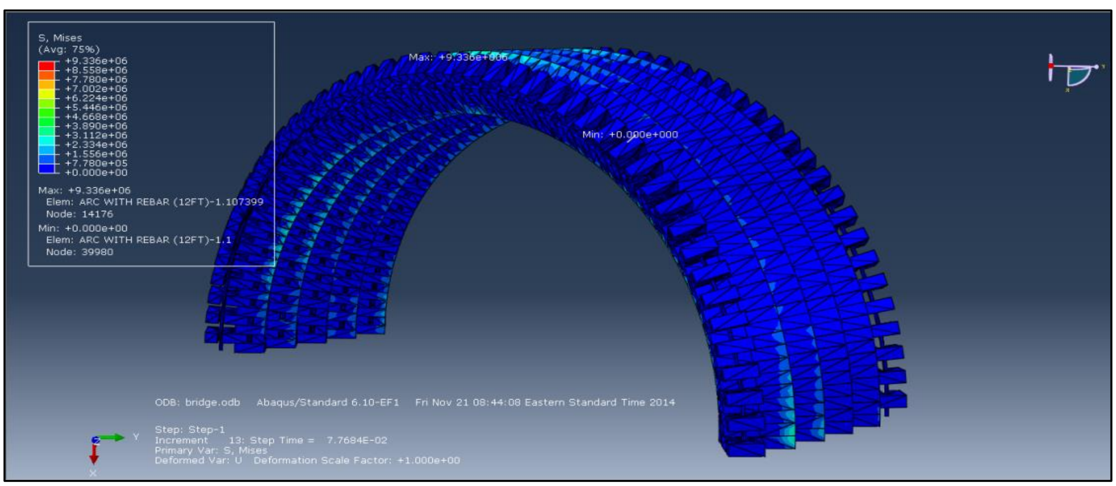


Figure 9 - Stress when the concentrated force was applied



Conclusion:

The company Spherical Block LLC has accomplished so much in such a short amount of time that as work continues nothing but good things will be to come. The innovated block design is like no other. Being simple, cheap, convenient, and strong the block is one that can very well change the masonry industry. This is a continuing project and future students will work on other aspects of it.

This project was funded by the Department of Mechanical Engineering at Alfred University.

References:

[1] Ghotbi, E. "Applying 3D Printing to Enhance Learning in Undergraduate Kinematic and Dynamic of Machinery Course." *2017 ASEE Annual Conference & Exposition*.