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Dynamic Load Test of Arquin-Designed CMU Wall

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Abstract

The Arquin Corporation has developed a new method of constructing CMU (concrete masonry unit) walls. This new method uses polymer spacers connected to steel wires that serve as reinforcing as well as a means of accurately placing the spacers so that the concrete block can be dry stacked. The hollows of the concrete block are then filled with grout. As part of a New Mexico Small Business Assistance Program (NMSBA), Sandia National Laboratories conducted a series of tests that dynamically loaded wall segments to compare the performance of walls constructed using the Arquin method to a more traditional method of constructing CMU walls. A total of four walls were built, two with traditional methods and two with the Arquin method. Two of the walls, one traditional and one Arquin, had every third cell filled with grout. The remaining two walls, one traditional and one Arquin, had every cell filled with grout. The walls were dynamically loaded with explosive forces. No significant difference was noted between the performance of the walls constructed by the Arquin method when compared to the walls constructed by the traditional method.

Acknowledgments

The author would like to thank the Small Business Assistance Program for supporting this collaboration between Sandia National Laboratories and the Arquin Corporation. The author would also like to thank Carlos Lopez and Jeff Cherry from Sandia National Laboratories for their reviews and helpful comments on this report. The author would also like to thank Dave Cole's group at Sandia National Laboratories, Dept. 54342, including Mark Naro, Weldon Teague, Ed Vieth, and Ed Virostko, for their work on setting up and conducting the explosives portion of the test. The author would also like to credit Ed Vieth for making the diagram showing the location of the pressure transducers and charges that was used for Figure 5. The work described in this report was funded through the New Mexico Small Business Assistance initiative at Sandia National Laboratories. Neither Sandia nor the U.S. Government acquired any rights in any Arquin Corporation intellectual property as a result of this work.

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Introduction

The Arquin Corporation has developed a new method of building concrete masonry unit (CMU) walls. This new method uses steel reinforcing wire and polymer spacers to rapidly dry stack the CMU blocks. The wire is configured into a continuous tie with the polymer spacers positioned so that the CMU block is located with the needed 3/8" vertical and horizontal spacing between each block. The spacers are placed on top of each course of block and the wire can be sized so that it acts as steel reinforcing for the wall. The original concept called for two wires per course of block as seen in Figure 1. The spacers allow for accurate and consistent block spacing. Figure 2 shows an assembly of blocks using the Arquin method. For this test, the original concept was modified to a single wire, located at the center of the block.

Through the New Mexico Small Business Assistance Program, Sandia National Laboratories (SNL) has provided technical assistance to the Arquin Corporation. Two separate analyses and one series of tests have been previously performed. The first was a study that used computational modeling to assess the construction method by evaluating suitable materials and designs to optimize the system and to assess the static load carrying capacity of walls constructed by the Arquin Method. These findings are detailed in the report written by Ho, et. al. (2008, SAND2008-5518). A second study by Lopez and Petti (2008, SAND2008-8123) reported a computational analysis of the Arquin method of wall construction under a dynamic loading condition. A series of tests were conducted by Jensen and Cherry (2008, SAND2008-8245), where a number of wall segments, which were constructed using both traditional methods as well as the Arquin method, were statically loaded to failure.

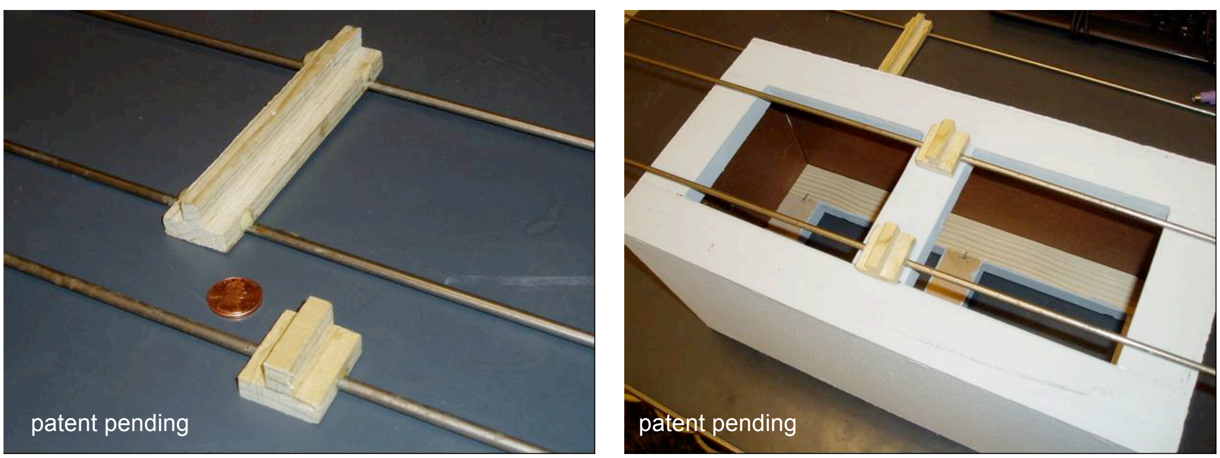

Figure 1. Left: Prototype designs made of wood for the Arquin spacer. Right: Filaments (ties) comprising the spacers and 9-gage steel wires are laid on top of a CMU. (From Ho et al., 2008)

This report details the results of a series of experiments that compares the performance, under dynamic loading, of CMU walls constructed using the Arquin method versus the traditional method of constructing CMU walls. Throughout this report, when the term "Arquin wall" is used, it refers to the walls that were constructed using the Arquin method of construction.

Whenever the term "traditional wall" is used, it refers to walls that were constructed using traditional construction methods.

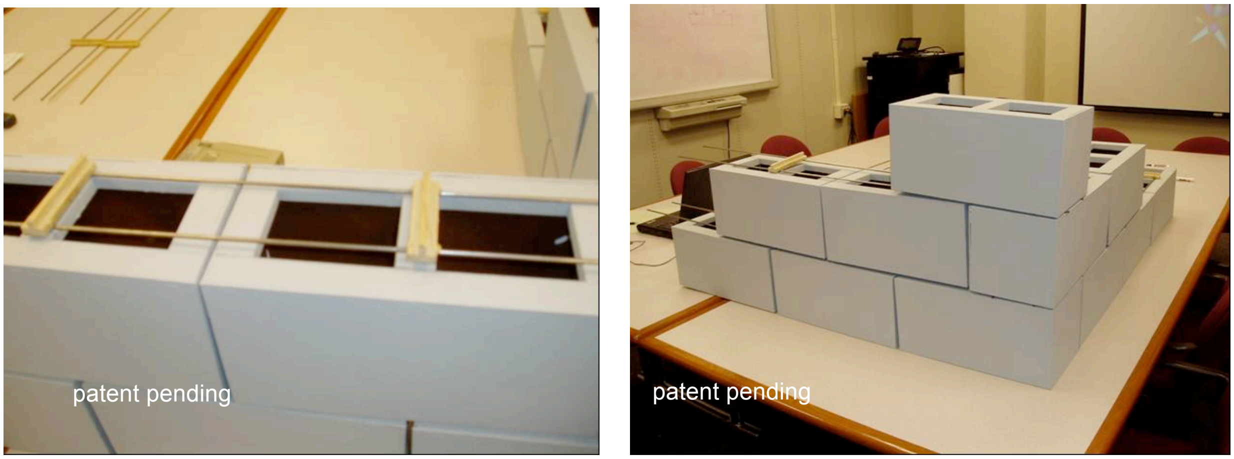

Figure 2. Left: Filaments of ties provide spacing and alignment for rows of CMUs. Right: Assembly of CMUs and filaments. (From Ho et al., 2008)

Materials and Methods

Experiments were designed to dynamically apply a uniform load across one face of the CMU walls. The principal intent was to determine how well the CMU walls built using the Arquin method performed compared to the CMU walls built using traditional CMU wall construction methods. Table 1 is a test matrix of the experiment.

Table 1. Experiment test matrix

Arquin Method	Traditional Construction Method
Every third cell filled with grout	Every third cell filled with grout
All cells filled with grout	All cells filled with grout

The dynamic load was applied to each wall through the use of an explosive charge. The principal layout of the walls was one Arquin wall separated from one of the traditional walls by a distance of 50 feet. At the midway point between the walls, a cylindrical charge was placed on the ground. When the charge was detonated, the pressure applied to each wall was very similar in both magnitude and impulse.

Wall Construction

For the test series, four walls were constructed, two walls using traditional CMU construction methods and two walls using the Arquin method. The walls were nominally 64 inches tall and

144 inches in length, with 48 inch long wing walls at both ends of each wall. Figure 3 shows a detail of the walls in plan view. The CMU block used are nominally 8” x 8” x 16”. For the traditionally built walls, there were a total of eight courses of block. The Arquin method used a half height block, nominally 4” x 8” x 16”, for the bottom and top courses, thereby resulting in a wall with nine courses of block. The blocks in all walls were placed in a running bond pattern. The traditional walls were built by bonding the block with a Type N mortar as the block was placed in the wall. After the mortar had cured, the cells of the wall were filled with grout. The Arquin walls were constructed by dry stacking the block using the spacers to align and locate each block. The spacers provided for a 3/8” vertical and horizontal gap between each block. After all of the blocks were stacked, the cells were filled with grout. After the grout had set, the spaces between the blocks were back-filled with Type N mortar. There were some instances where the mortar that was back-filled into the gap was noted to be friable and to be inset only surficially into the spaces between the blocks. This condition could lead to some degradation of performance. However, the area of poor mortar was a small percentage of the total area and therefore is unlikely to have much effect.

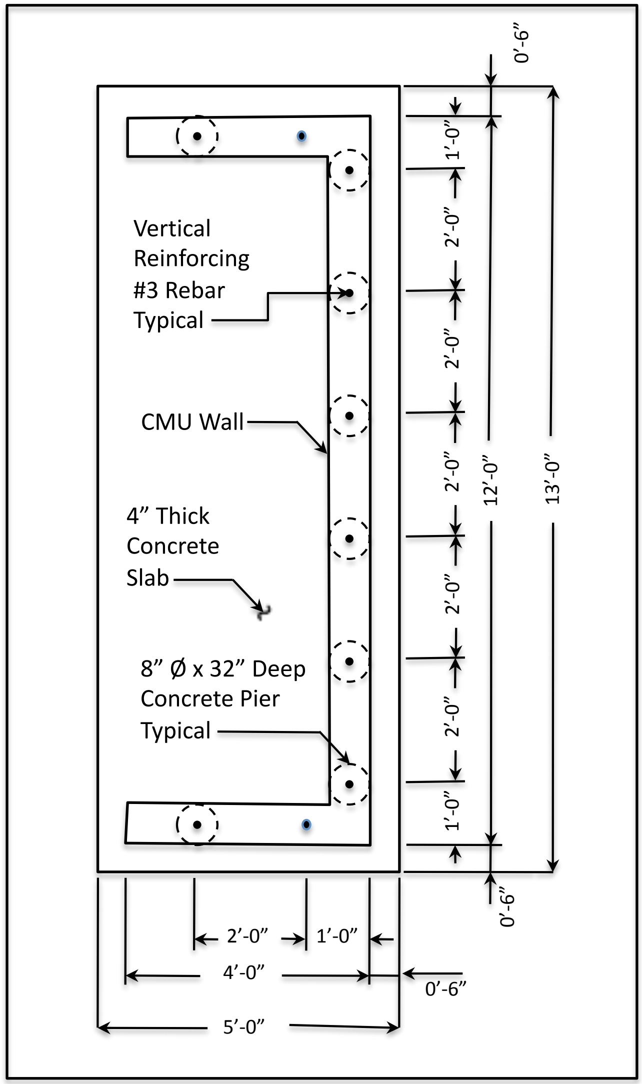

Figure 3. Plan view of wall segment. Dimensions and layout of wall are the same for both types of walls.

Both sets of walls had identical vertical reinforcing, a #3 Grade 60 rebar, spaced every third cell, the same concrete block, the same Type N mortar, and the same infill grout, a 4000 psi, 3/8” minus aggregate grout with a five inch slump. The concrete block, the mortar, and the grout all complied to ASTM C90-06b, ASTM C270-07a, and ASTM C476-07, respectively.

To provide support to the walls and to prevent the walls from moving horizontally during the explosive loading, a drilled pier foundation was used, with 8” diameter by 32” deep piers co-located with each vertical rebar. To construct the piers, an eight-inch diameter hole was augured to a depth of 36 inches, and then filled with concrete. Before the concrete was set, at each pier location, one piece of vertical rebar was place in the concrete. The vertical rebar extended from the bottom of the piers to the top of the walls. On top of the piers, a four inch deep by 14.33 feet long by five feet wide unreinforced concrete slab was poured monolithically with the piers, to provide a level surface upon which to construct the walls. Refer to Figure 3 for the location of the piers.

In the traditional walls, #3 grade 60 rebar was placed every other course starting with rebar being placed between the bottom course and the second course. The Arquin walls were reinforced with a 0.25" diameter steel rod (commonly called "pencil rod"), which had a yield strength of 80 ksi. The steel rod was placed at each course of the walls. In both wall types, the reinforcing was U shaped and ran continuously from one end of the wing wall to the end of the opposite wing wall.

The grouting of the walls was also a permutation. In grout type one, one Arquin wall and one traditional wall had every third cell in the walls filled with grout. In grout type two, one Arquin wall and one traditional wall had every cell in the walls filled with grout. Figure 4 shows the completed walls ready for testing.

The boundary conditions on the face of the wall that experiences the explosive blast can be assumed to be fixed on three edges and free at the top of the wall.

Figure 4. Completed walls just prior to initial test.

Data Recording

On the face of each wall, three pressure transducers were located to capture the pressure profile that the walls experienced during testing. The pressure transducers used were Kulite XT-190-100SG with a 50 amp gain. Additionally, a free-standing pressure probe was used to record the pressure wave from the explosive blast. Figure 5 shows the pressure transducer location in the wall and the positioning of the Arquin wall with respect to the traditional wall as well as the location of the explosive charge.

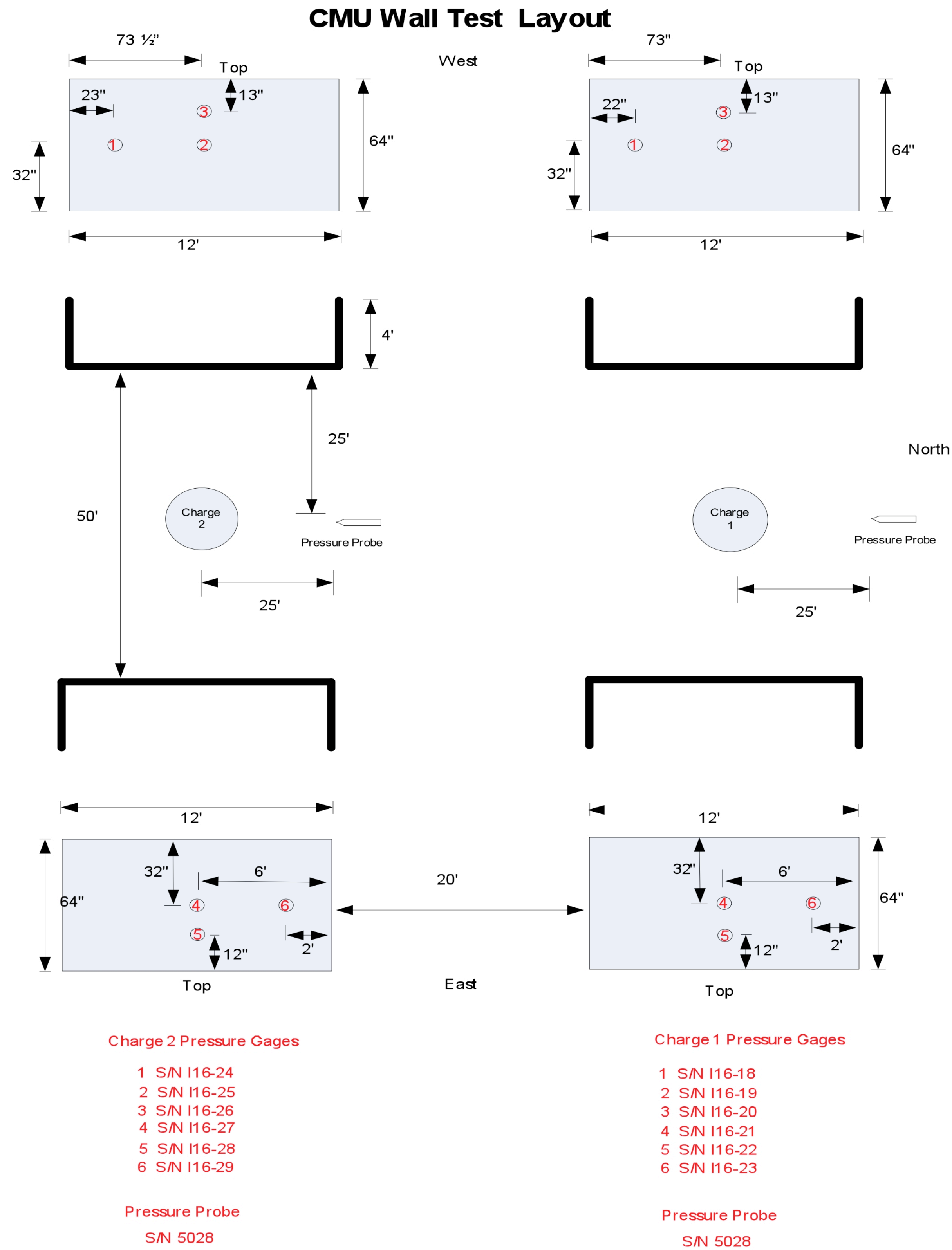

Figure 5. Diagram showing location of pressure transducers as well as location of charge with respect to the walls. Walls on the left have all cells filled with grout. The top walls are the Arquin walls.

High-speed photography was also used to record the effects of the blast. For each wall, one camera was located behind the wall to capture blast effects and another camera was located in the same plane as the front face of the wall to record the effect of the pressure wave hitting the wall.

Test Description

A total of seven explosive blasts were conducted, five on the walls with every third cell filled with grout, and one blast each on the Arquin wall and the traditional wall with all cells filled with grout. The explosive used in all blasts was C4.

Walls with every third cell filled with grout

The first three blasts were each a cylindrical charge equidistant from the walls. The explosive charge weight of the second blast was larger than the first blast and the third blast was at the maximum quantity of explosive that was allowed under the site permit that was requested. Due to reaching the maximum quantity allowed under the permit without breaking the walls, it was decided to split the charge into two cylindrical charges, place them closer to the walls, and detonate the explosives simultaneously. This would give a higher peak pressure but a slightly less uniform pressure wave with the center of the wall being impacted by the wave shortly before the ends of the wall. The total weight of the explosive used in the fourth blast was less than the weight of the charge in the third blast. The fifth blast was also two charges, with a charge placed closer to each of the walls being tested with both charges being detonated simultaneously. The total weight of the two charges used in the fifth test was equal to the maximum quantity allowed under the permit for the test. For the fifth blast, the distance from the charge closest to the traditional wall was 13.5 feet and the distance from the charge closest to the Arquin wall was also 13.5 feet.

Walls with all cells filled with grout

The sixth and seventh blasts were set off against the walls with all cells filled with grout. Since it was anticipated that these walls were stronger than the walls with every third cell filled, it was desired that the peak pressure would be higher than any of the first five blasts. Therefore, to obtain this higher pressure load, a charge was placed closer to the walls and detonated singly. The charge weight for the sixth blast was the same as the charge weight for the seventh blast. The distance from the sixth blast to the traditional wall was 13.5 feet. The distance from the seventh blast to the Arquin wall was also 13.5 feet.

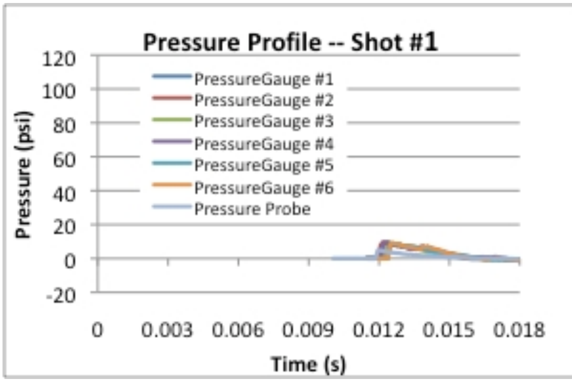

Figure 6. Pressure profile of first blast.

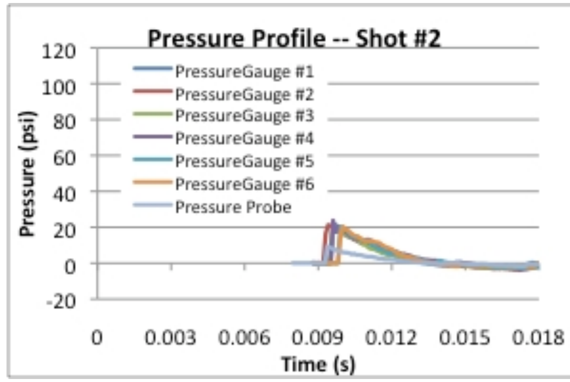

Figure 7. Pressure profile of second blast.

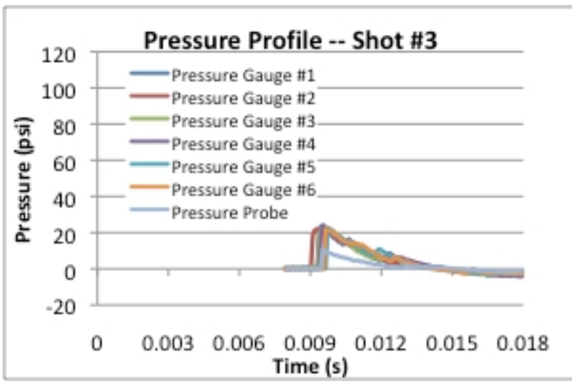

Figure 8. Pressure profile of third blast.

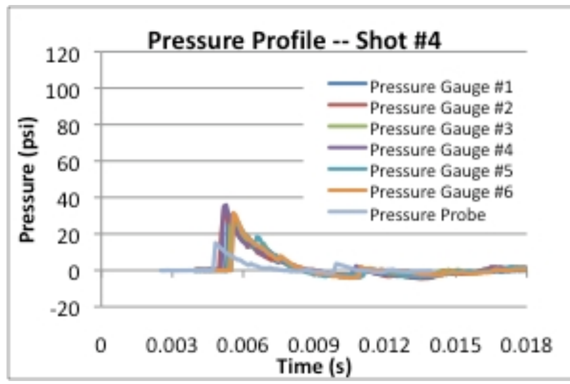

Figure 9. Pressure profile of fourth blast.

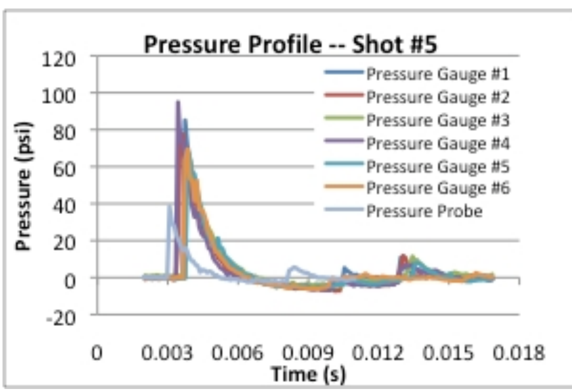

Figure 10. Pressure profile of fifth blast. The first through fifth blasts applied the dynamic load on the walls that had every third cell filled with grout.

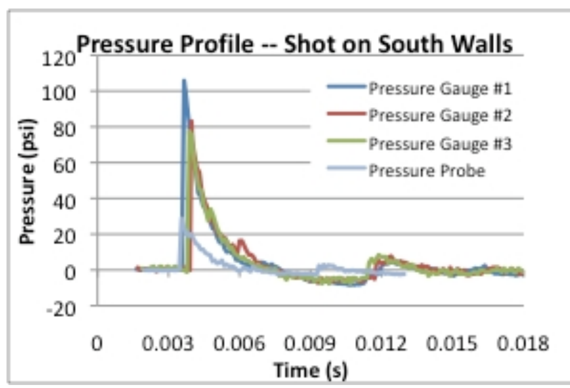

Figure 11. Pressure profile of seventh blast. This blast applied the dynamic load on the Arquin wall that had all cells filled with grout.

Figure 12. Photograph showing new location of explosive charges. In order to get higher pressures on the walls, the explosive charge was divided into two and moved closer to the walls. This enabled higher pressures to be achieved without exceeding the permitted charge weight.

Discussion of Results

The principal objective of these tests was to determine if, when subjected to dynamic loading, the Arquin method of constructing CMU walls performed as well as CMU walls that were constructed using more traditional construction methods. This was an extension of the static tests reported in SAND2008-8245.

The first five blasts were all set off against the walls that had every third cell filled with grout. The sixth blast was against the traditional wall with all cells filled with grout. The seventh blast was detonated against the Arquin wall that had all cells filled with grout.

The initial blast resulted in no discernable damage on the walls. Figure 6 shows the pressure profile of the first blast, including the free-standing probe. For the second charge, the explosive quantity was roughly doubled. The second charge also resulted in no discernable damage. Figure 7 shows the pressure profile of the second blast. The explosive charge was again increased, this time to the maximum amount allowed at the test range without additional permitting requirements. This third blast also did little to no discernable damage to the walls except for a few small cracks in mortar in the Arquin walls. Figure 8 shows the pressure profile of the third blast. Due to reaching the maximum allowed quantity of explosive per the required permit, it was decided to divide the charge and move each of the smaller charges closer to the walls. Moving the charge closer to the walls resulted in a larger peak pressure, but a slightly less uniform pressure load to the walls. Figure 12 shows the new location of the charges with respect to the walls and Figure 9 shows the pressure profiles from the fourth blast. Once again, the damage to the walls was minimal, principally some cracking in the mortar. Slightly more damage was ascertained to have occurred in the Arquin wall, though all damage was limited to cracking in the mortar, with the exception of the half block that was located directly in the center of the wall on the top course. This one block was broken free from the adjoining blocks and displaced several inches. However, this is probably an artifact of the design. Due to every third cell being filled with grout, some blocks in the walls had no grout in either cell. Since the Arquin wall had nine courses of block as a result of using a half height block as the first course, the top course was also a half height block. The center block of the top course of the Arquin wall had no grout in either cell. This made the block more susceptible to being broken free from the blast pressure, in contrast to the top center blocks in the traditional wall, which had grout in at least one cell of either block. The difference in block configuration and block damage can be seen in Figure 13 An additional measure of damage was the permanent horizontal displacement of the walls, at the center of the walls. In the first four blasts, no permanent displacement was measured from the vertical. The fifth blast had two cylindrical charges located 13.5 feet from either wall, with both charges larger than the charges used in the fourth blast and with a combined weight at the maximum allowed for the permit.

Figure 10 shows the pressure profile on the walls resulting from this blast. Damage on both walls was more extensive than evidenced in any previous blast with more and larger cracks in the mortar and some visible displacement of the block. Figure 14 shows images of the typical through block damage evidenced in both walls.

Additionally, at the centerpoint of both walls, the permanent horizontal displacement of the walls measured 0.5 inches. Subjecting the walls to a series of tests with an increase in the explosive loading on the walls with each subsequent test is not the best means of determining the ability of the walls to resist explosive loading. However, being that the intent of the test was to determine the relative performance of the Arquin wall to the traditional wall, as long as the walls were subjected to similar loadings, the comparison is still valid. At the conclusion of testing the walls partially filled with grout, the relative performance of the two types of walls was very similar.

Figure 13. The image on the left is the Arquin wall with every third cell filled with grout. The image on the right is the traditional wall with every third cell filled with grout. Note the difference in the number o courses in the Arquin wall because the bottom and the top courses are half height blocks. The block in the Arquin wall that was loosened had neither cell filled with grout.

Figure 14. Images of typical through block cracks following the fifth blast. The image on the left is the Arquin wall and the image on the right is the traditional wall.

The sixth blast was detonated against the traditional wall with all cells filled with grout. Unfortunately, the data recording failed to capture the pressure data for this blast. The quantity of explosive was the same as that used in the seventh blast and its distance from the wall was also the same, therefore it was assumed that the pressure profile is similar to that as the seventh blast, though this cannot be verified. The seventh blast was detonated against the Arquin wall with all cells filled with grout. Figure 11 is the pressure profile of the blast. In both the sixth and seventh blasts, no discernable damage was incurred on either wall, despite the higher peak pressures than the first five blasts that the walls with every third cell filled with grout.

Summary

Dynamic testing on four wall segments was performed. Two of the walls were built using the Arquin method of CMU construction and two of the walls were built using the traditional method of CMU construction. The Arquin method of constructing walls comprise using reinforcing wire on every course, the block laid in a running pattern, with either all of the cells filled or a portion of the cells filled with grout, the spaces between the block filled with mortar, and all of the materials complying with their respective ASTM specifications. The only principle difference between the traditional method and the Arquin method is the order of the steps of construction. Two walls, one Arquin wall and one traditional wall had every third cell filled with grout. Two walls, one Arquin wall and one traditional wall had every cell filled with grout. The dynamic loading was applied using C4 explosives. A total of seven charges/sets of charges were detonated. Five of the charges/sets of charges were detonated against the walls partially filled with grout. The last two charges, one against an Arquin type wall and one against a traditional wall, were detonated against walls that were fully filled with grout. After the five detonations, the partially filled walls showed evidence of failure manifested by significant cracking and permanent horizontal deformation with respect to vertical. The last two detonations, on the fully grout filled walls, showed no signs of damage.

The results of the these tests show that under the dynamic loading extent in this test series, a wall built using the Arquin method of constructing CMU walls performed as well as a wall that was constructed using traditional CMU wall construction methods.

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