# BENEFITS OF DRYSTACK INTERLOCKING CONCRETE MASONRY AS A COMPONENT OF COST EFFECTIVE CONSTRUCTION

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## ABSTRACT

Investigation of the various options currently employed to deliver structural and infill system for a construction project include each systems market compatibility and relative costs. This paper discusses the contribution drystack interlocking concrete masonry has had on several projects' affordability and reality.

## INTRODUCTION

Target planning for construction projects usually results in many intermediate tasks that will cause the reality of the project and the expectation of the final price to converge as initially desired and or promised. Investigating construction methods and their delivery systems many times direct the other tasks that marry the design with final budget.

The desire to reduce construction costs, improve product durability thereby reducing long term maintenance, is a well documented issue with the parties involved in the project, (1,2,3). The infill options available to the architect and/or contractor would not necessarily be limited to: i) steel stud framing, ii) wood stud framing, iii) multi-wythe clay masonry, iv) concrete masonry, v) glass. Structural options available would include: i) steel, ii) timber, iii) masonry, iv) concrete and others.

Masonry Construction Magazine has published several articles discussing the above options in comparison with masonry, (21,22,23). The benefit of the information is to show the masonry contractor how to use masonry and compete with these options. Identifying the benefits and opportunities of masonry will aid the contractor to educate architects, developers, and laymen about the available options masonry offers, (24). Articles have been written in trade journals giving the masonry contractor advice and methods to be more competitive not only in his bidding but operations management (4,5,6).

With all the discussions, articles, and work shops given towards these topics, the researched data seems to avoid the holistic approach to project development. The "holistic approach" can be defined by establishing the expected results and end goals, defining the intermediate goals required to obtain the results, selecting the delivery system required to obtain the intermediate goals and begin the project following the clearly established path set up by the intermediate goals. In this way the expectation and the reality converge minimizing surprises.

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Original paper presented at the 6th North American Masonry Conference, Drexel University, Philadelphia, Pennsylvania June 6-9, 1993.

**Building Design and Construction Magazine** recently reported its mid-year review of the non-residential construction outlook (8). Cited in the article was a languishing non-residential market slightly up from the previous year levels, with industrial and institutional markets tripling the previous years percentages. Although the forecast does not necessarily seem growth oriented, the masonry industry has many assets to overcome market lockout, and when properly devised, can capture projects and markets.

The NCMA has developed options the masonry contractor can use to compete with other building systems with their "Lifestyle 2000 " research house; constructed of concrete masonry drystack and interlocking components (4,7,). Concepts as shakable foundations, drystack veneers, groutless foundation (basement) walls, and floor systems. Due consideration was given to all the benefits of masonry as an economic tool, and what real time advantages favor the use of a drystack system over a mortared systems. The following concepts were evaluated:

## EXPANDING ON THE MASONRY ADVANTAGE

### Mortared Systems

Masonry components have inherent properties, when properly considered, can be a component in reducing construction costs. Some examples are i) unlike structural steel, masonry requires lower amounts of energy to produce, low energy intensive: ii) construction can be accomplished with lower technology in labor skills than with structural steel or reinforced concrete, skilled and semi-skilled labor force: iii) placing the units provides for closure, structure, and finish in one application, unit versatility (3,9,10)

Mortared systems, do however, require skilled masons to install the units. On average, a good crew, with minimal reinforcing, on straight walls, can lay 150 to 200 blocks per day, (crew consists of one mason and two helpers). Some crews have been known to accomplish 300 units per day (11). The main reason for these output quantities is the application of the mortar coupled with the vertical and horizontal alignment required to keep mortared system in proper position. Complicating the installation would be the application of horizontal and vertical reinforcing and grouting.

Workmanship is an overriding issue that can spread havoc through a project. Moving the unit after its initial set, improper tooling, incomplete head and bed joints (not filled), lack of horizontal wire reinforcing, cores to receive grouting not kept clean, are habits that individually and collectively diminish a masonry assembly's benefit and effectiveness, not to mention increased costs in after project expenses. Such are constant nemeses (9,12,13). Minimizing these results would greatly increase masonry's effectiveness and reduce associated project costs.

Mortar's benefits to masonry construction has been researched and studied in many ways from its early beginnings to present day (9). This glue between the units, by code, limits the assembly's strength and capacity unless acceptable field testing of data is used, (14), but this can be expensive. The majority of masonry projects do not have of testing of masonry materials, much less the type of lab testing that will allow higher limits of fm.. This practice limits the assembly's capacity to code values thus minimizes the effectiveness of masonry construction's contribution to a project's optimization. This should be intuitively understood when one considers the number of small scale commercial and residential construction is executed daily without a proper system of quality control.

I rather think the gentlemen placing the material in the wall should look beyond the wall. Affordable and competitive design and construction does not lie solely in trying to be more efficient in how, the same work done over the past 200 years, can be more efficient, but more to the point is why are we building this way? Seemingly the construction industry as a whole spends significant amounts of time and resources to make facilities more energy efficient and affordable. The effort is not really beneficial considering that the base construction materials used are not energy efficient. I believe a reordering of priorities is upon the architects, engineers and contractors to begin addressing more prudent methods and materials to build and repair facilities.

**Interlocking Mortarless (Drystack) Systems**

Concrete masonry systems that will reduce the use of mortar to minimal amount, thus reducing the obvious avenue for permeance, are self-aligning, and require a skill reduced labor force to install, can increase masonry construction's effectiveness as an integral part of construction planning. Problems experienced in water suction of the units, cracking of the mortar, joint permeance, etc. would no longer be factors on an assembly's composition.

Drystack Interlocking units that provide for simple stacking of one unit on top of another in a running bond, enable the mason to put more units in an assembly. Without the need of mortar and the time devoted to the mortar, additional units can be placed with the same period of time. Output has been as much as 900 to 1200 units a day per crew (15,16). Units can be placed by semiskilled and unskilled labor with proper guidance. Reducing the labor cost and increasing the output can translate to a labor cost reduction of up to 80% (1,3,11,15,17). Quality control of the assembly thus lies with the manufacturer of the interlocking CMU, and substantially reduced responsibility at the job site.

**Benefits of Interlocking Principals**

Construction assemblies require careful attention to ensure straight lines and verticality. Interlocking systems are no different in their inherent nature. The interlocking features provide stability during construction, assist with alignment and leveling as well as limiting the maximum construction tolerances. Beyond labor savings and construction speed, floor and roof loads can be directly applied to the wall assemblies in the dry state thus allowing progress without interruption. Depending upon the construction's occupancy condition, the assemblies can be completed in several ways:

A. **Plain:** Construction comprises drystack interlocking units typical of retaining walls, foundation walls, partitions and load bearing walls for unoccupied environments. Limiting heights may be approximately 9'-0".

**B**. **Surface Bonded**: Construction comprises drystack interlocking units which are finished on the interior and exterior with either a cementitious or acrylic bonding matrix reinforced with fiberglass mesh or plastic fibers. Matrix should completely cover the entire surface area of the walls. The surface bonding material serves as a rain and air barrier in addition to providing final surface finish, texture and color. Limits on heights may be approximately 21’-8" on two story load-bearing walls.

**C. Grouted:** Construction comprises drystack interlocking units which have their cores filled with grout (partially or fully), and can include both horizontal and vertical reinforcement. Unreinforced grouted walls provide for higher load capacities and heights than that of simply surface bonded assemblies. Reinforced, grouted walls provide reinforced masonry assemblies with properties and load capacities similar to conventional reinforced systems. Limits on heights may be approximately 36’-0" on three story load bearing walls.

Vertical interlocking is accomplished through the webs of the unit or by protrusions on the face shell. The protrusions should coact with the webs on adjacent rows of units to locate and hold the units together. Interlocking provides for self-aligning characteristics thus minimizing and sometimes eliminating the need for leveling and special skills (18).

Horizontal interlocking (head & bed joints) provides for grout containment and continuity of each unit and course. Testing of "System One Block" (Fig.2) revealed that when filled with grout the voids between face shells and ends would fill. The filling of the grout would provide for full contact of the lugs. This action will provide increased shear resistance capacity and minimize displacement (19). The unit’s increased compressive strength capability is achieved by mobilizing the grout strength without premature face shell failure that would be attributed to mortared systems. The face shells resist a smaller proportion of the total load relative to mortared systems because of "seating deformations" required for compatibility with grout fill. The webs are not in plane but alternately bear on the grout fill (20).

Reported testing results by Dr. Robert Drysdale (25) and Mancini (20), conducted on fully grouted "System One" indicates the shear, tension and horizontal load capacities to be much higher than a comparable grouted mortared grouted assembly. Mancini indicates also the superior strength acquired from surface bonding.

The "System One" units can be manufactured in the local job site area. Molds are shipped to the producer and placed into his block making equipment.

Testing of the "System One" by Drysdale (26), (Fig.l) offered system capabilities ranging uses without mortar or grout to fully grouted and reinforced assemblies. Virtually no skill is required to place the units and construct wall heights up to 12’-0" in height. The units can be produced locally provided the manufacturer has the equipment compatible with the molds. The "System Two" assemblies have five component configurations required to construct a typical wall. System One assemblies require only three component configurations to construct a typical wall.

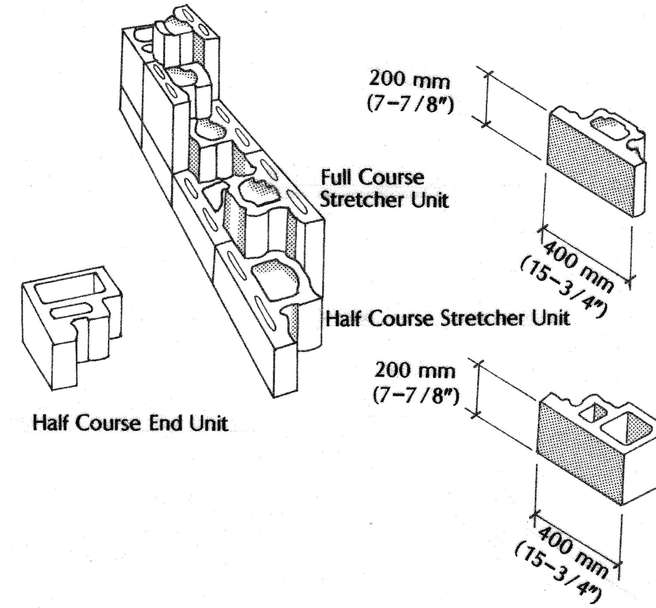


Figure 1 - "System Two" drystack interlocking concrete masonry units.

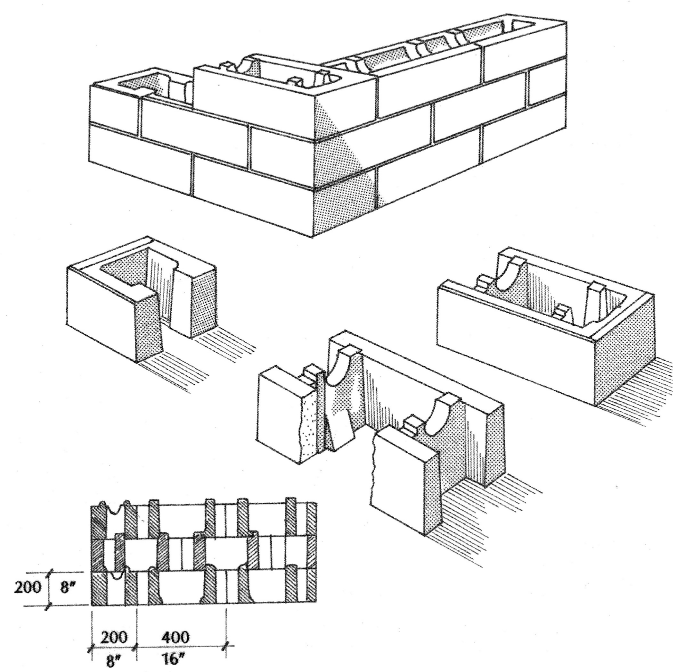


Figure 2 - "System One" drystack interlocking concrete masonry units

Enhanced fire resistance, reduction of accidental sound transmission and improved resistance to air flow are benefits facilitated because the head and bed joints are not continuous through the wall section (26).

Various drystack systems were evaluated (27,28,29), but not considered due to availability of molds and compatibility to the local producers' equipment.

## PROJECTS BENEFITTING FROM DRYSTACK INTERLOCKING CMU

### Project Descriptions

Two small scale projects the author was responsible for, at a Texas University, and anaerobic digester basin in California and convention center in North Carolina were either designed or are being evaluated, by the author, for the appropriateness of drystack interlocking cmu.

Drystack interlocking masonry units from "System One" were selected for these projects for the following reasons:

A. Of the various types of manufacturer's that make block making machines, two were in the general area of the author's office. The close tolerances achieved from one manufacturer's machine were better than blocks reviewed and received from the second manufacturer's machines.

B. Units are compatible with traditional units the local masonry industry was accustomed to given the first time the contractors' would be using the drystack interlocking block.

C. This system has only three shapes, flexible in design and course equally to conventional mortared systems.

**Project One** is a small equine facility measuring 160' in length and 28' in width. The total foot print of 4,480 Sq. Ft. is open on the front and partially on the ends (sides). The interlocking units were specified in the base bid and the mortared system was specified as an Alternate for comparison. The cmu walls were fully grouted for protection against the horses kicking the walls. Ten stalls were placed in the facility. The roof structure was to be a pre-engineered metal system and prefinished metal roof. The floor was not paved but free soil.

During the process of the bidding, each general contractor had access to the sample units on display by the author. Each general contractor was well aware of the effort by the author and the university to find alternate ways to construct facilities while maximizing the money available. The project was generally well received by the general contractors.

The concrete blocks were specified to be made with buff cement with plasticizer and water sealers integral with the mix. The mortared system was specified to achieve the same level of capability as the interlocking block. The project had roughly 2100 block, 8"x8"xl6".

The bids taken for the project showed the low bidder with a base bid of $138,000.00. The add alternate to substitute the mortared system for the interlocking system was $19,000.00 higher. Almost a 14% increase. The time to complete the project if the alternate was taken was 10 additional days (27).

**Project Two** was a research facility of 12,356 sq. ft. The building was broken into two parts: The maintenance facility measured 60 ft. in width and 150 ft. in length. This was a two volume space and the side walls were nearly 20 feet tall. The space contained a concrete floor and storage facilities for various types of research equipment. Tractors, trucks and cars were also maintained in this facility. The remaining portion of the building, used for classrooms and offices, measured 40 ft. in width and 80 ft. in length. The walls were 13 ft. tall and the roof was flat.

The cmu's were to be sealed with the gray color to be accented. Partial grouting was required. The remaining cells were to be filled with insulation. The space was to fully finished out for occupancy by students and staff. The interlocking units were part of the base bid with the mortared system as an add alternate for comparison. The mortared system was specified to achieve the same level of capability as the interlocking block. The project had roughly 6400 block, 8"x8"xl6".

The estimates taken for the project showed the potential low bidder to have a base bid of $338,000.00. The add alternate to substitute the mortared system for the interlocking system was $34,000.00 higher. Over a 10% increase. The time to complete the project if the alternate was taken was 25 additional days (28).

**Project Three** is a large convention center in North Carolina. The size of the facility is approximately 865,000 Sq. Ft. and 90 ft. tall. The facility has four floors. The structural frame is reinforced concrete and concrete protected steel columns with steel frames and concrete floor system. The perimeter skin is precast concrete with some exposed split face emu veneer. This building is in a Type II seismic zone and nearly all the emu is grouted and coated with an acrylic finish material.

The service level and third meeting room levels all have plain emu partitions and infill walls. The main hall has exposed split face white emu as high as 40 ft. Ceramic tile is placed over the emu in the restroom areas. The construction manager's estimate of masonry is nearly 900,000 block of various shapes and cement.

The estimated cost of the masonry package for the project provided by the Construction Management Company $3,167,580.00 and the construction time would be approximately 3,270 crew days or 4,844 man days. The author's estimate of savings would be approximately $1,239,220.00 and the construction time would be approximately 982 crew days or 1,454 man days. The difference in cost between the conventional mortared system and the drystack interlocking system is approximately 38%. The time of completion would by 60% less time or approximately 2288 crew days and 3390 man days (29).

Due to the engineering and seismic requirements of the project, only the cmu type was changed, with all other design requirements remain unchanged. The "System One" block has not been evaluated under seismic testing and the models are not available. The design logic seems to suggest that the system will perform at higher levels than a mortared system.

**Project Four** is an aerobic digester for a sanitary sewage treatment plant in northern California. The facility is located on the grounds of a federal prison. The digester is 120 ft. long and 40 ft. in width. The walls are 25 ft. high. The interlocking drystack block of "System One" is being used because the prisoners can build the facility, the block is readily available and the Prison Industries program has previous experience with the blocks. At this particular location, the prisoners have been using the material for several years. The advantages of the material, as mentioned earlier in the paper, enabled the facility to be built.

Located in a Type 4 Seismic Zone, there was more concern with the tsunami wave effect of the water in vessel in the event of an earthquake than with the block's ability to perform the task. Traditionally digester basins are round and of reinforced concrete. Using the block in a nontraditional application represents its flexibility.
The units would be fully grouted and sealers integrated in the block production and upon completion contains the methane gas and waste water from leaving the basins, or new water entering the basin (30,31)

Discussions with the prison officials reveals that the savings would be nearly 50% than that of a conventional poured in place reinforced concrete basin structure. The digester could not be built any other way due to limitations of funding.

**SUMMARY**

The above projects benefitted in similar ways by using drystack interlocking concrete masonry units as an integral design element of the project. Conventional mortared concrete masonry assemblages are shown to be more costly. In the case of the digester, the success of the project is the ability of the prisoners to build with the block and not requiring the services of a skilled mason.

Applying the system to the convention center will benefit the tax paying citizens of North Carolina in addition to the potential construction time savings thus providing early starts of the remaining work. During a demonstration for the project team, a local masonry contractor was poised to construct a wall, ten feet long with a corner five feet long. The contractor having never seen the interlocking units prior to 10:00 in the morning of the demonstration, skillfully adjusted his field crew and stacked the units. The real demonstration, later in the day, was very successful. As the author discussed with the project team the units and their benefits, the masonry contractor and two others stacked the entire wall, up to five high in less than five minutes.

Comments from the crew are summed up this way - The same number of units placed in the wall using mortar would have taken almost four time longer - the use of the system is not threatening to the industry and in their opinion, using the system would not only make them more productive and profitable, but there would be less wear and tear on the people and equipment (33). Understanding the many advantages and benefits available from specifying drystack interlocking concrete block from inception of the project will lead to opportunities and increase sales to the industry and provide affordability to all projects.

## CONCLUSIONS

Drystack interlocking concrete masonry units have been competing against reinforced concrete in Canada for many years (32) and winning. The structural strength, coupled with the quickness of speed in placing the units makes using the drystack interlocking concrete block a beneficial tool to be considered for most construction projects. The concepts and applications are strictly limited by the designer’s imagination. When the masonry industry (contractors, producers, designers) begin to agree that the future of their industry lives and dies with them, materials like interlocking drystack emu’s can only increase and expand their market shares.

The indicated savings for the aforementioned projects seem to aptly demonstrate, that interlocking drystack cmu’s, when incorporated as an integral part of the construction program provide i) shorter installation periods, ii) project affordability due to its initial cost savings, iii) increased structural capacity, iv) secondary undisclosed benefits for the industry and project such as potential early occupancy, in addition to the established and published benefits concrete masonry is well known for (34,35). Not discussed but in need of additional research and data is concrete masonry’s contributions in reducing long term maintenance costs compared with other materials used in similar situations.

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