The Use of Mortarless, Drystack, Concrete Masonry as a Contributor to Affordable Construction

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THE USE OF MORTARLESS, DRY STACK, CONCRETE MASONRY AS A CONTRIBUTOR TO AFFORDABLE CONSTRUCTION

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ABSTRACT

The benefits of masonry in construction are well documented throughout the history of the modern world, important factors to consider are: (i) manufacturing is low energy intensive, (ii) construction can be accomplished with lower technology in labor skills than required for structural steel or reinforced concrete and (iii) minimal machinery would be required to manufacture primitive units. Units or this caliber greatly contribute to the inherent strength of the assembly and much stronger than equal assemblies requiring mortared joints. This paper investigates the units most appropriate for developing countries and the relative benefits.

INTRODUCTION

Over the past twenty years, research has been devoted to developing a mortarless, dry stack technology that would maximize the use of semi-and unskilled labor to build very strong and cost effective facilities, with increased durability. This technology is affordable and available in today's world economy and can be used in developing nations as a marvelous tool.

Since exterior plastering (rendering) of the masonry is customary in developing countries, and tilling the cells is required for stability; mortarless, dry stack masonry and its appropriate finishes would be common place. Additionally, dry stacking for such purposes can reduce construction time while maximizing local capabilities.

Watching a mason lay concrete block walls, one would assume that the mortar acts as an adhesive designed to "glue" the block together. Such is not true. Mortar normally mixed and used has little, if any, strength in tension and has relatively poor adhesion. Except for use in direct compression, the strength of a mortar joint for structural purposes, must be considered negligible. The mortar serves mainly as a bed to aid in reveling the block. It also fills the joints between blocks to present what appears to be a "tight" wall to reduce entrance of rain and wind[(1)].

A mortared block wall is not a "tight" wall. The joints serve as capillary wicks and draw moisture through the cracks between the mortar and block interface, (2).

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In recent years a strong international interest has been sparked to develop concepts and systems for masonry laid without mortar. Program objectives include; (i) allowing for automation (3); (ii) reasonableness in constructability; and (iii) reducing labor cost concepts from installation by skilled masons to installation by semi- and unskilled labor. In view of the above concerns; the constant need to reduce building costs and increase labor and efficiency, mortarless, drystack systems have been attempting to resolve such dilemmas for over 100 years. Since 1880 there have been nearly one hundred interlocking block systems have been invented,(4).

Various concepts of mortarless and/or interlocking, and/or drystacking systems have been recently presented at various forums either to discuss state of the art and current research (5); depict particular units (6), explore strength characteristics of an existing system (7), or discuss new and untried options (3,8). In all these papers, the reasonableness of use and wisdom in the practicality of construction were not discussed.

CONCEPT

"I find it incredible that there will not be a sweeping revolution in the methods of building during the next century. The erection of a nouse wall, come to think of it, is an astonishingly tedious and complex business; the final result is exceedingly unsatisfactory. It has been my lot recently to follow in detail the process of building a private dwelling-house, and the solemn succession of deliberate, respectable, perfectly satisfied men who have contributed each so many days of his life to this accumulation of weak compromises, has enormously intensified my constitutional amazement of my fellow creatures. The chief ingredient in this particular house wall is the common brick, burned earth, and but one step from handfuls of clay of the ancestral mud hut, small in size and permeable to damp. Slowly, day by day, the walls grew tediously up, to a melody of tinkling trowels."

"Everything in this is hand work, the laying of the bricks, the dabbing of the plaster, the smoothing of the paper; it is built of hands-and some I saw were bleeding hands-just as m the days of the pyramids when the only engines were living men. The whole confection is now undergoing incalculable chemical reactions between its several parts. Lime, mortar, ana microscopic organisms are producing undesired chromatic effects m the paper and plaster; the plaster, having methods of expansion and contraction of its own, crinkles and cracks; the skirting, having absorbed moisture and now drying again, opens its joints; the rough-cast coquettes with frost and open chinks and crannies for the humbler creation. I fail to see the necessity of (and, accordingly, I resent bitterly) all these coral-reef methods. Better walls than this, and better and less-wasting ways of making them are surely possible." Such is the prophecy of H. G. Wells as quoted from his "Anticipations’1 published in 1902.

For the most part Wells is correct. Construction thinking has been the same in the industrialized world for the past 250 years. In developing countries, the indigenous methods have been the norm as additional to advanced technology brought in for governmental and large public works projects.

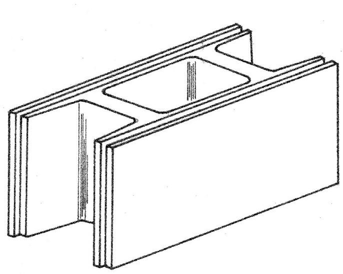
When one considers the elements of construction, i.e., (i) the project purpose, (ii) the high cost of funding, (iii) the human factor for construction, (iv) the owner's expectation and (v) the contractor's reality; a definitive result and goal should come together smoothly. Getting the project right the first time is essential. Owners have the right to expect the best level of effort from the team involved bringing the dream into fruition. Current world economy provides for no more back-up plans.

Contemporary programs should require project teams to look at all aspects of project economy. Achieving the goals with the least cost involves efficiency in: (i) delivery systems, (ii) minimizing the requirement of high technology labor for high technology; subsystems (iii) incorporate simple subsystems thus allowing lower cost in production with the maximization of durability, (iv) understanding the construction assembly practicality from the advantage point of the construction team, and (v) driving down the construction costs by employing economic materials with high durability and low over all maintenance costs over the life expectancy of the building.

Drystack, mortarless, interlocking concrete masonry systems, when incorporated in an overall comprehensive plan to maximize material capabilities and delivery systems, have shown to be very effective in reducing; labor costs, structural system costs, material costs, and construction time, while increasing durability and enhancing the overall aspect of the architecture.

THEORY OF MORTARLESS SYSTEMS

Almost all of the inventors believed that, for interlocking, the block had to have a tongue and groove concept, (4) at the ends, or on the face shells, (Fig.1a) or with dove tail patterns, (Fig. Ib)



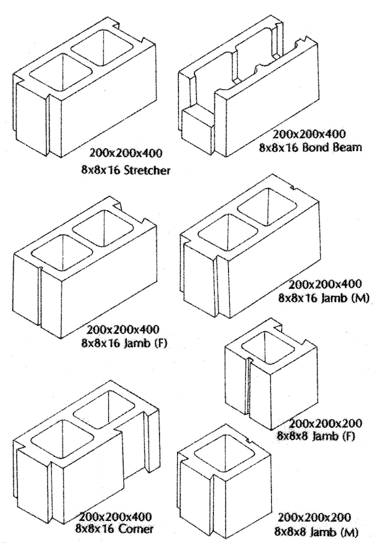


Figure 1a - T&G Block

Figure 1b - Dove Tail Block

Application

Using a tongue and groove concept on the face shell typified the researchers reluctance to dismiss the mortar bed effect of tensile transfer. Blocks following this tendency will not be very successful. To make a groove or an undercut on the bottom of a block with conventional high speed machines, special pallets with a apart mold are required; and the addition of these types of mechanical attachments to an existing pallet is costly and can exceed $200.00 (US) per pallet. These machines need between 1,000 to 4,000 pallets, (4).

Some machines use undercutting scissored or knife mechanism which are subject to short fatigue life. Machines manufactured in Germany have such capability but the manufacturing costs are known to be at least twice the cost of conventional block, (4). Success will come when a re-thinking of just what is the purpose of the block assembly and what is not required for the assembly.

Another disadvantage of all previous interlocking blocks is that the tolerances of the producing machines were not taken into account with the finished product (4). Different manufacturers of molds and machines could not guarantee the preciseness of the end product. High tolerances had to be adjusted from one machine to another. Not all blocks would fit with each other.

Principals of Interlocking

First, the principals of interlocking have to be explained before clearly understanding how self-seating mechanisms work. Interlocking without undercuts requires unique geometrical relations between the distances of the web and the interlocking protrusions or locks. These relations must also satisfy the requirements of the different building and material codes for performance and stresses, (4).

Secondly, the blocks must be economically produced on conventional block machines. Even if the geometry could be guessed by trial and error to achieve similar interlocking, it would be very difficult to find by guessing dimensions which also satisfy all the previous mentioned requirements (4).

Thirdly, the geometrical relations have to be expressed in the form of equations which allow the design of the block to be in accordance with given legal, structural and building code requirements in addition to be interlocking simultaneously, (4). Without rival, there is only one primary set of equations which can define an interlocking block without grooves on the bottom face shell. Indefinite possibilities of geometries are calculable from these relations. In its inception, a determination should be made if the construction assembly is be fully grouted, partially grouted, or not grouted. Reasoning then, a practical block should have one, two, three or more webs, (4).

The central cavity (Cc) has to be: $Cc = A1 + A2$ [1]

The central seat (Cs) has to be: $Cs = B1 + B2$ [2]

The total block length has to be:

$$L = A1 + B1 + Cl + A2 + B2 + C2 \quad [3]$$

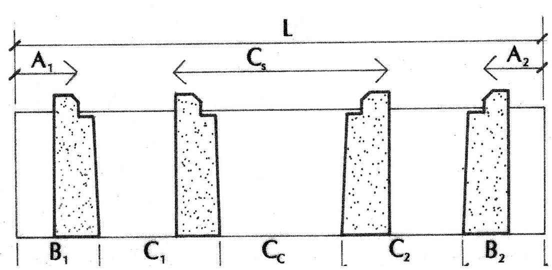
In a symmetrical four web block where: $A1 = A2$, $B1 = B2$, $Cl = C2$,

the length of the block is: $L = 2(A1 + B1 + Cl)$ [4]

To understand the concept, a four web block, (Fig.2) is shown in cross section.

A symmetrical two web block is obtained when [C_1 and C] are set equal to zero, & [$B_1 = B_2$] in equations 1 through 4. With these concepts, blocks may be assembled with mortar, mortarless, grouted, ungrouted, surface bonded (plaster or rendering) or with glue. By inverting the finish or top course, roof plates or other attachments may be obtained. This is an important feature.

The other required shapes, i.e. the end block and the half block are designed using the same equations. These shapes allow for: i) the maximum single cell possible, ii) stiffer webs, iii) interlocking for stability during erection and service life, iv) ease in the placement of vertical and horizontal steel, e) simplicity of installation with semi and unskilled labor, (4). In using three and only three shapes, confusion during construction can be minimized and the product serves to be aesthetically equal to mortared systems only stronger (7).



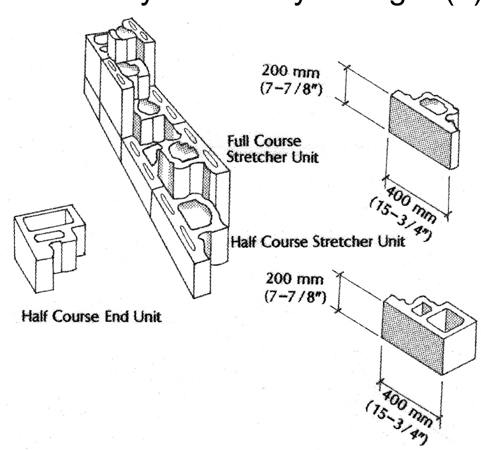


Figure 2 - Four web block

Figure 3 - Sparlock™ Block

PRODUCTS

Currently there are several mortarless, interlocking, block systems in various parts of the world which have been successfully used in building bearing wall structures. The most promising systems are the Sparlock™ Concrete Blocks (9), (Fig.3), and the Haener™ Mortarless Interlocking Block System (10), (Fig.4). Showing some promise but as yet unavailable is the WDH units currently under study at Drexel University (3), (Fig.5).

System Concepts and Limitations

Sparlock™ Concrete Blocks - Possess positive interlocking in both horizontal and vertical directions, this dry stacking system allows for the horizontal feature through shear keys.

Shown are the system's three basic units, stretcher, corner and jamb which enable horizontal locking to be accomplished at corners, end walls and jamb openings. Interlocking vertically is accomplished due to each course being half the height of the previous course. An overlap of 3-13/16 inches creates continuity past the weak areas of the bed joints. 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 (9).

Construction assemblies require careful attention to ensure straight lines and vertical alignment. This system is no different in its inherent nature, but beyond this, semi-skilled labor can be employed to install the block. The interlocking features provide stability during construction, assists 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 assembly in the dry state thus allowing progress without interruption. Depending upon the final construction's occupancy condition, the assembly can be complete in one of the following ways (9):

A. Plain: Construction comprises dry stacked units typical of retaining walls, foundation walls, partitions and load-bearing walls not intended for human occupancy, not to exceed 2.8M (9'-2") in height.

B. Surface Bonded: Construction comprises dry stacked units which are then finished on the interior and exterior with either a cementitious or acrylic bonding matrix that is reinforced with fiberglass mesh or plastic fibers and will completely cover all exposed surfaces of the block. This material serves as a rain and air barrier, as well as providing the final surface finish and color. Basement walls not to exceed 8'-3" in height; Single story building walls not to exceed ll'-10" in height; non load-bearing partition spanning horizontally not more than 13'-9" and limit 2 storey load bearing construction to a total wall height not to exceed 21'-8".

C. Grouted: Construction comprises dry stacked units which have their cores filled with grout and can include both both horizontal and vertical reinforcement. Unreinforced, grouted walls provide for higher load capacities and heights that of simply surfaced bonded assemblies. Reinforced, grouted walls provide reinforced masonry assemblies with properties and load capacities very similar to conventional reinforced systems. Basement walls not to exceed 10'-6" in height; Single story building walls not to exceed 17'-0" in height; non load-bearing partitions spanning horizontally not more than 25’-0" and limit 3 storey load bearing construction to a total wall height no to exceed 36’-0".

Sparlock requires the five different size shapes to build any section. This is due to the unique interlocking properties of the system. Walls begin with half height units then progress, alternately with full height then half height units. Workers with some level of technical skill are required to maintain the project continuity during placement of the units.

Determining the exact quantity of each size units is more involved than with a system that would very closely emulates a conventional system. Currently these blocks can be made commercially only on Besser type machines (9).

Haener™ Interlocking Mortarless Block System has a unique combination of lugs molded into the webs and tongues and grooves molded into the end faces permit the blocks to stack and lock together without mortar as shown in (Fig.4.)

Shown are the three standard size units, stretcher, half block and corner also used as an end block. The concrete masonry units are very similar to conventional units, but having projections and recesses that provide an interlocking function, facilitates erection and maintains a continuous clean cavity. Interlocking vertically is accomplished through the lugs on the webs. The system is constructed dry without the use of mortar resulting in a self aligning effect.

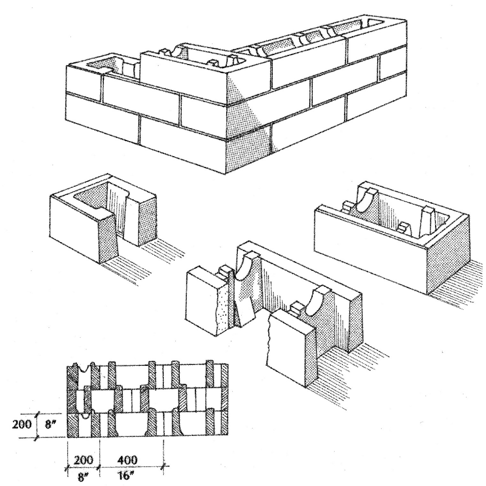


Figure 4 - Haener™ Block

Recesses between the lugs provide for reinforcing to be placed horizontally and vertically without tying. The initial course must be laid flat and plumb to allow for positive dry stacking of the remaining units. Technical skill is required for this phase. Once completed, semi and unskilled labor can be used to stack the remaining courses. It is possible for a laborer to place over 1200 block walls in one day into an assembly. The locking provisions allow for floor and roof dead loads to be directly applied to the assembly in the dry state thus allowing for progress without interruption (10).

Depending upon the final construction's occupancy condition, the assembly can be completed in one of the following ways (10):

A. Surface Bonded: Construction comprises dry stacked units which are then finished on the interior and exterior with a either a cementitious or acrylic bonding matrix that is reinforced with fiberglass mesh or plastic fibers and will completely cover all exposed surfaces of the block. This material serves as a rain and air barrier, as well as providing the final surface finish and color (10).

B. Grouted: Construction comprises dry stacked which have their cores filled with grout 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 very similar to conventional reinforced systems (10).

The design theory for the block has been based upon the "equivalent solid block" flexure theory. This methodology has been supported by the NCMA test verification program thus developing the principals for; (i) surface bonded strengths, (ii) grout filled strengths, (iii) grout filled and reinforced strengths, (iv) allowable stresses (ACI 531 format) related to prism and unit strengths (10).

Existing are unique slenderness (h/t) effects for allowable compressive stresses per grout filled and surface bonded walls as; (i) "Plane-sections-remain-inplane" flexure theory for grouted sections and "couple" flexure theory for surface bonded configurations, (ii) the "unity" interaction equation for combined bending and axial stresses, (iii) NCMA prism testing eliminates the requirement for ground bed joints for full compression strength and (iv) the unique shear strength of the lugs is accounted for in the equations (10).

Using the block fully grouted, the system uniquely mobilizes the grout strength without the premature Face shell failure attributed to mortared block of these reasons; (i) the face shells resist a smaller portion of the total load relative to a mortared configuration because of "seating deformations "required for compatibility with the grout, (ii) the webs are not in plane but alternately bear the grout fill. For the condition in which the grout strength equals or exceeds the unit masonry strength, the design may by conservatively based upon the following Unit Strength Method in lieu of the Prism Test Method (7,10).

f'_m		f'_{um}		f'_g Minimum	
Mpa	PSI	MPA	PSI	MPA	PSI
08.27	1200	11.03	600	11.03	1600
09.66	1400	14.84	2100	14.48	2100
11.03	1600	17.93	2600	17.93	2600
12.41	1800	22.76	3300	22.76	3300
13.80	2000	27.58	4000	27.58	4000

Where:

f'_m - specified compressive strength of the grout filled masonry - psi

f'_{um} - Unit masonry net compressive strength - psi.

This is based upon the net bearing surface stress rather than the average block net section.

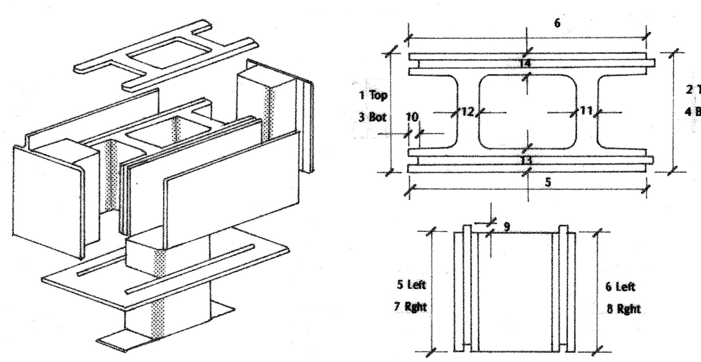
f'_g - grout compressive strength - psi.

Working with the Haener block provides a very simple assembly requiring only the three units. Once the initial course is placed square and plumb, all remaining courses may be stacked quickly. Periodic checking for plumbness of the wall is important and can be corrected if alignment is not true.

Modified "H" Block and the Whelan-Hatzinikolas-Drexel Block (WHD1 is an H block shape that has been researched and studied extensively. When used has a true shape only one web exists which presents several concerns when manufactured, shipped and set. With only one web, the section is subject to breakage. The modified H has open ends and two webs.

Average Geometric Dimensions of Modified H-Block
Full Scale Units - 8x8x16 and 8x8x8 Blocks

Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Inches	7.95	7.95	7.74	7.86	7.95	8.04	8.01	8.04	0.39	0.48	0.46	0.44	0.50	0.47	15.9	15.9
S.I. Units	.242	.242	.234	.240	.242	.245	.203	.245	0.12	0.15	0.10	0.13	0.15	0.14	.416	.416



A – Modified H-Block

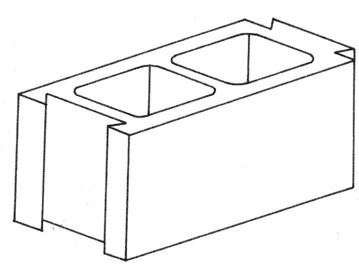

B – WHD Block

Figure 5 - Units studied at Drexel University

Harris (3) reports advantages and disadvantages to using this shape. He also discusses the advantages of wny tongue and grooves are placed on the face shells; but the fabrication concerns mentioned earlier spurs him to look at other alternatives (11). Unless the web is modified to accept horizontal steel and provides for the horizontal flow of grout, the Modified H block will have limited appeal. This could be accomplished by further identifying the dynamics of rotation in tne webs if its shape is modified.

When Whelan first reported his concepts (12), the unit was to be secured with an epoxy grout injected into a groove made by the face shells of interlocking blocks. Applying current technology, the WHD block eliminated the faceshell groove and the epoxy grout. Depending on surface bonding and grouting, the system promises to compete with other commercially available systems. Figure 5b depicts the three shapes currently being investigated.

BENEFITS OF SURFACE BONDING

Sufficient research over the past years in addition to practical experience present overwhelming data to realize that conventional Concrete Masonry Units (CMU) will absorb water and leak upon saturation (13). Installed unprotected will guarantee certain aesthetic, health and structural problems. Thus any type of block laid into a wall be it mortared or dry stacked, must be waterproofed by applying clear waterproofing sealers, masonry paint, pigmented waterproofing sealers, or clear sealers integral with the molding process. The application of a exterior rendering coat (stucco or plaster) will hide the joints but clear or pigmented sealers will not. Stucco can be expensive and is known to crack over time (1).

In northern Canadian Provinces, Scandinavian countries, many European Countries, and many Asian countries some type of exterior rendering is applied to the masonry construction providing (i) protection from water and air infiltration, (ii) color to the construction and (iii) hiding for poor quality labor or materials (15,16). Given the above scenarios, none of the applications contributed to structural enhancement of the assembly.

Prawel reported that the use of ferro cement as a surface coating enhances unreinforced masonry walls in seismic zones (14). The results also indicate that stability of masonry walls can be benefited regardless of seismic location. One may conclude that such coatings will hide the masonry and provide limited moisture protection. Surface bonding the interior and exterior of drystack, mortarless, interlocking masonry walls with a cementitious or acrylic matrix based cement reinforced with plastic fibers is a very simple method of constructing skin-stressed walls. When the bonding matrix has cured, the resulting block wall has a relative high tensile strength coating on each surface.

The blocks produce a high-strength compressive structure between the two thin coatings of bonding. Attempted flexure of the bonded wall puts a compressive loading on some portion of the blocks and a corresponding tensile loading on one of the bonding coatings. Since the bond coating has good adhesion to the blocks, and a relatively high tensile strength, attempted flexure of a wall section is resisted to the limit of the bonding-tensile strength (1).

Application of the material does not require the services of a skilled mason or technician. Children as young as 12 years old have been trained to apply the bonding material. The cost of the "bonding material is no more than the mortar to lay an equal number of blocks. These systems, when properly applied, mean a savings at least equal to the labor and material for waterproofing ana labor coat for painting. The cost incurred for the structural benefits of the coatings are shared in the application, thus increasing the benefits with lowered costs. Life cycle costs are minimal with respect to maintenance of the coating and structural characteristics (1).

Commercially available bonding systems provide for integrally mixed waterproofing, color, and fiber reinforcement combined with cementitious materials. These materials can be applied with trowel and hawk or spray and textures can be obtained in various fashions.

CONCLUSIONS

Since many developing countries depend upon a local indigenous work force these concepts should be encouraging. Surface bonding skip-grouted dry stack systems; (i) produces a wall system that is generally stronger than a mortared wall, (ii) eliminates the necessity of waterproofing after construction, and (iii) inexpensive to construct.

Several projects reviewed with the drystack, interlocking system have shown significant savings in construction costs, assembly timelines, and overall completion schedule reductions. Currently the Charlotte Convention Center in Charlotte, North Carolina, USA was analyzed by the author using the Haener™ System. The potential quantity of block to be used would exceed 800,000 in plain, split face and white colored umts in widths of 4", 6", 8", and 12".

Since interlocking units could only be manufactured in widths of 8" and up, only these applications were analyzed and cross-engineered. The potential to the city of Charlotte could be as much as $1.25 million dollars, (24).

An animal care facility, managed by the author while at Texas A&M University, bid in March of 1992 with the Haener™ System used for the base bid and conventional mortared system as an alternate. The comparable alternate came in over $16,000.00 above the base bid and increased the construction time by two weeks.

The concept of surface bonding drystacking, mortarless, interlocking concrete blocks as part of an overall construction methodology that will maximize results with least cost should be highly considered. The many benefits should be encouraging. Masonry is a low energy intensive building material and when properly used can yield to the development of inexpensive, durable structures that can be constructed with semi- and unskilled labor.

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