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Behavior of post-tensioned dry-stack interlocking masonry walls under out of plane loading

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HIGHLIGHTS

- Dry stack masonry walls behave as conventional walls under out-of-plane loading.
- Grouting of dry stack masonry walls improves energy absorption and load capacity.
- Ungrouted post-tensioned dry stack walls are efficient in medium seismic zones.
- MSJC provides applicable design equations for flexural dry stacked masonry walls.

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ABSTRACT

The researches done on wall construction to make it appropriate, easy, fast and cost effective have led to a promising technique known as “Dry-stack interlocking masonry system”. Nevertheless, there are several disadvantages attributed to using this system. One of the major drawbacks of this system is the low bending capacity that can be resisted by the interlocking keys alone. To overcome this problem grouting and reinforcing of the hollow block cells are required, which make the system a bit expensive. Additionally, the dry-stacked units had to settle down to balance uneven surfaces and notches, which may reduce strength and stiffness of the walls. One method that has been suggested to minimize this drawback is post-tensioning (PT) of these walls to eliminate grout and enhance the bending capacity.

The objective of the current research is to investigate the behavior of PT dry-stacked interlocking masonry (DSIM) walls constructed using locally available masonry units and PT bars under out-of-plane loading. Some of the expected factors that could affect the performance of these systems are construction system, grouting effect, PT technique and restraining effect of PT bars. The test results demonstrated that PT-DSIM systems considered in the current study, under out-of-plane loading, behaved similar to the conventionally reinforced masonry walls. In addition, the proposed PT technique proved its efficiency for grouted walls. It can achieve a remarkable increase in the cracking load triple that of the ordinary reinforced walls and in addition to improving the durability and enhancing the appearance. Furthermore, ungrouted PT walls proved to be the most effective construction detail. Since, their specific strength (capacity/weight) ranges between 1.3 and 1.6 times that of grouted PT walls, in addition to taking the advantage of minimizing construction cost, time, and weight of the structure.

1. Introduction and background

Masonry is one of the oldest construction materials. Nevertheless, there are several disadvantages of using conventional masonry systems in construction. Masonry construction often requires long time spent by highly skilled laborers, which adds to the project cost. This problem is now being magnified by the fact that the number of qualified masons is shrinking quickly [1]. Another disadvantage of conventional masonry construction is the amount of mortar that is required to be mixed on-site which increases construction time [1]. Shrinkage cracking is an additional significant challenge that faces concrete masonry units construction [2].

With the use of specially fabricated concrete masonry units known as “dry-stack units”, construction of these mortarless systems is simple, easy and cost effective. DSIM system provides a significant labor advantage over traditional mortared masonry since the interlocking mechanism of the blocks allows for mortarless construction [3]. This construction technique adopting interlocking

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Nomenclature

A_n	net cross-sectional area of the wall
A_{ps}	area of PT bars
a	depth of an equivalent compression stress block at nominal strength,
b	wall section width
d	distance from extreme compression fiber to centroid of tension reinforcement
f'_m	specified compressive strength of masonry
f_{pri}	initial stress in masonry wall due to PT force
f_{ps}	stress in PT bars at ultimate stage
f_{pu}	ultimate tensile strength of PT bars
f_r	modulus of rupture
f_{se}	effective stress in PT bars after all PT losses have occurred
K_{un}	precracking stiffness
K_{cr}	post-cracking stiffness
l_p	clear span of the PT walls in the direction of the PT bars
M_{cr}	cracking moment
M_n	ultimate moment strength
P_{cr}	cracking load
P_n	predicted ultimate flexural load
P_{nv}	predicted ultimate shear load
P_{psi}	initial PT force
P_u	ultimate load
S	section modulus
Λ_{cr}	deflection corresponding to cracking load
Λ_u	deflection corresponding to ultimate load

blocks has recently attracted worldwide interest. Reductions in labor cost up to 80% are realized due to increasing of the output and constructability of hollow dry-stacked reinforced masonry systems [4]. The geometric features of the individual blocks facilitate interlocking in horizontal and/or vertical directions. This method has significant potential for field adoption due to its inherent advantages such as simplicity in block laying, reduction in mortar consumption and general independence of workmanship variations. Some of the systems that enable reinforcement and have been recommended for adoption in earthquake resistant construction are Mecano system [5], the Haener system [6], the Modified H-block system [7], Azar block [8], Faswall system [9].

A major drawback with dry stacking is low bending capacity, especially in bending parallel to the bed joints. Several existing dry stacked concrete block masonry systems aim at diminishing this drawback by using hollow blocks with interlocking, vertical perforations that are grouted, reinforcement placed in vertical holes or surface bonding mortars [1]. The bending capacity parallel to bed joints of dry stacked masonry without any grouting is close to zero [10]. It should be noted that the interlocking keys of hollow blocks alone are normally not sufficient to resist stresses of design load for an assembled wall in a structure due to elimination of mortar layers and the limited key projection [11]. To overcome this problem, normal reinforced concrete is used at regular intervals in the holes provided in hollow blocks, which makes the structure a little bit expensive. In some cases, relatively lesser mortar (as compared to that required in normal brick masonry) is used with the interlocking blocks [12].

A proposed method to overcome most of the abovementioned disadvantages is post-tensioning DSIM walls by placing vertical bars through the cores. PT bars should be anchored within the concrete foundation at the base of the wall or in the bottom bond beam and tensioned at the top of the wall. The potential for post-tensioned masonry to become available system for contemporary masonry buildings is promising. However, its properties, analysis, and behavior must be thoroughly studied before architects, engineers, and builders can incorporate it safely and economically in building construction [13]. PT of DSIM system greatly influences the bending capacity, and the interaction of normal forces and bending moments determines the failure, where the higher pre-compression reduces the eccentricity and strengthens the compression zone to better withstand bending stresses [14].

The objective of the current study is to investigate the out-of-plane behavior of the PT-DSIM walls constructed using locally available interlocking concrete systems (Azar and Spar-lock) and locally produced PT bars.

2. Experimental program

2.1. Properties of used materials

Three different types of blocks were used in this study. The first was conventional concrete hollow block with average dimensions of 390 × 190 × 190 mm and average compressive strength of 17.5 MPa. While the second was Azar concrete hollow block with average dimensions of 400 × 200 × 200 and average compressive strength of 9.0 MPa. The last one was Spar-lock concrete hollow block with average dimensions of 400 × 200 × 200 and average compressive strength 6.5 MPa. Fig. 1 shows geometry, configuration, and dimensions of different types of blocks used in this investigation.

Type S mortar according to [15] was used in constructing the conventional block walls with mixing proportions by volume of 1: 0.5: 4.5 for cement: hydrated lime: sand. The water content of the masonry mortar was adjusted by the mason to provide a workable mix. Based on testing of 50 mm cube specimens, the average mortar compressive strength at 28 days was 13.5 MPa. A self-consolidating grout with average compressive strength at 28 days of 20.9 MPa was used to fill the cells for grouted specimens.

A total of nine fully grouted and nine ungrouted masonry prisms, each of three blocks high (three prisms for each block type), were built in stack bond pattern and tested under uniaxial compression to determine the grouted and the ungrouted masonry compressive strength. The grouted masonry average compressive strength was 8.9, 6.8 and 6.0 MPa for conventional, Azar and Spar-lock block types respectively, while the ungrouted masonry average compressive strength was 13.5, 7.4 and 6.2 MPa for conventional, Azar and Spar-lock block types respectively.

The reinforcing steel bars used in this investigation were high tensile strength deformed bars of grade (400/600), with nominal diameter 16 mm and average yield and ultimate tensile strength of 470 and 650 MPa respectively. High tensile strength PT bars of diameter 9.4 mm and length 2100 mm with 120 mm threaded parts at each end were used in this study for post-tensioning the masonry walls. The average proof and ultimate tensile strength of the PT bars were 1150 and 1570 MPa respectively.

2.2. Test matrix

A total of twelve vertically spanned walls (the loading span was perpendicular to the bed joint) were constructed and tested under out-of-plane loading. The walls were categorized into three groups. The first group represents mortared walls constructed using