Requirement of horizontal reinforcement for PVC Stay in Place concrete formwork Systems subjected to Axial loading and Out of Plane moment

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Abstract

This paper provides an opinion for the requirement of horizontal reinforcement for PVC Stay In Place (SIP) concrete formwork systems, subjected to axial loading and out of plane moment. The out of plane bending might be due to lateral earth pressure, hydrostatic pressure, wind load etc. Tensile stresses are created under the combined effects of compression and bending in these walls cross section. The discussion is based on Australian, American, British and Eurocode for concrete structures.

Based on this study, it can be stated that the horizontal reinforcement is required by Australian, American, British and Eurocode, for concrete walls under compression and out of plane bending. Concrete walls that are designed for compression and out of plane bending without horizontal reinforcement do not satisfy the code requirements of ACI 318-11, AS3600-2009 and BS 8110.1-1997 and EN 1992-1-1:2005.

1. Introduction

PVC SIP permanent formwork panel systems are made up of PVC extruded box casings interlocked together to form a concrete formwork. The box casings are fabricated with punched internal holes for fitting reinforcement and to allow the flow of concrete mix for the core filling. The systems are designed for the construction of reinforced and un-reinforced concrete walls. Once constructed the formwork systems do not contribute to the structural capacity of the wall which can be assumed as a normal concrete structure. For design purposes the wall can be designed as a standard concrete wall.

The walls discussed here are assumed to be laterally supported and restrained against deflection at both top and bottom and essentially act as one-way walls. The walls do not act as shear walls. Walls characterised by other design loads or serviceability requirements such as point loads, shear loads, deeps beams, foundation movement etc. shall be designed to their particular requirements and are not discussed in this paper.

2. Significance of the Investigation

It can be argued that the webs (crack inducers) in the PVC SIP systems ensure that a crack control mechanism is established for temperature and shrinkage stresses. Hence, there is no need for horizontal reinforcement (primarily used for crack control) for such walls, subjected to resultant loads located outside the middle third of the wall thickness.

The following discussion is based on the concrete structures code by ACI 318-11, BS 8110.1-1997, AS3600-2009 and EN 1992-1-1:2005 for concrete walls. The limitations of the empirical methods adopted by the codes are discussed. Also the requirement and significance of horizontal reinforcement for walls subjected to resultant axial load eccentricity of greater than one sixth of the wall thickness is discussed.

3. Concrete Structure Codes

3.1 Australian Standard for Concrete Structures - AS 3600 (2009)

Design of walls is covered in Section 11 of AS 3600 (2009). Clause 11.5.4 describes the vertical compressive load capacity of walls and is given by;

$$\emptyset N_u = 0.6\emptyset(t - 1.2e - 2e_a)f_c^{/} \qquad \text{Eq.1}$$

Where

$\emptyset$ = Strength reduction factor

N_u= ultimate axial strength per unit length of the wall

t = wall thickness

e = load eccentricity measured at right angles to the plane of the wall

e_a= additional eccentricity

$f_c^{/}$ = characteristic compressive strength of concrete

Eq. 1 is applicable for a resultant axial load eccentricity of less than one sixth of the wall thickness i.e. no tensile stresses develop across the wall cross-section under loading. The reinforcement is not considered in strength calculations.

The walls that are subject to axial load and out of plane moments (with resultant load eccentricity greater than t/6), Clause 11.1 b can be used to design the wall as a slab or as a column, as appropriate. For lightly loaded walls subject to out of plane moment, where the stress at the mid-height of a wall due to factored in plane bending and axial forces do not exceed the lesser of $0.03f_c^{/}$ and 2MPa, walls can be designed as a one way slab (Clause 11.1 (b)). In such cases a minimum reinforcement in the secondary direction (horizontal direction) is required - even for unrestrained slabs (Clause 9.4.3.3). Regarding the minimum reinforcement requirement for walls subject to simultaneous in-plane and out of plane load effect, it is informative to note that the code commentary states that "*It is recommended that these walls comply with the provisions of Clauses 11.7.1, 11.7.2 and 11.7.3….".* These clauses are for reinforcement requirements for walls and specify minimum vertical and horizontal reinforcement. If the wall is heavily loaded and is subject to out of plane moment, the wall can be designed as a column. The restraint for vertical reinforcement in the form of fitments is also required in addition to vertical and horizontal reinforcement as per section 10.7.4, to support and prevent buckling of the vertical bars. The restraint for vertical reinforcement can be omitted when requirements of Clause 11.7.4 are satisfied which are

$N^* \leq 0.5\emptyset N_u$ and

Concrete strength $\leq 50\ MPa$ and either

a. Vertical reinforcement is not used as compressive reinforcement or
b. The vertical reinforcement ratio is not greater than 0.01 and a minimum horizontal reinforcement ratio of 0.0025 is provided

Clause 11.7.4 (b) is similar to clause 14.3.6 of ACI.

3.2 Building Code Requirements for Structural Concrete - ACI 318-11

ACI allows the designer two options to design concrete walls:

Walls may be designed as compression members using the strength provisions for flexural and axial loads of Chapter 10 or they may be designed using the empirical design provisions of 14.5 or 22.6. The empirical design method may be used for the design of load bearing walls if the resultant of all applicable loads (axial and lateral) falls within the middle one-third of the wall thickness. The empirical method is a simple design procedure for these limited cases, requiring only a strength calculation to determine the design axial strength of the wall.

When wall geometry and the loading conditions do not satisfy the limitations of empirical design methods of 14.5 (particularly when lateral loads are present as in the case of basement retaining walls), walls shall be designed as compressions members by the strength design provisions in Chapter 10 for flexure and axial loads. It is to be noted that the provisions for minimum vertical and horizontal reinforcement according to Clause 14.3 still apply to walls, designed by either method. Clause 14.3.3 states the minimum horizontal reinforcement area for various reinforcement sizes. The vertical wall reinforcement also needs to be enclosed by lateral ties if the conditions of 14.3.6 are not satisfied. All other code provisions for compressions members apply to walls designed by Chapter 10 of ACI.

Cantilever retaining walls are designed by the flexural provisions of chapter 10 with a minimum horizontal reinforcement as per clause 14.3.3.

3.3 British Standard - BS8110.1 (1997)

Section 3.9 of BS 8110.1-1997 deals with the concrete walls.
BS 8110 Sections 3.9.4 covers plain concrete walls. Maximum design ultimate axial load for slender braced walls is given by;

$$n_w = 0.3(t - 1.2e - 2e_a)f_{cu} \qquad \text{Eq.2}$$

Where n_w is the axial load capacity of the wall and f_{cu} is the concrete cube strength.

In Eq. 2, the load is considered to be carried on part of the wall with the section in tension neglected. Eq. 2 is very similar to Eq.1.

When the wall supports uniform axial loading and transverse moment, a unit length of wall can be designed as a column (Cl. 3.9.3.6.2). In such cases the wall is reinforced. A reinforced wall shall contain a minimum quantity of reinforcement as noted in Clause 3.12.5. The reinforcement is also taken into account to determine the strength of the wall (Cl. 3.9.3.6.1).

According to BS 8110.1, the minimum area of horizontal reinforcement in walls where the vertical reinforcement resists compression and does not exceed 2 percent of the concrete area is given in the clause 3.12.7.4 as

$f_y = 250\ MPa$ 0.3% of concrete Area

$f_y = 460\ MPa$ 0.25% of concrete area

If the compression reinforcement in the wall exceeds 2%, links or ties shall also be provided throughout the wall thickness according to clause 3.12.7.5. They are meant to support the vertical reinforcement and provide restraint against buckling.

3.4 EuroCode 2 – EN 1992-1-1(2005)

The rules for the design of plain and lightly reinforced concrete walls are discussed in Section 12 of Eurocode 2 (EC2). A plain wall contains either no reinforcement or less than 0.4% reinforcement. The reinforcement is not considered in strength calculations.

It is also informative to note that in clause 12.6.2, it is stated that unless measures to avoid local tensile failure of the cross-section have been taken, maximum eccentricity of the axial force in a cross section shall be limited to avoid large cracks. The code also requires a number of serviceability states requirements to be considered to ensure adequate serviceability (Cl. 12.7). These requirements would lead to similar requirements for resultant compressive load eccentricity of less than one sixth of the wall thickness i.e. no tensile stresses develop across the wall cross-section. Because of the limited ductility of plain concrete, at ultimate limit state only elastic analysis with no redistribution is permitted (Refer 12.5). Section 12 (Cl. 12.1(2)) is not applicable to walls subject to dynamic loading and also excludes retaining walls.

If tension develops across the wall section, reinforcement shall be provided. The reinforcement is taken into account determining the strength of the wall. According to Eurocode Clause 9.6.2, the minimum and maximum amounts of vertical reinforcement required for a reinforced concrete wall are 0.002Ac and 0.04Ac, where Ac is the concrete area, outside lap locations respectively. Clause 9.6.3, requires that horizontal reinforcement shall be provided at each face and should have a minimum area of 25% of the vertical reinforcement or 0.001 Ac, whichever is greater. If compression reinforcement exceeds 0.02Ac, links must be provided in accordance with the rules of columns in clause 9.5.3.

For walls subjected to transverse moment and a uniform axial load, a unit length of the wall can be designed as a column. For walls subjected to predominantly out of plane bending, the rules for slabs apply (Cl. 9.3). If the wall is designed as a slab, Clause 9.3.1 (2) requires secondary transverse reinforcement of not less than 20% of the principal reinforcement for one way slabs.

4. Conclusions

The empirical design methods adopted in AS3600 (2009), BS8110.1-1997 and, ACI 318-11 and EN 1992-1-1(2005) may be used for the design of load bearing walls if the resultant of all applicable loads falls within the middle one-third of the wall thickness (resultant axial load eccentricity is less than t/6) and no tensile stresses develop in the wall cross-section. The empirical method is a simple design procedure for limited cases, requiring only a strength calculation to determine the design axial load of the wall. Primary application of the empirical design is for relatively short walls spanning vertically and subject to vertical compressive forces only, such as those resulting from floor or roof reactions. Applications become extremely limited when lateral loads need to be considered because the "effective/resultant" load eccentricity is limited to t/6. Walls not falling in this category shall be designed as compression members for axial load and flexure by the relevant provisions of the codes as discussed above.

It must be noted that the minimum wall reinforcement required by concrete structures codes such as ACI, AS3600, BS8110 and Eurocode do not substantially increase the strength of a wall above that of a plain concrete wall.

If the concrete walls under compression and out of plane moments are designed in accordance with code provisions of AS3600 (2009), ACI (2011), BS 8100.1-1997 and EN1992-1-1(2005), minimum horizontal reinforcement is required. It is the authors opinion that for a wall subject to a resultant axial load eccentricity of greater than one sixth of the wall thickness, treating the horizontal reinforcement for the purpose of crack control only for temperature and shrinkage stresses is an oversimplification of the actual conditions. For a wall that is subject to a resultant load eccentricity that creates tensile stress across the cross section of the wall, the minimum horizontal wall reinforcement runs at right angles to the main flexural steel. In addition to providing control of cracking due to shrinkage and temperature stresses, it also serves the purpose of tying the wall together and distributing non-uniform loads through the wall to ensure its acting as assumed in the design. It also provides support and restraint of the vertical compression reinforcement against buckling.

The crack inducers in the PVC SIP systems can ensure that the crack control mechanism is established for temperature and shrinkage stresses, and it can be argued that there is no need for additional reinforcement. However in the authors opinion, to eliminate horizontal reinforcement completely, without considering its additional important benefits for walls under net tensile stress, can lead to structurally inadequate solutions (particularly without any empirical support and/or supporting code provisions). Horizontal wall reinforcement shall be removed only, if it can be proved that the use of horizontal reinforcement in walls is for temperature and shrinkage concrete crack control only and it serves no other purpose. This claim shall be supported by empirical method or code clauses.

5. References

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