

A METHOD AND SYSTEM TO DESIGN A HOLLOW CORE CONCRETE PANEL

FIELD OF INVENTION

5 The invention relates broadly to a method and system to design a hollow core panel that can be produced by a concrete extrusion machine.

BACKGROUND OF INVENTION

10 Hollow core wall panels are pre-cast concrete members having continuous voids or cores to reduce weight and, therefore, cost. As a side benefit, the cores can also be used for concealed electrical and mechanical runs. These panels are currently produced by two basic manufacturing methods, the dry cast or extrusion system, and the slip form method.

15 In the dry cast or extrusion system, a very low slump concrete is forced through an extrusion machine and the cores are formed using augers or tubes, with concrete being compacted around the cores. The slip form method uses a higher slump concrete wherein the sides are formed either with stationary, fixed forms or with forms attached to the machine, with the sides being slip formed. The cores are formed with either lightweight aggregates fed through tubes attached to the casting machine, pneumatic tubes anchored in a fixed form or long tubes attached to the casting machine which slip form the cores. In both cases, the panels
20 are cast on long line beds. The panels are then saw-cut to the appropriate length for the intended project.

25 A properly designed mix proportion of the concrete can contribute to the stiffness of the panel. Notwithstanding this, if the concrete can be densely and uniformly compacted, this effort would further increase the stiffness of the panel. In addition, a denser concrete also
30 increases the resistance of the wall against indentation, improves anchorages and intensifies the moisture and water vapour resistance of the panel, resulting in higher durability.

Hollow core wall panels may be considered to be optimally designed if they are light and the stiffness against bending is large. Larger and more numbers of cores helps to reduce the weight of panels but results in lower bending stiffness. Besides this, the number and diameter of cores in the panel also influences the ability of the concrete to be well compacted during production, particularly in the extrusion method of production. Therefore, the proper selection of the number and diameter of cores is critical, not just for the cores themselves, but also for designing the extrusion machine which produces the well compacted hollow core wall panels.

In the extrusion method of hollow core wall panel production, very low slump concrete is used so that the concrete does not collapse after extrusion. As good compaction is critical for very low slump concrete, the extrusion machine has to be designed accordingly. However, as mentioned earlier, compaction is also governed by the number and diameter of the cores.

The amount of compaction provided by the extrusion machine is dependent, among other considerations, upon the resistance of the machine's movement when the augers extrude the panels with its forward thrust. For an effective forward thrust, a suitable auger blade height should be used. In the same context, the effective compacted zone in the panel also increases with an increase in the number of augers and blade height. However, bigger auger blades are not necessarily better, as too large a forward thrust may result in faster extrusion, leading to other associated problems.

There are also other physical constraints that have to be considered in the design of hollow core panels. These panels can be considered as a series of I-beams connected at the flange. Reducing the flange thickness would reduce the weight of the panel but undesirably reduces its bending stiffness. On the other hand, reducing the web thickness (the distance between hollow cores) would reduce the weight of the panel with negligible effect on the

stiffness. The web serves to resist shear at the centroid, which is generally low, when the panel is subjected to bending.

For a hollow core panel to be light and of high bending stiffness, the dimensions, and in particular the diameter and number of cores, should be optimally chosen. The choice of the
5 diameter and the number of cores should also take into consideration the ability of the concrete in the wall to be densely and uniformly compacted during production. Unfortunately, there is nothing currently in the art which allows for all of the above mentioned factors to be accounted for in the design of the wall panel.

SUMMARY

According to one embodiment of the present invention, an optimization method to design concrete hollow core wall panels is provided. Given the overall dimensions of the hollow core wall panel, the embodiment provides a specific methodology for producing the lightest hollow core wall panel with the highest bending stiffness. A series of optimised dimensions for a hollow core wall panel, according to one embodiment of the present invention, is also provided.

According to one embodiment of the present invention, a method to design a hollow core panel that can be produced by a concrete extrusion machine is provided. Within the method, the panel comprises a width (W), a thickness (T), a top surface along the width W , a bottom surface opposite the top surface, a first end along the thickness T and a second end opposite said first end. The panel further comprises a top flange located between an inside surface of the core and the top surface and a bottom flange located between an inside surface of the core and the bottom surface, the top flange and the bottom flange each having a flange thickness (t) and at least one hollow core extending along said length. The machine comprises at least one auger within a chamber having the dimensions of the width W , the thickness T and the length of the panel. The at least one auger has an outside surface with at least one blade extending outwardly from and spirally attached to the outside surface. A quantity of concrete is added to the chamber and each of the at least one augers is rotated within the chamber to produce the at least one hollow core within the panel. The method includes the steps of determining a minimum flange thickness (t_{min}), determining a specific number (N) and a specific diameter (D) of the augers such that a calculated value for t is greater than or equal to t_{min} , and using the specific number (N) and specific diameter (D) to optimize at least one specific design parameter for the panel.

In the method, the at least one blade has a height (A) above the surface, and the at least one auger produces an annulus in the concrete radiating outwards from the at least one core.

The step of determining t_{min} can include the steps of using the blade height A to calculate a thickness (R) for the annulus, then setting t_{min} to be equal to or greater than R . The step of

calculating the thickness of the annulus R can be accomplished by multiplying the blade height A by a compaction factor. The compaction factor can vary within a range of 1.25 to 5.

In accomplishing the steps of the method, the panel can further include an intermediate web located between each of the at least one cores, a first end web located between a first end core and the first end, and a second end web located between a second end core and said

second end. Each of the first end web and the second end web can have an identical end web thickness (E). The step of determining a specific number (N) and a specific diameter (D) can

then further include the steps of: setting an initial number ($N1$) of the at least one core to $N1 =$

1; calculating an intermediate web thickness (w) such that w is equal to $2A$ plus a tolerance factor; calculating the end web thickness (E) such that E is equal to A multiplied by an end

factor; calculating an initial diameter (DI) of said at least one core using the formula:

$$DI = \frac{W - (N1 - 1)w - 2E}{N1}$$

determining whether DI is less than T ; if DI is not less than T , incrementing the value of $N1$

by one and repeating the calculating and determining steps until DI is less than T ; calculating

t , wherein $t = (T - DI)/2$; and comparing the value of t to t_{min} . If $t = t_{min}$, one can proceed

to the step of using the specific number (N) and specific diameter (D) to optimize at least one

specific design parameter for the panel. If t is less than t_{min} , then the value of $N1$ is

incremented by 1, and the step of calculating a value for DI , and the subsequent steps, are

repeated, until t is equal to or greater than t_{min} .

In accomplishing other steps of the method, the panel can further include a core

spacing (S) measured from the center of one core to the center of an adjacent core. If $t = t_{min}$,

the step of using the specific number (N) and specific diameter (D) to optimize at least one specific design parameter for the panel can further include: setting $N = DI$, $D = DI$, and $S = D + w$.

In calculating additional steps of the method, the panel can further include a core spacing (S) measured from the center of one core to the center of an adjacent core. If t is greater than t_{min} , the step of using said specific number (N) and specific diameter (D) to optimize at least one specific design parameter for the panel can further include calculating a value $N2$, wherein $N2$ is equal to $N1$ minus 1; calculating a value of $D2$, wherein $D2$ is equal to T minus twice the value of t_{min} ; and setting one of $N1$ and $N2$ to be equal to N and setting a corresponding one of DI and $D2$ to be equal to D .

In some embodiments of the method, the step of using the specific number (N) and specific diameter (D) to optimize at least one specific design parameter for the panel can further include at least one of minimizing a weight of the panel and maximizing a bending stiffness of the panel. In still other embodiments, the step of using the specific number (N) and specific diameter (D) to optimize at least one specific design parameter for the panel can include both minimizing a weight of the panel and maximizing a bending stiffness of the panel.

In some embodiments of the present invention, the value of t is less than the value of R . The hollow core panel can have a substantially rectangular cross-section. The first end can include a tongue extending outwardly from the first end, and the second end can include a groove extending inwardly from the second end, such that the tongue of the first end of the panel is configured to nest within the groove of the second end of an adjoining panel.

In still other embodiments of the present invention, a center of each of the at least one cores is collinear with the longitudinal cross section of the panel. The compaction factor can be in a range of 1.25 to 5 millimeters (mm). The tolerance can be in a range of 1 to 5 mm,

and the end factor can be in a range of 1.5 to 3.5. The blade height can be in the range of 4 to 14 mm.

In addition to the method, a system for optimizing a design of a hollow core panel produced by the method of any one of claims 1-16 is provided. The system uses the specific
5 design parameters discussed above with respect to the method.

The embodiments of the method in accordance with the present invention provide several advantages over the prior art. In one embodiment of the method, a hollow core wall panel is produced that has an optimal light weight for a given set of input parameters. In another embodiment of the present invention, a hollow core wall panel is produced that has an
10 optimal bending stiffness for a given set of input parameters. In yet another embodiment of the present invention, a hollow core wall panel is produced that has an optimal bending stiffness and an optimal weight for a given set of input parameters. The reduced weight allows for a panel that is more economical to produce. The increased bending stiffness enhances the performance of the panels to withstand high crowd pressures and/or heavy door
15 slamming.

Additionally, the optimized design also ensures the dense and uniform compaction of the concrete within the panels, which improves the anchorage capacity of the panel, and also gives rise to better resistance against indentation. The uniform compaction further provides for a more dense concrete wall panel, which provides an increased resistance against water
20 vapour and moisture, as well as increased durability. These conditions favour the use of the panels, by way of example and not limitation, in external walls, or wherever water or moisture can be problematic.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated into and constitute a part of the invention, illustrate one example embodiment of the invention and serve to explain the working concept of the invention. It is to be understood, however, that the drawings are meant for illustration only, and not as a definition of the limits of the invention. The drawings, therefore, provide one example embodiment of the present invention in which:

Figure 1 is a cross-sectional view of a typical hollow core panel according to one embodiment of the present invention;

Figure 2 is a partial cross-sectional view of one embodiment of a concrete panel extruder machine according to one embodiment of the present invention;

Figure 3 is a cross-sectional view of the hollow core panel of Figure 1 showing the compacted area as an annulus around the core;

Figure 4 is an flow-chart briefly elaborating one embodiment of a method to optimize the design of the concrete panel; and

Figures 5A and 5B show Table 1, that provides values for a series of hollow core wall panels designed according to the method of Figure 4.

Figure 6 shows a flow chart illustrating a method and system to design a hollow core panel that can be produced by a concrete extrusion machine according to an example embodiment

In the figures, like parts are identified with like numerals.

DETAILED DESCRIPTION

Figure 1 illustrates a cross-sectional view of a typical hollow core wall panel, designated generally as reference numeral 100. Panel 100 has a width 102 that defines a top surface 104 and a bottom surface 106. Panel 100 further comprises a first end 108 and a second end 110. It is understood that the designations top, bottom, first end and second end are arbitrary designations provided for the sake of clarity in discussing the various features of the embodiment as illustrated in the Figures, and are not intended to limit this embodiment of the invention in any way. In some embodiments, the first end 108 can include a tongue 109 extending outwardly from the first end 108. The second end 110 can have a corresponding groove 111, such that the tongue 109 of one panel 100 is shaped and configured to nest within a groove 111 in an adjacent panel. In this embodiment, panel 100 has a uniform thickness 112.

Panel 100 further comprises a plurality of hollow cores 114. Each of these cores 114 can have a diameter 116. Furthermore, each of the cores 114 can be separated by a distance S (center to center distance), designated generally with reference numeral 117. It is understood that, while the specific embodiment described here describes the cores 114 as round and having a diameter 116, the cores 114 can have other shapes without departing from the scope of this embodiment.

Each of the cores 114 has an inside surface 118. The portion of panel 100 between the inside surface 118 of the cores 114 and the top surface 104 and bottom surface 106 of panel 100 is called a flange, designated generally as reference numeral 120. Furthermore, an intermediate web 122 is defined as the space between adjacent inside surfaces 118 of adjacent cores 114. Additionally, an end web 124 is defined as the thickness of the concrete between the inside surface 118 of the end core 114 and the left side 108 or right side 110. For the purposes of illustration in this embodiment, the thickness of all of the flanges 120 are shown

as uniform for all cores 114 within panel 100. Likewise, for the purposes of illustration in this embodiment, the thickness of all of the intermediate webs 122, and both end webs 124, are shown as uniform for all cores 114 within panel 100. However, this need not be the case, and the thicknesses can vary without departing from the scope of the embodiments of the present invention.

Figure 2 illustrates one example of a concrete panel extrusion machine, designated generally as reference numeral 200, for producing the hollow core panel 100. The machine 200 includes a frame 201 that supports the attachment of the various other parts of the machine 200. The machine 200 also includes one or more augers 202 used to make the cores 114 of panel 100 in Figure 1. The augers 202 include one or more blades 204 spirally attached to a surface 206 of the auger 202. Each of the blades 204 have a height above the surface 206 of the auger 202, designated generally as reference numeral 208. The blades 204 are attached to the surface 206 at an angle, designated generally as reference numeral 210.

The machine 200 can further include a motor 212 connected by a drive belt 214 to a gear box 216. The motor 212, drive belt 214, and gear box 216 can be attached to the frame 201, and collectively drive the augers 202. A concrete hopper 218 is attached to the frame 201 for providing concrete for the manufacturing process. A vibrator 220 is attached to the frame 201 to facilitate the compaction of the concrete from the hopper 218. A counter weight 222 can also be attached to the frame 201 to further assist in the manufacturing process. It is understood that the particular configuration for the machine 200 discussed above is provided for the purpose of illustration only. Any machine configuration that produces a hollow core panel using an auger blade is considered to fall within the scope of the embodiments of the present invention.

Concrete (not shown) from the hopper 218 is introduced into the machine 200. The augers 202 form the hollow core panel 100 by extruding the concrete into a chamber 223

having the desired dimensions of the finished panel 100. In some embodiments, chamber 223 can further include a tongue and groove former 224, designed to form the tongue 109 on the first end 108, and the groove 111 on the second end 112. In some embodiments, the machine 200 can move in a direction illustrated by an arrow 226, while the concrete wall panel 100 is extruded in the direction of an arrow 228. It is understood that the directions shown are for the purposes of illustration only, and are not meant to limit the embodiments of the present invention in any way.

Figure 3 illustrates a cross-sectional view of the hollow core panel 100 showing an annulus 126 of compacted concrete around cores 114. The annulus 126 is generated when the augers 202 of the extrusion machine 200 produce a core panel 100. Since, in this embodiment, the annulus 126 is basically circular, a plurality of regions of uncompacted concrete, designated generally as reference numeral 128, can be found in the hollow core panel 100 as well.

Figure 4 illustrates one example of a method, designated generally as reference numeral 300, for producing the hollow core panel 100 according to one embodiment of the present invention. The following discussion references Figures 1-4. In designing the augers 202 for the extrusion machine 200, the rate of production, that is, the speed of extrusion of the wall panel 100, would first have to be decided. Besides economic factors, practical constraints such as the quality of the wall panel 100 produced should also be taken into consideration. The design of the auger 202 includes the determination of the height 208 and pitch 210 of the blade 204 with respect to the auger 202. As the auger 202 thrusts the wall panel 100 forward (direction 228), this thrust can compact the concrete in the wall panel 100, producing annulus 126. Since the thrust is primarily created by the forward motion of the one or more blades 204 as the augers 202 rotate, the portion of the concrete nearer to the core 114 would be subjected to the highest compacting effort. Since the blade height 208 directly

affects the uniformity in the compaction of the concrete in the wall panel 100, this parameter will be considered in the design of a method to produce the hollow core wall panel 100.

The compaction of the concrete can be uniform at any equal radial distance from the centre of the auger 202 or the core 114. This then allows one to assume the annular compacted zone 126 around the core 114 as shown in Figure 3. The thickness, designated generally with the letter R , of this annulus 126 could then be obtained by factoring the blade height, designated generally with the letter A (208 in Figure 2), with an appropriate compaction factor f as shown in Equation 1 below:

$$R = fA. \quad (1)$$

In the absence of any scientific determination of the compaction factor, f may be conservatively assumed to be equal to 2. It is understood, however, that other compaction factors f may also be used without departing from the scope of this embodiment of the present invention. For example, in some embodiments, the compaction factor f can fall within the range of 1.25 to 5. In some embodiments, it may be desirable that the thickness of the flange 120 is less than R (the thickness of the annulus 126), as this will minimise the less-compacted zone. Additionally, in some embodiments, the blade height can be in a range of 5 to 15 mm. In other embodiments, a range of 7 to 10 mm is preferred.

The thickness of the flange 120 is also governed by other factors, such as resistance against impact and provision for the anchorage of nails, screw, etc. A minimum flange 120 thickness t_{min} may be defined for this purpose from which the blade height can then be decided based on equation 1. One formula for determining t_{min} is shown in Equation 2 below:

$$t_{min} \leq R. \quad (2)$$

As mentioned earlier, a minimum intermediate web 122 thickness is desired. However, for this, the distance between augers 202 should also be a minimum within a practical limit. The minimum thickness of the intermediate web 122 between the blades of adjacent augers, is then twice the blade height plus a tolerance factor. The value of the tolerance factor can depend on a number of variables, such as, by way of example and not limitation, the amount of wobble in the auger, which can further depend on the accuracy of the extruder fabrication process. In some embodiments, the tolerance factor will be about 2 or 3 mm. In alternate embodiments, the tolerance factor can be between 1 and 5 mm.

In order to determine an adequate blade height, a number of factors can be considered. It can be desirable to minimize the web and flange thicknesses so that the void area is maximized, thus reducing the weight. Simultaneously, the blade height should be sufficiently large so that the thrust of the auger is sufficient to extrude the wall. In some embodiments of the present invention, a blade height of between 7 to 10 mm is contemplated. In yet other embodiments, the blade height can be from 4 to 14 mm.

Annotating intermediate web thickness 122 as w , the minimum web thickness 122 can be expressed using Equation 3 below:

$$w = 2A + \text{tolerance} , \quad (3)$$

where the tolerance depends on the machining accuracy. With reference to the end web 124 as shown in Figure 1, a thickness, designated generally with the letter E , of the end web 124, can similarly be given by Equation 4 below:

$$E = 2.5A . \quad (4)$$

It is understood, however, that the thickness E can be derived from other multiples of A without departing from the scope of this embodiment of the present invention. For example, E can be in the range of from about 1.5 to 3.5.

Referring now to Figure 4, given the panel width, designated generally with the letter W , and thickness, designated generally with the letter T , the optimization method 300 begins by setting the number of cores $N_1 = 1$, as shown in step 302. The subscript 1 and 2 used for the number of cores N and core diameter D are for the convenience of separating the two optimised solutions, one optimised for minimum weight and the other optimised for maximum stiffness. Knowing the intermediate and end web thicknesses from Equations 3 and 4 above, as shown in step 304, and with the initial number of cores 114 as 1, the diameter of the core 114 is computed from equation 5 below, as shown in step 306:

$$D_1 = \frac{W - (N_1 - 1)w - 2E}{N_1}. \quad (5)$$

This equation computes the diameter 116 of the core 114 such that when the cores 114 are distributed between the webs 122, 124, the total length would equal the panel width, W (102). If the diameter 116 of the core D_1 is larger than the thickness T (112) of panel 100, this is undesirable, as shown in step 308, and the number of cores N_1 is progressively increased, as shown in step 320. Steps 306, 308, and 320 are repeated until D_1 is smaller than T . The flange thickness 120, designated generally as the letter t in equation 6 below, can then be computed as shown in step 310:

$$t = \frac{T - D_1}{2}. \quad (6)$$

In step 312, it is determined if the flange thickness t is equal to t_{min} . If t is equal to t_{min} , the diameter and number of cores obtained are both optimal, providing a panel with both the highest possible stiffness and lowest weight, as shown in step 314. This ends the process, as shown in step 316. The optimised solution is then $N = N_1$, $D = D_1$, and the spacing S between the cores 114 becomes $S = D + w$.

Next we determine if the flange thickness t is greater than t_{min} (computed in equation 2), as shown in step 318. If t is not greater than t_{min} , the number of cores 114 is progressively increased, as shown in step 320. Steps 306 to 318 are then repeated until t is more than t_{min} , as shown in step 318.

At this junction, one half of the solution, that is for subscript 1, is obtained, while the other half can then be obtained by using equations 7 and 8 below, as shown in step 322:

$$N_2 = N_1 - 1 \text{ and} \quad (7)$$

$$D_2 = T - 2t_{min} . \quad (8)$$

The subscript 1 provides a solution in which N (the number of cores 114) is maximum whereas subscript 2 provides a solution in which D (the diameter 116 of cores 114) is maximum.

To differentiate the solutions for optimal lightweight and stiffness, the equations of moment of inertia and void ratio are used. The moment of inertia, designated generally with the letter I , along the longitudinal axis of the panel cross-section is given by equation 9 below:

$$I_{xx} = \frac{WT^3}{12} - \frac{\pi ND^4}{64} \quad (9)$$

Additionally, the void ratio, designated generally with the letter α , is given by equation 10 below:

$$\alpha = \frac{\pi ND^2}{4WT} \quad (10)$$

5 where the variables have all been previously defined.

On inspecting equations (9) and (10), one may conclude that a larger product of N and D^2 would increase the void ratio but decrease the stiffness.

Based on this rational, the two solutions with subscript 1 and 2 can be differentiated for optimal weight and stiffness, accordingly, as shown in step 330. To determine the optimal
10 weight, if the product of N and D^2 using subscript 1 is larger than the product of N and D^2 using subscript 2, then a first solution that minimises the weight is provided, as shown in step 326. This leads to the solution that $N = N_1$, $D = D_1$, and the spacing S between the cores 114 becomes $S = D + w$.

As further illustrated in Figure 4, if the product of subscript 1 is smaller than the
15 product of subscript 2, then an alternate solution that minimises the weight is provided, as shown in step 326. This leads to the solution that $N = N_2$, $D = D_2$, and the spacing S between the cores 114, as measured from the center of one core to the center of an adjacent core, likewise becomes $S = D + w$. In some embodiments of the present invention, it may be desirable to choose the number N and the diameter D which provides a solution closest to $t =$
20 t_{min} .

At this point, one can compare the product of N and D^4 , as shown in step 330 to determine the optimal stiffness. If the product of subscript 1 is larger than the product of subscript 2, then a first solution that maximises the stiffness is provided, as shown in step 332.

This leads to the solution that $N = N_2$, $D = D_2$, and the spacing S between the cores 114 becomes $S = D + w + \Delta$. The value of Δ can be computed by equation 11 below:

$$\Delta = \frac{L - ND - (N - 1)w - 2E}{N + 1} \quad (11)$$

where each of the variables in equation 11 have been previously defined. This leads to the
 5 end of the method 300, as shown in step 334.

If, on the other hand, the product of subscript 1 is not larger than the product of subscript 2, then an alternate solution that maximises the stiffness is provided, as shown in step 336. This leads to the solution that $N = N_1$, $D = D_1$, and the spacing S between the cores 114 becomes $S = D + w + \Delta$. The value of Δ can again be computed using equation 11. This
 10 alternate solution also leads to the end of the method 300, as shown in step 338. In some embodiments of the present invention, it may be desirable to choose the number N and the diameter D which provides a solution closest to $t = t_{min}$, depending on whether one wishes to minimize the weight, maximize the bending stiffness, or both.

The optimal design is one in which the panels 100 would be the lightest with the
 15 highest stiffness against bending, given the practical constraint to produce them. The lightness is achieved by increasing the volume of the hollow core(s) 114. Since air is a better insulator than concrete, this provides the additional advantage of further reducing the thermal transfer value of the hollow core(s) 114. The design also allows the panel 100 to be densely and uniformly compacted in the extrusion process, resulting in a panel 100 with a dense
 20 structure. Besides contributing to the bending stiffness, the dense structure also provides a foundation for a strong anchorage, increases the resistance of the panel 100 to indentation, the ingress of water, moisture and water vapour, hence enhancing the durability of panel 100.

In this embodiment of the present invention, the method 300 allows one to determine the optimal design of the panels 100 by selecting the diameter 116 and the specific number of

cores 114 to minimize the weight of the panel 100. Alternately, the method 300 allows one to determine the optimal design of the panels 100 by selecting the diameter 116 and the specific number of cores 114 to maximize the stiffness of the panel 100. Additionally, the method 300 allows one to determine the optimal design of the panels 100 by selecting the diameter 116 and the specific number of cores 114 to both minimise the weight and maximise the stiffness of the panel 100.

Based on one embodiment of the optimisation method 300 of the present invention, a series of optimised dimensions have been derived for the hollow core panel 100 having a width of 598 mm as shown in Table 1, Figures 5A and 5B. In Table 1, the thickness is the thickness of the panel, designated generally as reference numeral 112 in Figure 1. Similarly, the method provides a number, designated generally with the letter N, of cores 114 having a diameter 116, designated generally with the letter D, as discussed with reference to Figure 1 and the equations. The void ratio is computed using Equation 10. The volume (in cubic metres per metre length of the wall) is computed using the formula in Equation 11 below:

$$Vol = 0.6T - \frac{\pi ND^2}{4} \quad (12)$$

where D and T are diameter and thickness respectively in metres.

In deriving the optimised dimensions illustrated in Table 1, the following were assumed:

panel width, W	=	598 mm
minimum flange width, t_{min}	=	16 mm
auger blade height, A	=	7 mm
tolerance	=	2 mm
compaction factor, f	=	2

The results for which both stiffness and lightweight are optimised are shown in bold typeface in Table 1. Based on the results obtained in Table 1, the following can be considered to be the optimum number of cores for the corresponding thickness of the panels:

	Panel Thickness Range	Number of Cores
	70 – 72 mm	11
	70 – 78 mm	10
	74 – 86 mm	9
5	81 – 95 mm	8
	90 – 109 mm	7
	100 – 120 mm	6
	116 – 120 mm	5

The above was based primarily on a solution to provide an optimum lightweight and only the optimum stiffness solution for which the void ratio difference is less than 10% has been considered. This is because, as previously stated, lighter weight is a more critical requirement for wall panels in terms of economic benefits. However, it is understood that a larger or smaller void ratio difference can be used without departing from the scope of the present embodiment of the invention. By way of example and not limitation, the void ratio can be in a range of 0 to 78.5%, and the void ratio difference can be in the range of 5 – 30%.

It is understood that Table 1 and the discussion of the results are provided by way of example only. The method 300 can be applied to a wall panel 100 having any width and any thickness. Additionally, all of the other variables are provided by way of example only. Specifically, the minimum flange width, t_{min} , the auger blade height, A , the *tolerance*, and the compaction factor, f , can all be varied without departing from the scope of the claims which define the embodiments of the present invention. It should therefore be understood that the specific dimensions discussed above are provided to illustrate one of many possible applications for this embodiment of the present invention. They are not intended to limit the scope of this embodiment of the present invention in any way.

Figure 6 shows a flow chart 600 illustrating a method and system to design a hollow core panel that can be produced by a concrete extrusion machine according to an example embodiment, the panel comprising a width (W), a thickness (T), a top surface along the width W , a bottom surface opposite the top surface, a first end along the thickness T and a second end opposite said first end, a top flange located between an inside surface of the core and the top surface and a bottom flange located between an inside surface of the core and the bottom surface, the top flange and the bottom flange each having a flange thickness (t) and at least one hollow core extending along said length, the machine comprising at least one auger within a chamber having the dimensions of the width W , the thickness T and the length of the panel, the at least one auger having an outside surface with at least one blade extending outwardly from and spirally attached to the outside surface, wherein a quantity of concrete is added to the chamber and each of the at least one augers is rotated within the chamber to produce the at least one hollow core within the panel. At step 602, a minimum flange thickness (t_{min}) is determined. At step 604, a specific number (N) and a specific diameter (D) are determined for said at least one hollow core such that a calculated value for t is greater than or equal to t_{min} . At step 606, said specific number (N) and specific diameter (D) are used to optimize at least one specific design parameter for the panel.

This embodiment of one method in accordance with the present invention provides several advantages over the prior art. In one embodiment of the method, a hollow core wall panel is produced that has an optimal light weight for a given set of input parameters. In another embodiment of the present invention, a hollow core wall panel is produced that has an optimal bending stiffness for a given set of input parameters. In yet another embodiment of the present invention, a hollow core wall panel is produced that has an optimal bending stiffness and an optimal weight for a given set of input parameters. The reduced weight

allows for a panel that is more economical to produce. The increased bending stiffness enhances the performance of the panels to withstand high crowd pressures and/or heavy door slamming.

5 Additionally, the optimized design also ensures the dense and uniform compaction of the concrete within the panels, which improves the anchorage capacity of the panel, and also gives rise to better resistance against indentation. The uniform compaction further provides for a more dense concrete wall panel, which provides an increased resistance against water vapour and moisture, as well as increased durability. These conditions favour the use of the panels, by way of example and not limitation, in external walls, or wherever water or moisture
10 can be problematic.

The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes which
15 come within the meaning and range of equivalency of the claims are to be embraced within their scope.

CLAIMS

We claim:

1. A method to design a hollow core panel that can be produced by a concrete extrusion machine, the panel comprising a width (W), a thickness (T), a top surface along the width W , a bottom surface opposite the top surface, a first end along the thickness T and a second end opposite said first end, a top flange located between an inside surface of the core and the top surface and a bottom flange located between an inside surface of the core and the bottom surface, the top flange and the bottom flange each having a flange thickness (t) and at least one hollow core extending along said length, the machine comprising at least one auger within a chamber having the dimensions of the width W , the thickness T and the length of the panel, the at least one auger having an outside surface with at least one blade extending outwardly from and spirally attached to the outside surface, wherein a quantity of concrete is added to the chamber and each of the at least one augers is rotated within the chamber to produce the at least one hollow core within the panel, the method comprising the steps of:

determining a minimum flange thickness (t_{min});

determining a specific number (N) and a specific diameter (D) for said at least one hollow core such that a calculated value for t is greater than or equal to t_{min} ; and

using said specific number (N) and specific diameter (D) to optimize at least one specific design parameter for the panel.

2. The method of claim 1, wherein the at least one blade has a height (A) above the surface, the at least one auger produces an annulus in the concrete radiating outwards from the at least one core, and wherein

said step of determining t_{min} further comprises the steps of:

using said blade height A , calculating a thickness (R) for the annulus; and
 setting t_{min} to be equal to or greater than R .

3. The method of claim 2, wherein the step of calculating the thickness of the annulus R is accomplished by multiplying the blade height A by a compaction factor.
4. The method of claim 3, wherein the panel further comprises an intermediate web located between each of the at least one cores, a first end web located between a first end core and the first end, and a second end web located between a second end core and said second end, each of the first end web and the second end web having an identical end web thickness (E), wherein the step of determining a specific number (N) and a specific diameter (D) further comprises the steps of:

setting an initial number (NI) of the at least one core to $NI = 1$;

calculating an intermediate web thickness (w) such that w is equal to $2A$ plus a tolerance factor;

calculating the end web thickness (E) such that E is equal to A multiplied by an end factor;

calculating an initial diameter (DI) of said at least one core using the formula:

$$DI = \frac{W - (NI - 1)w - 2E}{NI} \quad (1)$$

determining whether DI is less than T ;

if DI is not less than T , incrementing the value of NI by one and repeating the calculating and determining steps until DI is less than T ;

calculating t , wherein $t = (T - DI)/2$;

comparing the value of t to t_{min} , such that,

if $t = t_{min}$, proceed to the step of using said specific number (N) and specific diameter (D) to optimize at least one specific design parameter for the panel;

if t is less than t_{min} , then the value of $N1$ is incremented by 1, and the step of calculating a value for $D1$, and the subsequent steps, are repeated, until t is equal to or greater than t_{min} .

5. The method of claim 4, wherein the panel further comprises a core spacing (S) measured from the center of one core to the center of an adjacent core, and wherein, if $t = t_{min}$, the step of using said specific number (N) and specific diameter (D) to optimize at least one specific design parameter for the panel further comprises setting $N = D1$, $D = D1$, and $S = D + w$.
6. The method of claim 4, wherein the panel further comprises a core spacing (S) measured from the center of one core to the center of an adjacent core, and wherein, if t is greater than t_{min} , the step of using said specific number (N) and specific diameter (D) to optimize at least one specific design parameter for the panel further comprises calculating a value $N2$, wherein $N2$ is equal to $N1$ minus 1;
calculating a value of $D2$, wherein $D2$ is equal to T minus twice the value of t_{min} ;
setting one of $N1$ and $N2$ to be equal to N and setting a corresponding one of $D1$ and $D2$ to be equal to D .
7. The method of any one of claims 1-6, wherein the step of using said specific number (N) and specific diameter (D) to optimize at least one specific design parameter for the panel further comprises at least one of minimizing a weight of said panel and maximizing a bending stiffness of said panel.
8. The method of any one of claims 1-6, wherein the step of using said specific number (N) and specific diameter (D) to optimize at least one specific design parameter for the panel comprises both minimizing a weight of said panel and maximizing a bending stiffness of said panel.
9. The method of any one of claims 2-6, wherein t is less than R .

10. The method of claim 3, wherein the compaction factor is in a range of 1.25 to 5.
11. The method of claim 4, wherein the tolerance factor is in a range of 1 to 5 mm.
12. The method of claim 4, wherein the end factor is in a range of 1.5 – 3.5.
13. The method of claim 4, wherein the first end includes a tongue extending outwardly from the first end and the second end includes a groove extending inwardly from the second end, such that the tongue of the first end of the panel is configured to nest within the groove of the second end of an adjoining panel.
14. The method of any one of claims 2-6, wherein the blade height is in the range of 4 to 14 mm.
15. The method of any one of claims 1-14, wherein the hollow core panel has a substantially rectangular cross-section.
16. The method of any one of claims 1-15 wherein a center of each of the at least one cores is collinear with the longitudinal cross section of the panel.
17. A system for optimizing a design of a hollow core panel produced by the method of any one of claims 1-16.