THE USE OF AS3600 – 2009 / EUROCODE FOR DINCEL WALLS

Preface

The following is an assessment for the design of unreinforced 110mm and 200mm Dincel Wall for ductility, strength and fire design purposes.

This explanation is provided to address the following questions:

- **Why we use reinforcement in AS3600, can we omit the use of reinforcement in AS3600?**
- **What is wrong with AS3600 – 2009?**
- **Why use EuroCode instead of Table 5.7.2 of AS3600 – 2009?**
- **Do you comply with the fire requirements of AS3600 by specifying concrete strength only?**
- **Why the EuroCode, British and American Codes provide a limit to the thickness of unreinforced concrete wall?**
- **The proof, how Dincel Walls increases the ductility of concrete.**
- **Dincel Wall serviceability recommendation/steel reinforcement use.**
- **WHAT IS THE BENEFIT FOR DESIGN ENGINEERS?**

BACKGROUND INFORMATION

The current engineering codes define ordinary concrete as a brittle material. As a result crack control and ductility is conventionally achieved by placing reinforcing steel bars into the concrete. Currently, there is no provision in the engineering codes other than using steel reinforcement to minimise the brittleness of concrete, hence increasing ductility. The presence of steel reinforcement is also used by AS3600 – 2009 for crack control purposes provided the concrete walls are normally reinforced in between the crack control joints normally placed at 6m to 8m centres.

Concrete Structures Codes such as ACI318, BS8110, DIN1045 and EuroCode allow the use of plain concrete (i.e. unreinforced concrete walls) where a method of crack control is provided.

CRACK CONTROL JOINTS AT 125MM CENTRES

PHOTO OF CRACK CONTROL JOINT

The most effective method of crack control is achieved by closely spaced control joints. The necessary spacing to achieve total crack control is not practical and expensive with conventionally formed concrete, and as a result joint spacing is normally placed at 6m to 8m centres in concrete walls. Minimum crack control reinforcement is then recommended by the codes between the joints to keep the crack widths within an acceptable limit so that the width of the cracks does not result in durability problems in concrete walls.

When Dincel Walls are used, the composite concrete-polymer material behaves differently from the convention of the current engineering codes. The reasons are as follows:

- Dincel webs work as crack control joints (refer photo above). The total width of a crack is maximum 0.01mm (refer Dincel Structural Design Engineering Manual certified by the University of New South Wales).

- The cracks initiated by Dincel webs are filled by calcination due to ongoing hydration because of the presence of the permanent Dincel polymer as a formwork. This facility therefore offers the best curing methodology for concrete.

- Dincel webs, working as crack initiators provide control joints at maximum 125mm centres (as shown on the photo above), and as a result crack control reinforcement that is normally required is omitted. **(Download – Common Engineering Questions,** Items 1, 2, 4 and 11).

- Dincel Wall including its joints between adjoining panels, as tested by CSIRO, even under 6m head of water pressure is waterproof; therefore, the presence of Dincel panel joints or induced cracks within the permanent Dincel polymer formwork does not lead to durability problems. Dincel's crack inducers eliminate the need for crack control reinforcement, including horizontal reinforcement. **Therefore, even if the Dincel joints were to allow the ingress of water, the elimination of horizontal steel reinforcement will remove any possibility of steel corrosion/spalling.** If any steel reinforcement is used, steel bars are to be placed to have minimum concrete cover since AS3600 does not accept the presence of any protection including membranes or galvanising as a replacement for concrete cover.

- However, AS3600 allows the reduction in exposure classification of Table 4.3 where a permanent membrane system such as Dincel is used.

- The Dincel polymer and concrete infill works compositely. Dincel's earthquake tests and flexural beam tests clearly demonstrate the increased ductility behaviour of the composite section. The ductility behaviour of the composite section is somewhere between the reinforced concrete and structural steel behaviour.

Dincel has performed tests to verify the above claims through NATA registered laboratories.

(1) THE USE OF UNREINFORCED DINCEL WALL

AS3600 – 2001 or 2009 versions are for reinforced concrete, not for plain concrete walls. The British, ACI and EuroCodes allow plain concrete walls (i.e. unreinforced walls) where ductility and shrinkage/temperature crack control is addressed. However, for some reason, AS3600 did not include unreinforced concrete as per the other codes which AS3600 is copied from. If AS3600 – Section 11 is viewed, the formula for strength calculation does not include any reinforcement quantity. Therefore, it has to be clear to any engineer that AS3600 requires steel reinforcement for other than strength purposes, even if the walls are subject to axial compression load only.

The use of unreinforced Dincel Wall has been certified by the University of New South Wales **(Download – Structural Engineering Design Certificate).** This document stresses 2 very important issues.

(i) AS3600 – Section 11 and ACI318 – Section 22.6 (Unreinforced Walls) are in close agreement. ACI318 – Section 14 for reinforced walls gives 43% more loading capacity in comparison to Section 22.6 of ACI318 hence Section 11 of AS3600.

(ii) The reinforcement in an axially loaded wall of a braced structure is only required for crack control purposes.

British BS8110-1; 1997 Clause 3.9.4 (19) states that "Reinforcement may be needed in walls to control cracking due to flexure or thermal and hydration shrinkage. The maximum load carrying capacity is given by Clauses 3.9.4 (15) and (16) and (17) without any quantity of reinforcement and in close agreement with ACI Clause 22.6 and AS3600 – Section 11.

The certification from the University of New South Wales shown at **(download – Structural Engineering Design Certificate)** therefore clearly states that AS3600 can be used without any reinforcement in the case of axially loaded Dincel Walls.

(a) WHAT HAS CHANGED WITH AS3600 – 2009?

(i)
- Wall definition – longer dimension is greater than 4 × shorter dimension = wall.
- Column definition – longer dimension is smaller than 4 x shorter dimension = column.

(ii) AS3600 – 2009 Section 11 and Section 5.7 can be adopted for wall or blade column (i.e. wall) design.

(iii) Structural fire adequacy is a function of load, slenderness, concrete grade and eccentricity allowance for the wall. All these issues must be considered to determine the fire resistance level of a slender wall.

AS3600 – 2009 has changed the calculation for Fire Resistance Period (FRP) drastically in comparison to the previous AS3600 – 2001 or earlier AS1480. Engineers can no longer state that 100mm concrete is for 90 min. FRP, 150mm concrete is for 180 min. FRP and 170mm concrete is for 240 min. FRP. **Engineers must consider the applied loads, slenderness and concrete mix design in accordance with AS3600 in determination for Structural Fire Adequacy.** The current AS3600 – 2009 does not help much but refers the engineer to EuroCode for fire design (refer AS3600, Clause 5.3). **Dincel has developed software to assist Australian engineers** (which is highly valued because of the complexity of the EuroCode) **who design and specify Dincel walls.**

(iv) Alternatively, EuroCode can replace Section 5.7 of AS3600 – 2009 (see Clause 5.3).

Dincel adopts EuroCode2 – Zone Method which is a higher tier and more accurate method in accordance with EuroCode2 than Table 5.7.2 of AS3600 which is also a table adopted from the EuroCode and referenced as an appropriate method in comparison to the Zone Method.

(v) Section 11 of AS3600 – 2009 for ultimate load capacity can also be replaced by EuroCode since a fire design will always be more critical design.

(b) WHAT IS WRONG WITH AS 3600 – 2009?

Table 5.7.2 of AS3600 – 2009 gives unnecessarily conservative results. The reason for this is that Table 5.7.2 is based on the slenderness ratio of 40 as stated in Clause 5.7.3 – AS3600 – 2009 and also has very limited load cases (two cases only), it does not take the concrete grade into account and design eccentricities are totally ignored. The maximum slenderness ratio adopted by British Code is 30, American and EuroCode is 25 which are significantly less than 40 of AS3600, and as a result the AS3600 – 2009 version recommends minimum 120mm wall thickness for 90/90/90 FRL at the load level shown in Table 5.7.2. **This can be misleading for a slender member with a low load and concrete grade but high eccentricity which can easily fail for a 120mm wall (or even 150mm wall) achieving 90/90/90 FRP.**

(c) WHY USE EUROCODE?

The AS3600, Table 5.7.2 is also adopted from the EuroCode – lower tier design method.

The EuroCode Zone Method – higher tier method addresses the abovementioned anomaly of AS3600 – 2009 by providing a methodology which allows for all slenderness, loads, concrete grades and design eccentricities.

The methodology that Dincel has adopted is the **EuroCode ZONE METHOD** which allows unreinforced, i.e. plain concrete walls and blade columns provided that crack control reinforcement is not required as in the case of Dincel. The zone method can also be used with lightly reinforced members.

AS3600 – 2009, Table 5.7.2 is a table adopted from the EuroCode. The EuroCode states that the Zone Method is a higher tier and a more accurate method than Table 5.7.2 of AS3600.

The **Dincel Design Tool** that was developed to comply with EuroCode accounts for all possibilities of load, slenderness, design eccentricities, concrete grades and provides a simple design solution for engineers. This allows a much more reliable design methodology in comparison to AS3600 – 2009 table 5.7.2.

(d) Do you comply with the fire requirements of AS3600 by specifying concrete strength only?

No. If you only specify concrete compressive strength without the water content, the concrete supplier will commonly provide W/C ratio of 0.65 to 0.72 (which is a conventional block mix concrete use) – this has no chance of complying with AS3600, Fire Design Properties.

The load, slenderness and design eccentricities are ready inputs for the calculation of the FRP for structural adequacy; the remaining issue is the concrete mix design. The spalling of concrete under the cellulosic fire curve does not happen if the moisture content is less than 3% by weight. In order to be consistent with the EuroCode's fire design methodologies, the Dincel concrete mix design aims to adopt the recommended value by BS EN 1992 – 1 – 2 : 2004 – Clause 4.5.1 which is 3% by weight for normal density concrete (i.e. 2,300 kg/m^3).

The total amount of moisture within the concrete, either as water or water vapour, is known as the moisture content, M (%) and is generally expressed as the percentage of the mass of the concrete.

For ordinary Portland cement W/C = 0.25 is required to hydrate all cement. However, W/C = 0.15 is physically absorbed by cement paste and thus not available for hydration. Therefore, W/C = 0.40 represents minimum water content to achieve full hydration. The W/C >0.40 is excess water that remains as free water in the cementitious structure and forms capillary pores (this is the component which causes explosive spalling). In the case of Dincel the recommended maximum is W/C = 0.65. The free water (W/C = 0.65 – 0.40 = 0.25) is available in the concrete mix in which part of it will dissipate under gravity; the water will eventually be absorbed by the floor slabs. The Dincel permanent polymer does not allow evaporation and as a result the hydration will continue and the original capillary voids by the excess water will be filled with the products of cement hydration resulting in lesser voids, hence denser concrete with increased compressive strength. This improvement in strength is obvious in Holcim's concrete mix design. Refer **Dincel Fly Ash Concrete Mix Design (download).**

Relative humidity (RH) of 75% represent 2%, (RH) of 90% represent 3% moisture content by weight, RH of 95% represent 4% moisture content by weight (Straube, J Canada Research, Report 00-132, 2000). Also refer Moisture in Concrete by the Cement and Concrete Association, Australia (http://59.167.233.142/publications/pdf/Moisture.pdf - Moisture in Concrete). The waterproof Dincel polymer avoids any external moisture source penetrating into the concrete infill. The only issue is to control the total free water/cementitious material ratio in the Dincel concrete mix hence moisture content.

The EuroCode's recommended figure is 3% by weight which relates to RH 90%. Conventional concrete walls without true membrane protection, particularly in the coastal zone will always have much more than 3% moisture by weight because of the high relative humidity around 90% plus the moisture already existing within the concrete wall. This condition will place all concrete façade walls other than Dincel beyond the fire spalling values adopted by the concrete codes, such as EuroCode and hence AS3600. This raises the question of compliance of non-Dincel concrete façade walls to the design engineers.

At the time of a fire, if the moisture content is greater than this recommended value by the EuroCode, the spalling for any concrete wall will be excessive under cellulosic fire conditions hence premature buckling and failure can happen even under small loads. This is why AS3600 – 2009, Clause B2.3 states that if any "alternative solution" is to be verified by fire testing, the test load shall be 100% equivalent of the design load (i.e. no "alternative solution" can be used above the fire test load).

Conventional concrete available in the Australian market is sold with W/C = 0.65 to 0.72. This is a typical range that is commercially available unless the W/C ratio is specified by the design engineer. This type of concrete for conventional concrete walls has no chance of complying with AS3600/EuroCode moisture content recommendation. The amount of free water will well exceed 3% by weight and will take an extremely long time to reduce in quantity of water, particularly in façade walls due to ambient humidity conditions which will be additional moisture to concrete with high water/cement ratio. The quantity of free water from the relative humidity, in addition to the high water/cement ratio will make explosive spalling worse in the event of a fire. This will be the case if the moisture content generated by external relative humidity is not prevented from entering into the concrete walls by means of paints consisting of vapour proof membrane systems.

The following example can illustrate the non-compliance. A concrete wall with total W/C = 0.72, i.e. W/C = 0.40 for hydration purposes hence the remaining component of W/C = 0.72 – 0.40 = 0.32 is for free water. The W/C = 0.32 free water represent minimum 2% by weight, the additional 2% will occur when RH > 75% totalling 4% which exceeds EuroCode's recommendation.

Therefore, the designer must take into account that ambient conditions which will add a further average of 2.5% moisture (i.e. RH about 80%) to free water available in the concrete wall without true membrane protection, particularly in coastal areas. This is why W/C concrete mix design for conventional concrete walls must not exceed W/C = 0.50. The reason for these ambient conditions adds an average of 2.5% moisture by weight. The free water W/C = 0.50 – 0.40 = 0.10 represents a further 0.6% moisture by weight. Therefore, a conventional wall with W/C = 0.50 at the time of concrete pouring could have 2.5% + 0.6% = 3.1% moisture by weight at the time of concrete pouring which is above the EuroCode's (and AS3600) limit of 3%.

The waterproof Dincel forms (waterproofing confirmed by CSIRO's test certificates) will maintain the excess water above what is required for the content's hydration process which will continue to occur for a long time. This excess water can only dissipate through the capillary action of concrete slabs which Dincel walls are placed on. Floor slabs, where Dincel Walls are placed on, dry much quicker due to their exposure to open air. The dryer slab components draw the free water under gravity from Dincel Walls. However, if we ignore the dissipation of free water in Dincel by gravity, and further assume that a fire occurs at 28 days, W/C = 0.65 will provide W/C = 0.65 – 0.40 = 0.25 free water which is equivalent to 1.6% free water by weight which is significantly less than 3% allowed by EuroCode.

Dincel has organised fire testing with CSIRO Australia. The concrete mix used consisted of a mix design. F'c = 20 Mpa at 28 days, slump 180mm (typical block mix sold in Sydney with minimum water/cement ratio = 0.70). The CSIRO's fire test result gave 240/240/236 minutes when a test panel of 3m x 3m was tested under 80 tonnes maximum available test rig loading. Therefore, this fire test (download – Dincel Wall Fire Assessment) is proof that Dincel achieves satisfactory results even with water/cement ratio of 0.70.

The EuroCode also clearly states that 3% of the recommended water content by weight can be exceeded if the explosive spalling influence on performance requirements be taken into account. The fact is that no engineer designs a structure up to the 100% limit of its fire limit state design. The other fact as mentioned above is that at the time of the fire Dincel Wall will have less moisture (thanks to the waterproof Dincel polymer) during the life of the Dincel Wall.

The reason why Dincel Wall does not need excess water for workability is explained in **(download) Engineering Questions, Items 3, 4 and 5.**

The above explanations as supported by CSIRO's fire test results demonstrate that the excess water available within the Dincel Wall does not compromise the fire capacity of Dincel Wall. In fact, this superiority of Dincel Wall results with much better concrete strength of concrete in comparison to non-Dincel concrete walls.

The design engineer may also easily consider 56 days design strength in lieu of 28 days. The reason for 28 days compressive strength was originally concrete cylinder/cube testing time, durability and early removal of formwork for concrete floor slabs. Therefore, there is no reason why Dincel concrete cannot be based on 56 days since the majority of design loads are not applied on the Dincel wall at this time. It is obvious to the engineers that in the majority of cases, walls have very low stress levels (except for high rise shear walls).

The above concrete mix specification, with particularly a 56 days compressive strength specification has significant cost reduction implications and also within the parameters of Green Concrete promoted by the Green Building Council of Australia. Refer **(download) Dincel Fly Ash Cement Concrete** which is available on the Dincel website. Cost effective, green and fire design compliant concrete together !

(e) DOES 110MM DINCEL WALL (HAVING 105MM NET CONCRETE) PROVIDE 90/90/90 FIRE RATING?

The answer is **"YES".** AS3600 – 2009 already confirms that there is no issue with integrity or insulation requirements of FRL when the minimum concrete wall thickness of 100mm is used. The issue in question is the structural adequacy component of FRL which is given in Table 5.7.2 of AS3600 – 2009 as minimum 120mm wall thickness.

The above topic **"What is wrong with AS3600?"** explains the very conservative approach of AS3600. The structural adequacy is based on the slenderness ratio, applied loadings, concrete grades and design eccentricities. Engineers can no longer pick up a figure for wall thickness from a table unless a very conservative approach of AS3600 – 2009, Table 5.7.2 is adopted. However, this "lower tier" approach by AS3600 may represent problems as highlighted above for conditions of slender members at a low load, low concrete grades and high design eccentricities. Therefore, it can be concluded that AS3600 – 2009 Table 5.7.2 is misleading and unreliable if applied without the consideration of the issues not covered by Table 5.7.2 of AS3600. **It would therefore be incorrect to state that the minimum wall thickness allowance of AS3600 – 2009 is 120mm since Clause 5.3 of AS3600 – 2009 is a higher tier design approach and allows the more appropriate assessment of EuroCode. AS3600 – 2009 recognises the inadequacy of Table 5.7.2 hence recommends in Clause 5.3 the use of EuroCode as a "higher tier" design approach.** EuroCode does not provide limitation for 110mm Dincel Wall provided the EuroCode design criteria are satisfied. In other words, if compliance of the EuroCode is achieved, the automatic compliance of AS3600 – 2009 is also achieved as specifically referred to in Clause 5.3 of AS3600 – 2009. This is the reason why Dincel has developed the **Dincel Design Tool** in compliance with EuroCode to demonstrate that the 110mm Dincel Wall provides 90 minutes or even 120 minutes structural adequacy under fire conditions **which are subjected to the abovementioned design conditions.**

WOULD A 110MM DINCEL WALL PROVIDE 90/90/90 FRL? THE ANSWER IS YES, SUBJECT TO THE FOLLOWING EXPLANATION.

The 90/90/90 FRL stands for Structural Adequacy/Integrity/Insulation of 90 minutes for the fire rating level.

Any concrete wall having minimum 100mm thickness complies with Fire Integrity/Insulation criteria in accordance with AS3600. **Dincel Wall has minimum 105mm net concrete hence complies with the Integrity/Insulation criteria.**

Structural Adequacy FRL

Many engineers are still not aware that this criterion must be calculated by the design engineer in accordance with AS3600 – 2009 Concrete Structures Code, depending on the applied load, the height of the wall, concrete grade use, reinforced or unreinforced and second order design eccentricities (which is zero for approximately equal spans).

For example, in the previous code, 170mm represented 240/240/240 minutes FRL depending on the abovementioned design criteria, the same 170mm wall may not even qualify for the 90 minute structural adequacy FRL. It is no longer allowed to determine the structural adequacy based on the concrete thickness alone.

The following results are from the DINCEL DESIGN TOOL that may be used as an example. However, each engineer must perform their own design.

Unsprinklered residential building with live loads of 1.5 kPa, having slabs with approximately equal spans and loads on both sides of a 110mm Dincel Wall:

110mm Dincel (2.85m Net Wall Height)	**Reinforced Wall (e.g. N12 @ 666 Vertical Bars)**		**Unreinforced Wall**	
Concrete Grade	Ultimate Load	Fire Load 90/90/90 FRL	Ultimate Load	Fire Load 90/90/90 FRL
25 MPa	957 kN/m	321 kN/m	765 kN/m	257 kN/m
32 MPa	1,226 kN/m	411 kN/m	980 kN/m	329 kN/m
40 MPa	1,532 kN/m	514 kN/m	1,225 kN/m	410 kN/m

NOTE: The DINCEL DESIGN TOOL is available to all practicing structural engineers upon request. This Tool is currently used by more than 600 Australian engineers.

(f) DINCEL WALL COMPLIANCE WITH THE BUILDING CODE OF AUSTRALIA (BCA) AND AS3600

The BCA compliance for a structural wall element is required in the following way:

(i) Compliance with the deemed-to-satisfy condition {BCA Specification A2.3(d)(ii) and Part B – B1.4(b)}. Dincel Wall complies with this approach. If Dincel Wall complies with AS3600 (or EuroCode as specifically referred by AS3600 Clause 5.3) compliance is achieved.

Dincel Wall complies with AS3600 (or EuroCode) for the following reasons:

- **The concrete used within the Dincel polymer is identical with the concrete defined by AS3600.**

  Dincel Wall does not consist of partially embedded metallic components within the concrete which compromises AS3600 – Section 4 – Durability or exposed metallic components causing additional spalling to concrete under fire conditions.

  Where Dincel Wall incorporates steel bar reinforcement, bars are placed with minimum concrete cover requirements as allowed by AS3600. Therefore, the use of Dincel Wall is identical with AS3600. Dincel Walls' only difference is the presence of polymer formwork which improves concrete's curing performance and protects the concrete in the long term against environmental attacks.

- **The University of New South Wales has provided certification** that Dincel complies with the "deemed to satisfy" definition of the BCA and Dincel Wall can be engineered to comply with the Concrete Structures Codes of Australian (AS3600), American (ACI318) and British (BS8110). Further to the above, AS3600 – 2009 – Clause 5.3 allows the use of EuroCode 2 Concrete Structures Code.

(ii) **Structural walls that are non-compliant with the deemed-to-satisfy condition can be treated as an alternative solution.** The BCA requires a structural alternative solution to comply with each and every part of AS3600 by providing a certified test report. **A structural engineer accepts all liabilities if a non-certified alternative solution is specified for the projects.** Therefore, an alternative solution for a structural wall must provide test certificates of the following to comply with AS3600 and hence the BCA.

- AS3600 – 2009 Section 4 – Durability and Section 14 – Embedded Items state that all metallic components of a wall must have minimum concrete cover. AS3600 does not provide concession in omitting the minimum concrete cover requirement if membranes or galvanising are used.

- AS3600 – 2009 – Section 5 – Design for Fire Resistance.

  - The alternative solution is to obtain a fire test certificate to satisfy the intent of AS3600.

  - The alternative solution should not be used for conditions exceeding the fire test facility's load capacity.

  - A CSIRO test report is only a report and not a test certificate which is required to be certified by an appropriate body acceptable by the BCA.

- AS3600 – 2009 – Section 11 – Design of Walls.

Dincel has organised a EUROCODE – DINCEL DESIGN TOOL for structural engineers to calculate the ultimate load capacity with fire on one or both sides and without fire for 110mm and 200mm DINCEL WALLS and BLADE COLUMNS.

Contact Dincel on construction@dincel.com.au to request the Dincel Design Tool.

(2) THE MINIMUM WALL THICKNESS REQUIREMENTS BY THE BRITISH, AMERICAN AND EUROCODE

The Australian AS3600 does not specify minimum wall thicknesses for design strength as per the above codes. The reason for this is that the above codes deal with reinforced and plain concrete walls simultaneously. AS3600 does not refer to unreinforced, i.e. plain concrete walls even though the strength calculations of AS3600 – Section 11 is based on unreinforced walls of the American (and British) codes as stated by the University of New South Wales **(download) Structural Engineering Design Certificate.**

The British, American and EuroCode comment about the minimum wall thicknesses as follows:

MINIMUM WALL THICKNESS

(i) BRITISH CODE

BS8110.1:1997, Clause 3.9.4.4, the slenderness limit for an unreinforced wall of a braced or unbraced structure is: effective length ÷ wall thickness = 30. However, this limit is reduced to 15 and minimum wall thickness required is 150mm for a reinforced concrete wall of an unbraced building in which the wall is acting as walls providing lateral stability to reinforced concrete framed buildings (refer Clause 4.6.2.1 of The Institution of Structural Engineers, July 2002, Manual for the Design of Reinforced Concrete Building Structures, Second Edition).

The 150mm wall thickness is specifically for walls which provide lateral stability to the overall structure. The British Code does not specifically give a minimum unreinforced wall thickness of a braced structure. However, the wall thickness is controlled by a slenderness ratio of 30 for a braced or unbraced structure.

(ii) AMERICAN CODE

ACI318, Chapter 22.6 is for structural plain concrete walls. Commentary R22.6 – Walls recommend to use of Chapter 14 for reinforced concrete walls (where minimum above ground wall thickness is 100mm at slenderness (effective length/thickness) limit = 25 at Clause 14.5.3.1 and 190mm for basement wall thickness at Clause 14.5.3.2) for multi-storey and major structures where differential settlement, wind, earthquake or other unforeseen loading conditions require the walls to possess some ductility and ability to maintain their integrity when cracked.

R22.6 also states that unreinforced braced walls will only be used for conditions where walls are braced for lateral translation (refer 22.6.6.4). This is the exact model presented in the Dincel Structural Engineering Design Manual which is certified by the University of New South Wales.

Clause 22.6.6.3 requires minimum thickness of 190mm for earth retaining perimeter basement walls (which are required to be reinforced for flexural stresses generated by the lateral earth pressure irrespective). Therefore, Clause 22.6.6.2 limits slenderness ratio to 24 and 140mm minimum unreinforced wall thickness of a braced structure to account for the ductility need of multi-storey buildings as referred in commentary Clause R22.6. Otherwise as per ACI Section 14 minimum wall thickness is 100mm. It is clear from this statement of ACI318 that the requirement of 140mm is clearly for ductility requirement since the steel reinforcement is not used to carry the compression load.

(iii) EUROCODE – EuroCode 2 (BS EN 1992-1-1:2004)

- Clause 12.6.5.1 (5) of the EuroCode limits slenderness to 25 for cast-insitu plain (unreinforced) concrete wall. The American code, ACI318 – Clause 14.5.3.1 also requires a slenderness limit of 25 and minimum wall thickness of 100mm for a reinforced concrete wall.

- EuroCode 12.3.1 applies a capacity reduction factor of 0.8 to account for reduced ductility in the case of plain unreinforced concrete walls.

- EuroCode Clause 5.2 (9) and the Dincel Design Tool allows additional eccentricity to account for the geometrical imperfection of a cast-insitu conventionally formed concrete wall. Dincel is a factory manufactured precise form which does not allow the geometrical imperfection normally experienced with the insitu concrete walls referred by the EuroCode.

- EuroCode Clause 12.9.1 for detailing purposes of conventionally formed cast-insitu concrete structural wall nominates 120mm minimum thickness to address serviceability deformations (refer Clause 12.7 (2) (b) of EuroCode 2).

Comment on the Minimum Wall Thickness

It is clear that the concern of the British, American and EuroCode is the ductility issue of concrete walls in multi-storey buildings to limit the unreinforced wall thicknesses. This is clearly demonstrated both in the British and American codes that the 100mm wall thickness is not an issue where the slenderness is limited to 25. This is particularly a concern if unreinforced load bearing concrete walls are used in an unbraced structure (i.e. sway is not prevented). Dincel's structural engineering manual (as certified by the University of New South Wales) clearly states that when Dincel Walls are used, the reinforcement (except end connections) can be ignored for a wall subject to axial compression provided it is a part of a sway prevented structure. Refer for further explanation; **(Download – Common Engineering Questions,** Items 10 and 12).

The EuroCode2 limitation of 120mm unreinforced wall thickness is a serviceability requirement as stated in Clause 12.7 (2) (b). Further to this, Clause 12.9.1 specifically calls 120mm for cast-insitu concrete walls which may represent compaction, honeycombing and geometrical imperfections which are not relevant to Dincel Walls. Refer for further explanation **(Download – Common Engineering Questions,** Items 4 and 5). Therefore, the following may also be considered by the design engineer because the presence of the Dincel polymer increases ductility of conventional concrete.

(3) DINCEL WALLS INCREASES THE DUCTILITY OF CONVENTIONAL CONCRETE WALLS

The following tests are a clear demonstration of increased Dincel Wall's ductility behaviour.

(i) **(Download) Dincel Flexural Testings**

(ii) **(Download) Building Solution for Earthquake Prone Regions**

The above earthquake testing and its supporting letter/report from the University of Technology Sydney signed by Professor Bijan Samali who is the head of the engineering department, states that Dincel polymer encapsulated unreinforced walls improves the ductility and can be adequate to use for up to magnitude 9 earthquake in a sway prevented structure. The report also states that reinforced Dincel Wall as shear walls are adequate in resisting magnitude 9 earthquake.

The University of Technology Sydney is a NATA registered laboratory and the only laboratory with an earthquake shake table facility in Australia. Our regulations by the BCA requires that the results of NATA registered laboratory be accepted by practicing engineers, which in this case confirms that Dincel polymer encapsulation increases concrete's ductility behaviour by at least a factor of two (2). However, despite having significantly increasing levels of ductility for Dincel Wall, EuroCode Clause 12.3.1 is included in the Dincel Design Tool.

EuroCode is written for in-situ concrete walls which are subjected to geometrical imperfections. Refer BS EN 1992-1-1:2004 Clause 5.2 (9). As a result, EuroCode incorporates reduction in in-situ wall's capacity. Dincel Walls, due to its factory manufactured components have precise dimensions and are not subjected to capacity reduction because of geometrical imperfections.

Finally, EuroCode Clause 12.9.1 is specifically for cast-insitu concrete walls. Dincel Walls which are even better than the precast walls are precisely manufactured without any geometrical imperfections. Therefore, the requirements of 120mm for cast-insitu conventionally formed concrete walls are not relevant to Dincel Walls.

Considering the above comments, the practising design engineers therefore can disregard the minimum unreinforced wall thickness of 120mm for ductility reasons as referenced by EuroCode 2 and instead use 105mm (minimum) thick unreinforced Dincel Walls.

Those design engineers who may have difficulty in understanding the abovementioned tests as testimony to Dincel's improvement to conventional concrete's ductility behaviour or those who wish to be conservative may consider using vertical bars only for the purpose of ductility requirements of the EuroCode. For example:

110mm Dincel Wall 12mm Diameter at 666mm or 1,000mm cts vertical bars.

Naturally the above discussion is not applicable to 200mm thick Dincel Walls which are greater than the 120mm serviceability criteria referred by the EuroCode.

(4) DINCEL WALL SERVICEABILITY RECOMMENDATION/STEEL REINFORCEMENT USE

This document explains that both the 110mm and 200mm unreinforced wall/blade columns can be used in a building structure.

The isolated elements such as blade columns may be subjected to accidental loadings, such as impact. The following is a recommendation for design engineers' consideration:

The robustness of isolated blade columns in areas such as basements should be considered where there is a possibility of accidental loads such as impact loads from vehicles. An engineer may refer to Item No: (3) above for flexural and earthquake testing results to understand that Dincel is already a ductile and resilient structural element. However, conservatively, the design engineer may also consider using centrally located vertical bars with a minimum reinforcement ratio of 0.002 (which is the reinforcement ratio by the EuroCode if the reinforced concrete wall solution in lieu of a plain concrete wall is adopted) without conventional column ties only if the impact/robustness is to be considered.

If for any reason, an engineer elects to use steel reinforcing bars, the ultimate strength and ultimate fire capacity can be increased by a factor of 1/0.8 = 1.25 (i.e. 25% additional capacity) in the DINCEL DESIGN TOOL. The reason for this is that unreinforced plain concrete that is adopted in the DINCEL DESIGN TOOL uses a capacity reduction factor of =0.8 for plain concrete walls.

Important Note

It is important to understand that for the calculation of structural adequacy fire resistance level, the **EuroCode only allows concrete spalling for aggregate thermal expansion** during a fire event (Annexure B – Fig B.5, BS EN 1992 – 1 – 2: 2004). If for any reason, steel bars are used **there must be minimum concrete cover** recommended by the EuroCode. **This is why the Dincel Design Tool is not suitable for some proprietary concrete walls where partially embedded metallic components have no concrete cover which is directly exposed to fire and hence thermal expansion related concrete spalling occurs. This type of spalling is not allowed by the EuroCode and the Dincel Design Tool. The increased spalling from the metals' thermal expansion, especially in highly stressed walls, can easily have structural failure.**

(5) WHAT IS THE BENEFIT FOR THE ENGINEER USING LOAD BEARING DINCEL WALLS?

- Simpler wall/column design by using the DINCEL DESIGN TOOL.

  - Repeat customers for achieving up to **43% COST SAVINGS.** Refer **Costing Analysis – download** for an example.

  - Load bearing walls result in simple one-way slabs which allow the use of mesh reinforcement (preferred by the industry) and 150mm thick slabs (Dincel provides acoustic certification).

  - Column-slab frame structures with infill walls are required to have minimum 200mm thick slabs (Table 5.5.2 (B), AS3600 – 2009) and mesh reinforcement is not allowed to be used (refer **Item 26 of Common Engineering Questions – download)** Dincel blade columns can be used without conventional column tie reinforcement.

- Eliminates the engineer's liability for wall cracking.

- Refer **Information for Design Engineers (download)** for further explanation.