Connecting to Eurocode 2: an investigation of reinforcement continuity connections for construction joints

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Abstract . As the local market moves away from cheaper foreign labour and focusses on higher productivity, we should use every possible avenue and technique to ensure that this does not result in a ballooning in construction costs. One such way is to take advantage of the move away from BS 8110 to EN 1992-1-1; there are a number of subtle changes between the standards that can result in reduction of materials, providing we know where to look. The move has not been seamless as there are a number of omissions from Eurocode 2 that has caused confusion, for example, there are no longer any requirements for mechanical splices as this is deemed to fall outside the scope of a design standard. However, there are equally some new areas that are covered in much more detail and it is these we should focus on. This paper will look specifically at the design provisions of construction joint continuity and show how they can be utilised to both improve productivity and reduce the amount of steel required across the joint. This not only saves the contractor time and money due to lower material costs, but will also reduce the amount of embodied CO_2 present in the structure as less steel will result in a "greener" solution. It will address the differences between current practices and new technologies that will enable smarter connections while staying firmly within the scope of MS EN 1992-1-1.

1.Introduction

As the drive towards improved productivity in construction continues, the technical challenge is in relation to the acceptance of these technologies and differentiating between the "good", the "bad" and the "ugly". The "good" technologies are those that are fit for purpose, technically sound and result in actual increased productivity at a comparable or lower cost. The "bad" technologies are those that are fit for purpose, technically sound but result in no actual productivity gain or less than what is claimed and result in an actual similar productivity at a higher cost. The "ugly" technologies are those that, due to poor Quality Control in the supply chain result in solutions that are not fit for purpose and could result in structural problems or collapse. These often arise when traders see an opportunity to earn some quick money without understanding what they are actually selling.

This paper will consider one such productivity technology that is fit for purpose and technically sound with its design origins in EN 1992-1-1. It will look at the whole process from design right through to installation and highlight possible risks that contractors might miss in their attempts to make projects commercially viable due to a lack of understanding on the intricacies of the technology.

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2.Technology – reinforcment continuity boxes

One easy way to improve the overall productivity of a high-rise construction is to use jump form or slip form construction to build the lift and stairwell core. The slabs and additional shear walls can then be connected on to the core walls using traditional cast in-situ concrete.

However, the starter bar connections between the core wall and the slabs are traditionally overdesigned and incredibly time consuming to create. Traditional methods are to either (i) drill and chemically anchor reinforcing bars in to place or (ii) simply bend the starter bars over and hide them behind the formwork. The problem with the first method is clear that the amount of time spent drilling holes would negate a lot of the productivity gained from using jump/slip form in the first place. Coupled with the fact that a chemical that is strong enough to transfer the load from diaphragm action in to the concrete is also expensive. Therefore you run the risk of ending up with a "bad" solution.

The second method is also problematic, but not so obvious. In this case there are 2 issues that would reduce productivity. The bent reinforcing bars are often encased in concrete fines preventing the bars from being straightened out without significant amounts of localised hacking. This in itself pushes this solution to the "bad" category. However, further investigation of the Malaysian Standard for reinforcing bars MS 146:2014 [2] highlights a significant problem. The bend and re-bend test requires a rebar supplier to bend to 90 degrees from straight and then straighten back by 20 degrees. In this application, the bars are bent to 90 degrees and then often re-bent at a different location with no bend radius control to 90 degrees again. The best we can hope is that it is straightened fully, which is also outside the scope of the standard and could embrittle the rebar causing a significant drop in the load capacity. This now fall well and truly in to the "ugly" category.

The solution to these issues is to use a proprietary technology (FIGURE 1) which creates a defined box, in to which the reinforcing bars can be installed. In addition to making it easier to straighten the bars, it also creates a shear key between slab and core wall concrete that will reduce the amount of steel required for the connection.

Figure 1

It being a proprietary system, better controls can then be put on to the supply chain of the rebar to make sure that only bars which can be fully re-straightened are utilised.

3.Design principles

The traditional methods use dowel action principles to calculate the capacity in vertical shear. This is done because the geometry of the joint is unknown and therefore the shear friction taken by the concrete cannot be determined. Instead, the entire vertical load it taken by the reinforcing bar.

If the geometry would be known, then there are provisions in clause 6.2.5 of MS EN 1992-1-1 [1] to assist you in determining the shear friction across the construction joint. There are 4 categories in total:

1) Smooth
2) Rough
3) Very Rough
4) Indented

By choosing a geometry that provides an indented surface, we are able to maximise the connection, reduce the amount of reinforcing bars present and therefore use a solution that has less embodied CO_2.

NOTE – Something to consider is that less rebar being installed is a key target for everyone except the rebar installer. They are usually paid per tonne of steel installed, so less tonnage will mean less revenue for them. This might seem like a small matter, but with all new technologies, you rely on the feedback from the installer to assess its actual success. Their bias and desire for bigger revenues could result in a "good" technology being labelled as a "bad" one. A separate agreement needs to be made with the installer to make sure that this done not happen.

3.1. Strength
The traditional methods utilise dowel action to gain its strength and the characteristic shear resistance of the steel can be calculated as follows:

$$V^0_{Rk,s} = 0.6 \, x \, f_{yk,s} \, x \, A_s$$

Where A_s is the stressed cross sectional area of steel and $f_{yk,s}$ is the characteristic (nominal) ultimate tensile strength the steel. The actual capacity is closer to a factor of "0.7 or $(1/\sqrt{2})$" but as the relationship between tensile and shear strength varies, most design codes (e.g. CEN/TS 1992-4 [3]) use a factor of 0.6.

For the purpose of this example, we will focus exclusively on vertical shear. In reality, the slab will work via diaphragm action with the core wall to provide structural stiffness and seismic robustness.

In the case of H16 bars ($f_{yk,s}$ = 500MPa) installed perpendicular to the joint at 200mm centres top and bottom of a 200mm thick slab with a concrete compressive strength of 40Mpa, this would give a capacity per metre of:

$$V^0_{Rk,s} = 0.6 \, x \, 500 \, x \, (2 \, x \, 201 \, x \, (1000/200)) \, x \, 10^{-3}$$

$$= 603.2kN/m$$

$$V^0_{Rd,s} = V^0_{Rk,s}/\gamma_{m,s}$$

$$= 603.2/1.4 \qquad = 430.8kN/m$$

The definitions of an indented surface are provided in figure 6.9 of MS EN 1992-1-1 [1]. If this can be achieved then the potential savings in rebar are greatest.

In the case of most reinforcement continuity (e.g. Plakabox), you are able to meet these requirements. This enables you to design the construction joint using shear friction by following the design provisions in Clause 6.2.5 of MS EN 1992-1-1 [1].

These design provisions are broken down in to 3 parts: The first part "c . f_{ctd}" is a function of the tensile strength of the concrete. The second part "m . s_n" is a function of the normal stresses applied to the concrete joint via dead weight, post tensioning etc. The third part "r . $f_{yd,s}$. (m . sin a + cos a)" is a function of the rebar contribution. As the usual applications utilising these boxes are core wall to slab or core wall to shear wall it can be safely assumed that the second part is equal to 0 and that the capacity of the finished joint is just a

function of concrete tensile strength and rebar contribution. However, if a normal force could be achieved with post tensioning, then the savings would be greater.

Referring back to our example, the amount of rebar required to resist the same vertical shear is calculated as follows:

c is taken from figure 6.9 where the value for an indented surface is **0.5**

f_{ctd} is taken from clause 3.1.6 (2)P and is **1.667** for grade 40 concrete

r is the relationship between the area of steel and the total area of the construction joint and is **$A_s/(200\times1000)$**

m is taken from figure 6.9 where the value for an indented surface is **0.9**

a is the angle between the rebar and the construction joint and is **90^0**

$f_{yd's}$ is the design yield strength of the reinforcing bar and is 500/1.4 = **357Mpa**

Therefore

$$V_{Rd,i} = (0.5 \; x \; 1.667) + (((A_s/(200\times1000)) \; x \; (0.9 \; x \; sin \; 90 + cos \; 90))$$

and

$$V_{Rd,i} = V^0_{Rd,s}/A_i$$

$$= 430800/200000$$

$$= 2.154 \; MPa$$

If we want to match the shear capacity of the dowel action, we need to re-arrange for A_s

$$2.154 = (0.833) + (A_s/(200000) \; x \; (357 \; x \; 0.9)$$

$$A_s = (2.154-0.833) \; x \; 200000/321.3$$

$$= 1046mm^2$$

Therefore, if we can change the bar size to 12mm with a spacing of 215mm as this would provide us with 1052mm^2 of steel (For Singapore H13 bars, we could increase the spacing to 250mm as this would provide us with 1062mm^2) Assuming 40 x bar diameter as a development length, this would mean that the total weight of steel per metre for the 2 design methods is as follows:

Dowel Action   = *(16 x 40 x 1.580/1000) x (2/0.2) = 10.1kg/m*

Clause 6.2.5   = *(12 x 40 x 0.888/1000) x (2/0.215) = 4.0kg/m*

(Singapore = *(13 x 40 x 1.043/1000) x 8 = 4.3kg/m*)

With current rebar prices at about RM2.5/kg (S$0.78/kg) the total cost saved is about RM15.25 per metre (S$4.5/m). For a 30 storey building, assuming a core wall perimeter of 80 linear metres, this would equate to a total cost saving of RM36,600 (S$10,800) for the project. This is a small saving in real terms, but the soft savings in relation to increasing the productivity and reduction of the programme time are huge. Productivity plus actual cost savings result in

3.2. Water tightness

There is an additional design advantage that is not covered in the scope of the standard. Some boxes (e.g. Plakabox) create a dovetail arrangement between the first and second cast of concrete, so that even in tension, there is a physical interlock across the joint. This means that the crack pattern across the concrete joint will form in a similar way to a monolithic construction, with multiple hairline cracks and not with a risk of a single large crack opening up at the construction joint surface. This will reduce the risk of water penetration through the slab and provide a more robust solution. In the event of a head of water building up above the slab, the dovetail has further protection by complicating the path which any water would need to take. In the case of the thinner boxes with a single dovetail, the water would have to flow uphill twice. With the wider boxes, there is a double dovetail meaning that the water has to flow uphill 4 times in order to penetrate through the slab (FIGURE 2).
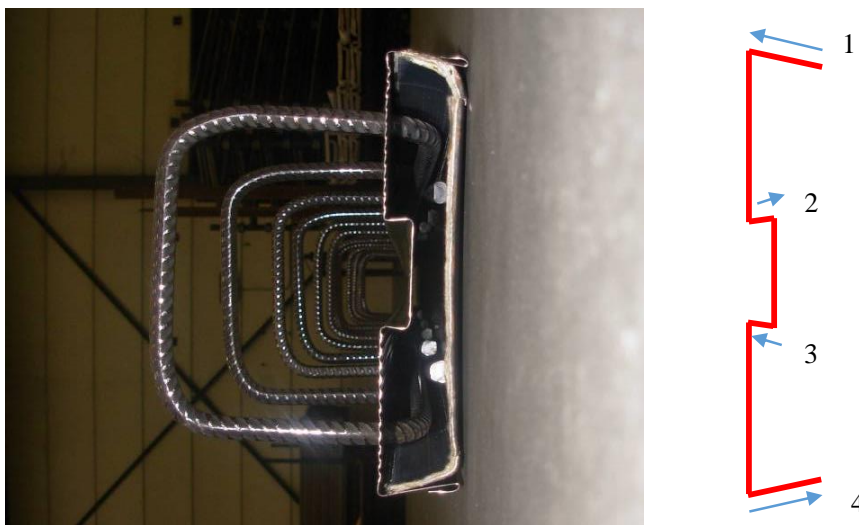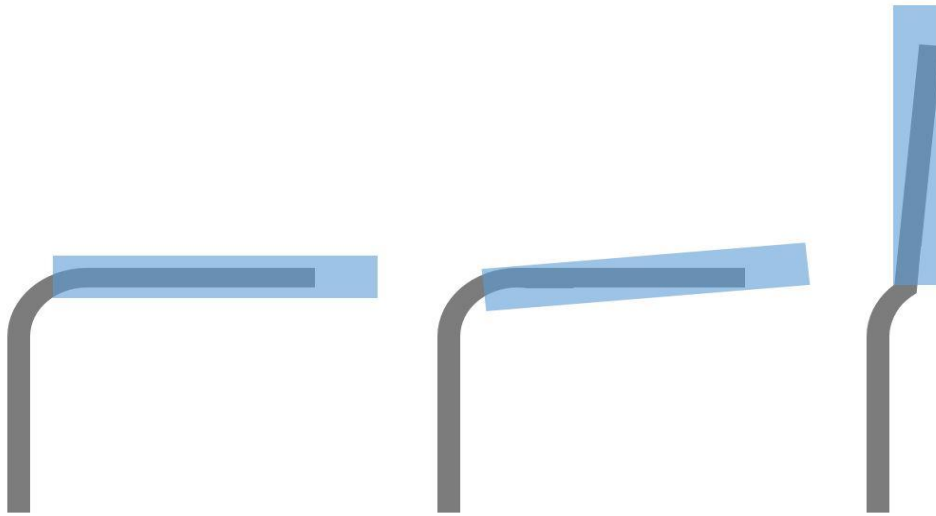

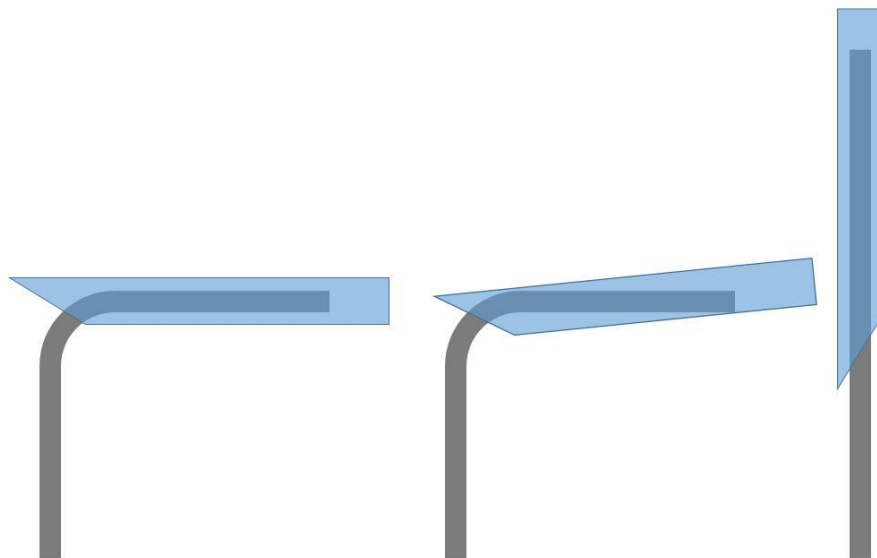*Figure 2*

3.3. Rebar requirements

Unlike some overseas countries, the Malaysian rebar standard MS 146:2014[2] bend / re-bend test only requires for the bars to be straightened by 20 degrees after bending whereas the bars in this application are fully straightened after the initial bend. This means that there is a risk of cracking or even breaking of the reinforcing bars due to strain embrittlement. To mitigate this risk, the boxes should some complete with the reinforcing bars from a trusted supplier of the system. This gives the supplier the ability to control his supply chain and request bars that have been tested to be fully straightened after the initial bending.

Also, relating to the tools used to straighten the bars, or any bars for any application on site. If you choose to use a piece of hollow tubing to straighten the bars, you are not actually straightening them but instead, creating a new bend around a radius of less than 1 x bar diameter at a different location (FIGURE 3). This will create an "S" shape.

Figure 3

Instead, you should try and use the smallest tube size that will fit over the bar and cut a 45 degree chamfer at the end of the tube. This way, you can ensure that the straightening of the bar is done without any risk of cracking or breakage (FIGURE 4).

Figure 4

4.Conclusion

In conclusion, the advantages of these continuity systems are not currently being assessed correctly. Too often the traditional method is being compared to a box type with the same reinforcement and it is being discounted without even considering the productivity benefits.

The above comparison will help the system get past the initial procurement checks and allow the productivity savings to be fully explored and push it firmly in to the "good" technology category. However, care needs to be taken within the supply chain to make sure that bars which are unable to be straightened to not result in this becoming an "ugly" technology and people losing faith.

The author highly recommends that systems such as this fall under a Malaysian Construction Industry Development Board (CIDB), Singapore Building Construction Authority (BCA) or independent certification such as the types seen overseas with UK's Certification Authority for REinforcing Steels (CARES), France's Association Francaise de Certification des Armatures du Beton (AFCAB), USA's International Code Council – Evaluation Service (ICC – ES), Europe's European Technical Assessments (ETA) and Australasian Certification authority for Reinforcing and structural Steels (ACRS).

5.References

1. MS EN 1992-1-1:2010 MALAYSIA NATIONAL ANNEX TO EUROCODE 2: DESIGN OF CONCRETE STRUCTURES - PART 1-1: GENERAL RULES AND RULES FOR BUILDINGS
2. MS 146:2014 Steel for the reinforcement of concrete - Weldable reinforcing steel - Bar, coil and decoiled product - Specification (Fourth revision)
3. CEN/TS 1992-4:2009 DESIGN OF FASTENINGS FOR USE IN CONCRETE