Combined Reinforcing For Concrete - Not Just For Heavy Duty Pavements

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Abstract: Using a combination of steel fibres and conventional reinforcing mesh to reinforce concrete pavements for container parks and other very heavy duty slabs has become recognised and proven as the perfect solution over the past few years. By utilising the benefits of both types of reinforcing in combination we are able to achieve a long lasting durable pavement, economically.

Whilst very many such pavements have now been constructed and in operation for some years, similar benefits of combined reinforcing can also be used to better deal with the difficulties and requirements of modern day facilities for their internal slabs and lighter weight pavements. Automated high-bay racking, much higher applied loads, more precision driven handling equipment, and poorer ground conditions, all lean towards seamless slabs, and this can be achieved by utilising combined reinforcing.

We are seeing many more facilities constructed using this solution for different reasons, and this paper will discuss briefly the methodology behind this type of design, as well as showcase a number of local projects constructed over the past few years.

Keywords: Fibres, Combined Reinforcing, Combi Slab

Introduction: Combined Reinforcement for concrete has been around for quite a few years now, and many of you will have seen previous papers on it being used particularly for Heavy Duty Pavements such as container parks.

But there is far more to this type of solution, and it has many different applications and can be used to achieve many different outcomes.

When steel fibres alone cannot provide the solution required for a particular application, and trying to use conventional reinforcement is going to be too cumbersome and expensive, combining the two can often achieve the outcome you are looking for. The use of steel fibres will still provide all of the benefits of steel fibre reinforced concrete (SFRC) you have become used to, such as not having any unreinforced zones above the conventional steel at surfaces and edges and greater crack control earlier, whilst also allowing for a significant reduction in the amount of conventional reinforcing steel that would otherwise be required.

Concrete Basics: Concrete is a brittle material and cracking will occur. In fact the reinforcing, of any type, is not doing anything until the concrete cracks, it's how we deal with that cracking that is important. If these cracks are controlled within specified levels for the particular application, they are not detrimental to the structural integrity or the serviceability of the structure. In more conventionally reinforced concrete this control is achieved by providing a suitable percentage of steel reinforcing and providing joints as required.

A major design consideration for any structure is the location of those joints, and the associated detailing of them. For slabs and pavements this can become very critical, depending on the types of vehicles and movements in the facility, as they will usually be the first areas prone to breaking down or requiring maintenance, so the objective is often to remove them from critical paths and minimise them as much as possible. For other types of structures the location of those joints can be critical for achieving watertight structures, or simply dealing with the differential stresses in the concrete that will otherwise potentially cause unwanted dominant cracking.

Most reinforced concrete is designed and detailed to limit the stresses induced by restraint, temperature, and shrinkage, ensuring that it remains less than the tensile capacity of the concrete, so it is theoretically designed to remain uncracked. However that also puts fairly prescriptive limitations on the size and shape of it and is not always possible.

Innovation in the design of concrete elements over the past few years has led to the development of design rules and standards that allow for the use of steel fibre reinforced concrete in combination with conventional reinforcing to make it possible to design an economical solution for controlled cracking under serviceability stresses. So now we can design a slab, pavement, or other concrete elements of any shape or size, which can also be completely joint free if necessary.

Eliminating or Minimising Joints: When we eliminate or minimise typical movement joints, we are not eliminating the shrinkage or movement within the concrete, it still needs to be taken up somewhere. By instead designing that shrinkage and movement to be taken up at much closer centres throughout the concrete, rather than at those greater centres, then the width of those joints, now micro-cracks, will be much finer and can remain serviceable in the concrete element. In turn by keeping them as fine in width as suitable for each application, they are far less likely to deteriate and require maintenance.

This approach can initially be difficult to grasp, most designers, and even more so end users, have been brought up trying to avoid cracks in their concrete, believing that they will be a problem. But that's not the case. If they are designed for and are controlled correctly, cracks can actually be a good thing. It is, however, crucial to design them correctly for each required application, and this can only be done with the right high performance steel fibre and the right amount of conventional reinforcing steel. In most applications, particularly slabs and pavements for example, the concrete still needs to be designed in ULS to carry the applied loads, then an SLS design will be carried out to ensure that the serviceability requirements are being met.

Crack widths for serviceability will vary depending on the particular application and there are guidelines available for consideration. If the concrete is required to be watertight, for example, then a much thinner crack width will be required than that for a typical trafficable pavement with only pneumatic tyres. You should ensure that you know what your crack width requirements are for your particular application so that a suitable solution can be designed to suit.

Some Design Considerations: Whilst this paper doesn't go into the full detailed design methodology, there are some points that are worth noting, and some that again require a little different way of thinking.

It is very important to understand the application, and what you are looking to achieve. What is the reason for using a combined reinforcement solution? Is it actually restrained, or is it relatively lightly loaded and you just want to minimise the joints? Does it need to be watertight, or need to withstand chemical penetration? Is it an awkward shape or a long and narrow section? Does it have multiple penetrations and plinths through it? And of course, what are the applied loads?

Detailing for the restraint, and at re-entrant corners is still extremely important, and consideration needs to be given to the pour layout and sequence.

Often the most difficult aspects to comprehend is the accuracy of your concrete strength and thickness. Whilst it would seem that actually receiving a higher than ordered concrete strength on site would be a bonus, for a combined reinforced concrete design this is not the case. An increase in concrete strength will require an increase in the percentage of steel, so the reinforcing mesh or bar, to match the concrete stresses. And an increase in thickness would similarly be seen as a bonus on site, however this can also require an increase in steel percentage, and more importantly, in a slab application at least, as the bar chairs won't change in height, so it usually results as an increase in cover to the reinforcing steel, which in turn means that the cracks are arrested by that steel at an increased depth potentially resulting in an increase in the nominal crack width at the surface.

With all concrete designs there are many aspects and influences to take into consideration, these are just a few of them, and it is important to familiarise yourself with all of them.

Tied Joints or Stitched Joints: From a practical construction point it is not always possible to pour the entire concrete element in a single run. A slab or pavement will often be far larger than what is achievable in a single pour, and other structures will often have shapes and restrictions that will limit what can be poured all at the same time, so there will usually be a requirement to stop the concrete at some point and return to continue the concrete pour the next day or soon after. In this situation we are again avoiding the use of more typical movement joints, and instead are designing them as a Tied Joint or Stitched Joint. Essentially we are looking to replicate the designed crack width for the rest of the concrete at this location, but now in a straight line. As there will be no steel fibres crossing the crack or joint at that location, we are unable to consider them in the design there, so we need to increase the amount of conventional steel across that joint, or straight crack, locally to ensure the same crack width design is being maintained.

- Tied Joints designed to the same nominal crack width.

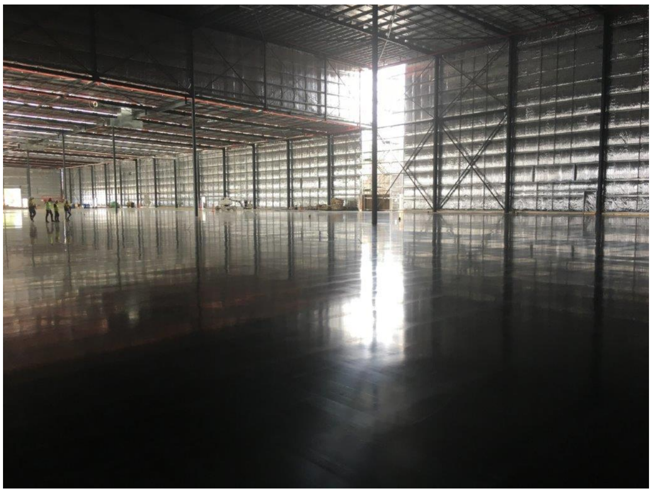
Applications:

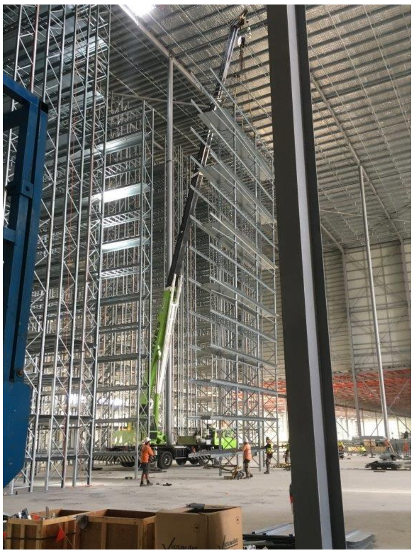
Restrained Internal Slabs: Slabs can be restrained by any number of influences, posts and columns supporting mezzanine floors above, plinths and pits cast into or through the slab, very heavy equipment or machinery, and even a small area of extra heavy storage, can all restrain a slab locally. Instead of trying to detail the slab to isolate these influences out, the slab can be designed to be fully restrained and deal with those influences. Here we can use combined reinforcing to take up the stresses and the shrinkage within the slab itself rather than at the joints, and we can better deal with the odd shapes and re-entrant corners that might also be created.

- 100m long completely joint free Cold Room in Sydney to reduce long-term maintenance.
- Warehouse facility using combined reinforcing to deal with multiple penetrations for future equipment.

- Manufacturing Facilities with multiple trenches and set-downs can be easily accommodated.
- Warehouse Slab supporting mezzanine floor above uses combined reinforcing locally.

High-Bay Warehouses: As more and more facilities become completely automated, and in some locations available land becomes more scarce, High-Bay racking continues to increase in popularity. These facilities can have racking as high as 38 metres, and the resulting post loads from such high racking in turn also significantly increases, in the vicinity of 27 Tonnes and greater. These sorts of point loads not only require thicker concrete slabs to support them, but they also work to pin or restrain the slab locally. By doing this the slab can no longer shrink and expand as it normally would, and this shrinkage needs to be taken up throughout the slab across it's entire area rather than only at dowelled movement joints that might be 30 metres or more apart. By designing the slab as fully restrained, we can now also completely eliminate the movement joints which also allows us to minimize any potential for differential vertical movement at those joints which can otherwise have a detrimental effect on the operation of the automated handling equipment.





- Coca Cola Amatil – Richlands QLD – 9000m2 of high-bay racking, 35m high and 27 Tonne post loads.
- Ikea Distribution Facility – Marsden Park NSW – Fully automated high-bay racking facility.


- Project Broccoli / Coles Distribution Facility – Redbank Plains QLD – High-bay automated facility with varying thicknesses and detailing throughout to accommodate different racking loads and requirements.

Watertight Concrete: Whilst watertight concrete can be achieved with conventional reinforcing steel, it usually requires a huge amount of steel to be able to design to a such a tight specific crack width. By replacing a large amount of that conventional reinforcing steel with fibres we can design the concrete to be watertight by achieving a specific nominal crack width for a much more economical and far easier to construct concrete solution. Watertight requirements can differ, so it is important to know what you are actually designing for. The concrete can be required to hold water or other liquid, it can be required to resist water pressure from underneath or behind, or it can be just to stop excess leaching. Of course the concrete itself is still only part of the overall watertight system so it is important to consider other aspects such as drainage and potential build-up of water pressure.


- ACT Waterways Flood Mitigation Project – Watertight seamless joint free containment area.


- Perth Busport WA required a watertight raft slab at 750mm – 900mm thick.
- Happy Valley Spillway SA – 700m long x 8m wide fully restrained walls and slabs for high water flow.

External Lightweight Pavements Just To Remove Saw-Cuts: We've seen plenty of fully restrained external pavements designed and constructed with combined reinforcing to completely eliminate the need for any joints and saw-cuts for the very heavy duty pavements, as previously mentioned. But what about lightweight or standard external pavements, those for typical semi-trailers and road-going vehicles. Even under those relatively light wheel loads we tend to see the saw-cuts breaking down and requiring repair, so why not eliminate them. We don't always need to go to the extent of a fully restrained seamless pavement and eliminate the dowelled movement joints, we can often keep the joints and just remove the saw-cuts for a more robust and durable pavement. With fibre only it's not practical to remove the saw-cuts as we usually do for internal slabs, because there are too many other external elements to consider, but by adding some light reinforcing mesh we can. And because we are still keeping the typical movement joints, the stresses in the concrete remain fairly low so we are able to use a fairly low dosage rate of steel fibres with relatively light top reinforcing mesh.

- A typical Yard Slab with movement joints at 25m x 25m centres and now with no saw-cuts can accommodate semi-trailers and single containers.

Odd Shaped Slabs: Traditionally we want a concrete slab to be fairly square, or at least within a length to width ratio of 1:1.5, to minimize the risk of differential shrinkage in each direction occurring and therefore running the risk of a dominant crack forming. But that isn't always possible with the shape of the slab panel sometimes dictated by other factors. Awkward shapes with acute angles as the buildings or driveways are shaped to maximize the site and land available, loading docks, offices and amenities often jotting out into the perimeter panel creating smaller rectangular shaped slabs, long narrow strips, and others would all become difficult to detail or require lots of extra joints and saw-cuts to keep them relatively square. Instead we can utilize steel fibres in combination with reinforcing mesh to deal with it.

- Raupuha Tunnel in Tarinaki New Zealand is 130m long by 3m wide and now has now joints or saw-cuts.

Removing Multiple Saw-Cuts At Loading Docks: Loading docks in warehouses and distribution facilities are usually a series of small cut-outs in an otherwise standard square panel. If the larger typical slab panel was to be poured in and around the top of the loading docks, there would be a lot of significant re-entrant corners and restraint, so they are generally isolated out of the main slab. But even then those re-entrant corners and restraint would require a great deal of reinforcement detailing or a huge number of saw-cuts off each corner in all directions. So instead we can used combined reinforcement and pour that entire strip of loading docks in a single run. We still need to trim the re-entrant corners, but the amount of conventional steel required is now minimal, we've eliminated all of the saw-cuts, and we get the added benefit of the concrete being reinforced all the way through to the surface with steel fibres at one the most highly trafficked areas in the facility.

Raft Slabs: Raft Slabs are generally very thick slabs at the bottom of tall buildings, usually designed to provide a certain amount of mass, and due to the thickness have massive amounts of conventional reinforcing steel throughout the depth. Often a large amount of that steel, especially through the centre of the depth, is not particularly required structurally. Steel fibres can be used instead, often meaning that only a top and bottom mat of conventional reinforcing is required with stirrups to hold them in place, with the steel fibres providing the rest of the reinforcing requirements including almost all, if not all, of the shear requirements. This provides a huge cost saving on these types of projects, but even more importantly a huge time and labour saving as well.

- Queenstown Apartments Raft Slab – 1000m2 x 900mm deep raft slab.
- Dramix 5D 65/60BG steel fibres @ 25kg/m3 reduced conventional steel by approximately 40%.

- Dunn Road Apartments Raft Slab New Zealand – Dramix 5D 65/60BG steel fibres allowed for a reduction in conventional steel required for Shear, Bending Moments and Crack Control.

Better Accommodate Poor Ground: As prime land becomes more difficult to come by the quality of the ground conditions is becoming worse where some of the larger structures are being constructed. Ports are often on reclaimed land, and even locations where existing buildings have been demolished to make way for new structures can have poor quality subbase. Combined reinforcing can assist in dealing with some of those concerns without costing a fortune. Of course there are limitations, however where it can be achieved by designing the slab with steel fibres and mesh we can either span over any soft spots, or allow for a more articulated slab, as a way of accommodating the differential settlement.

Similar Design Concepts For Vertical Applications Such As Retaining Walls And Shotcrete: Shotcrete around the perimeters of construction sites, between piers and shoring, is required to resist the horizontal ground loads from behind, and is often required to be watertight. When we think of combined reinforcing, and particularly given the papers that have been presented over the past few years, we are usually thinking about slabs and pavements. But that isn't necessarily the case, the same design principles apply in vertical applications as well. The shotcrete can be designed to a specific nominal crack width to provide a watertight ground support to the perimeter of the site or building. Basement carparks for example may be accepting of some water ingress, where as a hospital site may need to keep all possible water and other impurities out. Retaining walls will often have fairly significant bending moments applied to them as well as needing to be aesthetically pleasing on the front face. Using steel fibres with conventional steel can ensure that both of these requirements are met, by designing the concrete to accommodate the bending moment as well as to an acceptable nominal crack width on the face.


- Perth Children's Hospital – 5km of shotcrete to cover the continuous piles surrounding the site to a specified crack width using 35mm long steel fibres and standard reinforcing mesh.

Track Slabs: Railway track slabs usually require a lot of hold down bolts for the rail tracks, and those huge numbers of bolts need to be surveyed to ensure they don't clash with the top reinforcing steel. By designing these using combined reinforcing, the conventional steel can often be moved to the bottom of the slab away from those bolts, and therefore eliminating the concerns of any interference.


- Dart 1 Ontrack Railways New Zealand – Track Slab using combined reinforcing eliminated top reinforcing steel to avoid any clashes with the very congested anchor bolts.

Conclusion:

It is clear and proven that using a combination of steel fibre reinforced concrete and conventional reinforcing steel provides the designer with far more flexibility removing the usual constraints, such as restraint, shape and size. And there are many more applications other than heavy duty pavements that can also benefit from this type of solution. Using combined reinforcing can often save time and money on a project, but of far greater value is the much more optimised design and benefits that can be achieved.

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