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**Field Applications of Steel Fibre Reinforced Concrete Pavements  
Two Case Studies - A Contractor's Perspective**

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**Synopsis:** The paper details two case studies of the application of steel fibre reinforced concrete pavements. For two design and construct contracts, steel fibre reinforced pavements were chosen over conventionally reinforced pavements on the basis of speed of construction and cost effectiveness. Full scale field-testing was implemented to confirm design assumptions for subgrade reaction. Tender assumptions of benefits from ease of construction in the field were realized.

**Keywords:** Pavement Design, Cost Effective Pavements, Pavement Case Study, Pavement Cost Analysis, Steel Fibre, Reinforced Concrete Pavements

### **Biography**

Bob Lyons is the Senior Civil Engineer and State Quality Assurance Manager for Consolidated Constructions Pty Ltd, a medium sized building – civil engineering contractor with its Head Office in Perth, Western Australia and a branch in Sydney, New South Wales. Bob graduated in Civil Engineering at the University of Western Australia in 1976 and has since completed postgraduate diplomas in Applied Science, Management, and is a registered Builder.

### **INTRODUCTION**

Steel fibre reinforced concrete pavements have been used extensively overseas in numerous applications including bridge deck overlays, scrap steelyard hard stands. In Australia, the use of steel fibre reinforced concrete for pavement construction is slowly gaining acceptance as the benefits in cost effectiveness, speed of construction and durability are being realized.

This paper details the process by which steel fibre reinforced concrete pavements was chosen over conventionally reinforced pavements for two design and construct competitively tendered projects and details the construction methods used, and the benefits realized during construction.

### **DESCRIPTION OF PROJECTS**

#### **Bunbury Port Authority Facility**

The Port of Bunbury is located approximately 160KM south of Perth. The brief was to provide a materials storage and handling facility, at the inner harbor to store under cover 30,000 tonnes of mineral silica sands, with receival capability of 500 tph using B-Double Road trains and export capability of 1,000 tph via conveyors to an existing shiploader. The facility had to provide for future expansion and upgrades without requiring major structural changes.

The storage provides for two-product separation and consists of 4.5m concrete tilt up retaining walls on three sides with the remainder of the walls and roof metal clad. The products are received damp at some 7 to 10% moisture content and is exported at approximately 3% moisture content so the facility provides for the collection and disposal of liquor seeping from the stockpile. The material is handled during receival and export with a CAT 990L series front-end loader. Product stockpiles are expected to peak at some 14m.

The subgrade consists of hydraulically placed fill, dredged from the harbor, which had been pre-consolidated by surcharging with soil stockpiles. No geotechnical information

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was available at time of tender. Site inspection indicated silty sands with clay lenses, with a water table within approximately 2.0m of the surface.

### **Summit Fertilizer Facility**

A Fertilizer storage facility was required to replace an existing facility in the Port of Bunbury. The site chosen by the proprietor is a rural block some 11 KM from the Bunbury Port. The facility is located at the top of a low rising sand dune surrounded by low lying fields subjected to winter flooding. No geotechnical information was available at time of tender. Site inspection indicated the subgrade was medium/loose coarse 'Hungry' sands.

Fertilizer and chemicals are received in bulk over a weighbridge within the facility and stockpiled using a CAT 966 Front end Loader to heights of some 12m using pusher blades. Provision had to be made within the facility for future expansion and upgrading without major structural changes.

The structure consists of 5.0m precast tilt up walls on three sides, 5.0m precast tilt up bunker walls and high bay structural steel. The remainder of the walls and roof was metal clad and weather tight.

## **INVESTIGATION OF TENDERS**

### **Bunbury Port Authority**

Visual inspection of the site and local knowledge indicated silty sands, with clay lenses. The area was generally level, with ponded water on the surface. During recent construction of the adjacent Berth, we had the opportunity to witness the construction of a similar sized facility on the adjacent block. It was noted that the water table was fairly close to the surface, within 2.5M and that the material lost strength when saturated - typical silt behavior. This had caused construction problems with access for construction plant, dewatering problems with pits, and difficulties in compaction of the material. This was evident as well during road construction adjacent to the Berth.

It was noted that the earthworks and pavement construction period would be during the winter months of July-September.

### **Summit Fertilizer Facility**

Visual inspection indicated that the subsoil was coarse white medium/loose 'Hungry Sand'. The proposed location for the facility was sparsely treed, however the trees were of substantial girth. Access to the site was over low-lying flood plains with pasture grass over the same coarse sands.

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Experience indicated that the material would cause access difficulty for construction plant, even when compacted, as it was essentially cohesionless.

## TENDER CONSIDERATIONS IN CHOICE OF DESIGN

### Tender Cost Constraints

Due to the competitive nature of the construction industry, it is generally not feasible to carry out a detailed geotechnical investigation for each competitive design and construct tenders of this sort, as the cost of lost tenders is too prohibitive. Tenderers generally rely on local knowledge and experience for preliminary design assumptions and qualify the bid accordingly for 'Latent Conditions'.

Similarly, this Company's expertise lies in Design Management, and relies on known design consultants to carry out tender designs "on spec".

### Tender Objectives

The objective was to win a competitive design and construct tender, by offering a facility which met all the client's requirements in a cost effective way. FRC concrete pavements were viewed as a means to gain a competitive edge with the following perceived advantages.

- Competitive construction costs compared to conventional pavements
- Speed and ease of construction
- Compatibility with precast tilt up construction
- Increased toughness, wear resistance, durability in aggressive environments

### Perceived disadvantages of conventionally reinforced concrete pavements

Conventionally reinforced concrete pavements were perceived to have the following disadvantages.

- Not as cost effective
- Slower to construct, due primarily to jointing details, and the necessary additional formwork and time taken to place reinforcing
- Slower to get access onto the slabs for craneage due to the requirement to pour slabs 'Hit and miss'
- Perceived long term problems with wider joints allowing the sealant to be pulled out by loader blades
- Precast tilt up construction may be delayed until sufficient slab area has been laid

### Design of the steel fibre reinforced pavements

Several local suppliers of steel fibres were approached and given the design parameter (Table 1) and invited to tender for the design of the pavements and supply of the steel fibres.

**Table 1**

	K (MN/m <sup>3</sup> )	f <sub>c</sub>	Bulk density (kg/cm)	Stockpile Height (m)	Operating Plant
Bunbury	80	32	1.5	14	Cat 990 L
	250mm subbase Bidum A24	40			68 Tonne axle load
					Road Train
					21 Tonne Axle Load
Summit	80	50	1.5	12	Cat 966
	150mm subbase Bidum A12				27 Tonne axle load
					Road Train
					21 Tonne axle load

Where

f<sub>c</sub> is Characteristic strength of Concrete

K is Modulus of Subgrade Reaction



FERC SLAB	150	180	\$47.05	CONVENTIONAL SLAB	180	\$52.30		
	UNIT	QTY	RATE	\$	UNIT	QTY	RATE	\$
LEVEL AREA AND COMPACT LIMESTONE SUBBASE - 150MM	SQM	1	1.50	\$1.50	SQM	1	1.50	\$1.50
LEVEL AREA AND COMPACT	SQM	1	3.00	\$3.00	SQM	1	1.50	\$1.50
GEOTEXTILE	SQM	1	1.20	\$1.20	SQM	1	0.30	\$0.30
PLASTIC, 2 LAYERS	SQM	2	0.30	\$0.60	SQM	1	0.10	\$0.10
PLACE PLASTIC	SQM	2	0.10	\$0.20	SQM	1	0.10	\$0.10
50MPa + 20KG/CM DRAMIX + MICROPOZ	CM/SQM	0.15	191.00	\$28.65	CM/SQM	0.18	151.00	\$27.18
LABOUR TO PLACE	CM/SQM	0.15	40.00	\$6.00	CM/SQM	0.18	40.00	\$7.20
PUMPING	CM/SQM	0	14.00	\$0.00	CM/SQM	0.18	14.00	\$2.52
CUTTING + JOINTS	SQM	1	1.00	\$1.00	LM/SQM	0.1125	10.00	\$1.13
[6MX6M PANELS]						X	8.00	
EDGE BEAMS	400	X	200.00					
[PANELS L x W]	42		24.00					
CONCRETE - 40MPa - 15% WASTE	CM/SQM	0.01204761	191.00	\$2.30	CM/SQM	0.015525	151.00	\$2.34
PUMPING \$14/CM	CM/SQM	0	14.00	\$0.00	CM/SQM	0.015525	14.00	\$0.22
LABOUR	CM/SQM	0.01204761	40.00	\$0.48	CM/SQM	0.015525	40.00	\$0.62
EXCAVATE, TRIM TRENCH	CM/SQM	0.01047619	15.00	\$0.16	CM/SQM	0.0135	15.00	\$0.20
FORMWORK	LM/SQM	0.13095238	15.00	\$1.96	LM/SQM	0.1125	15.00	\$1.69
F72 MESH	SQM	1			SQM	1	5.00	\$5.00
LABOUR	SQM	1			SQM	1	1.20	\$1.20
REBAR	(KG/CM)/SQM	0			(KG/CM)/SQM	0	950.00	\$0.00
LABOUR	T/SQM	0			T/SQM	0	400.00	\$0.00
CRANAGE	HRS/SQM	0.01			HRS/SQM	0.01	110.00	\$1.10

Table 3 – Cost comparison of FRC versus Conventionally reinforced Pavement design  
Summit Fertiliser Facility

The most critical assumption was the modulus of subgrade reaction or K. Discussions with the steel fibre suppliers (1,2), and local geotechnical consultant's (3) lead to the assumption of K as 80mN/mm.

The choice of concrete strength assumed in the design was influenced by cost, durability, and in the case of the Summit pavement, resistance to chemical attack.

In Australia nomination of structural concrete in design is identified by an 'N' or 'S' prefix. The 'S' prefix indicates that various parameters of the design mix, for example cement content, slump, water/cement ratio, aggregate grading curves, and additives have been defined by the Engineer. Eg S32 indicate 32 MPa concrete with Engineer specified parameters. The 'N' prefix indicates 'normal concrete' eg N32 indicates 32 MPa with the design mix parameters not specified by the Engineer.

For the Bunbury Port pavement, S32 and S40 concrete strengths were investigated. For the Summit Pavements, discussions with concrete supplier's (4) design engineers led to the choice of an S50 mix including 5% silica fume to reduce permeability of the concrete matrix and so increase resistance to chemical attack.

As different fibres have different properties, the designs for the pavement thickness varied with differing fibres, dosage rates and concrete strengths. These were costed to give the most economical solution and then compared to conventional designs. (Table 2, 3 above). It should be noted that the design of the internal cut joints was assumed to be that of a free edge at 80% of internal floor loadings, ie. 20% load transfer across the joint through aggregate interlock (2).

The chosen design solution was for the DRAMIX ® RC65/60 fibres dosed at 20kg/m<sup>3</sup>. This lead to a design thickness of 210mm for the Bunbury facility and 150mm for the Summit facility.

The suppliers were also able to supply advice on construction details for the pavements. Key features of the details incorporated into the design are as follows. (Figures 1,2)

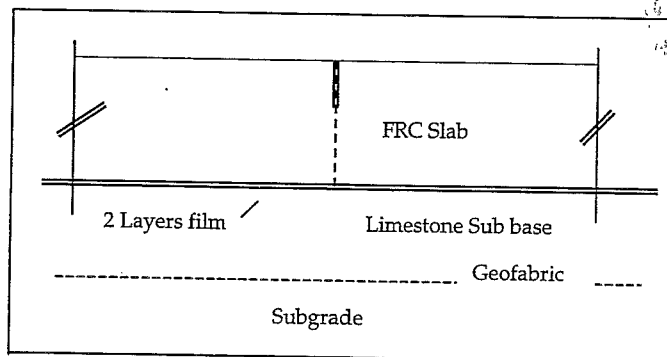


Figure 1: Typical internal cut joint

- Two layers of 200uM plastic film under the slabs to reduce ground friction. This allows the slab to contract freely, and enables cracks to be induced at known locations
- The retaining wall footings were tied to the slab to prevent the footing from sliding(6)
- To reduce the effect of loads at edges, all free edges subject to loading were supported by 'sleeper beams (Figures 2,3) with four layers of 200uM plastic film between the slab and the beam. This also allowed the slab edges to contract freely. The common practice of using edge thickenings was discounted as they effectively restrained the edges of the slab, and would lead to shrinkage cracking of the slabs with the panels
- Although the pavements were poured in relatively large panels - some 42m x 20m, they were cut the same day into nominally 6m x 6m panels. The cuts were approximately 30% of the depth of the slab i.e. 75mm. The objective was twofold:
  - Induce shrinkage cracks at known locations
  - Reduce the size of the shrinkage crack and so enable transfer of loads through aggregate interlock

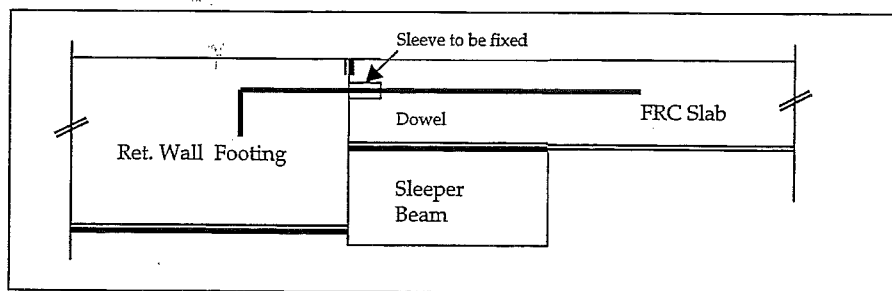


Figure 2: Slab Edge Sleeper Beam

- After primary shrinkage has occurred (at least 28 days from date of pour), water blast clean, then fill the induced cracks with a fine silica sand and low viscosity epoxy filler. The objectives of this were as follows:
  - To prevent silica fines being drawn into the cracks and so cause 'jacking' of the slabs. This had been observed on an adjacent storage facility
  - To prevent draining liquor from the stockpile from migrating under the slab, as this might cause problems with the subbase
  - To ensure that the slab acted monolithically and ensure load transfer across the joint

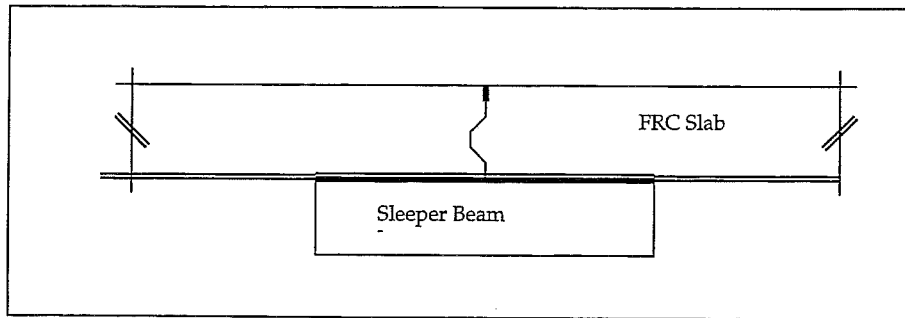


Figure 3.  
Construction Joint (Expansion Joint similar)

- It was decided to avoid, where possible, flexible joint sealant, as they were prone to damage during operation with the loader. This was of concern as it could lead to water ingress into the subgrade and jacking of the pavements
- During construction, the pavements were to be initially compacted, by immersion vibrators, and finally by drawing a vibrating screed slowly over the surface. The vibrating screed as drawn at a rate of about 1-2m per minute. The objective was to compact the concrete and also to ensure that the steel fibres settled slightly below the surface. This ensured that a smooth steel trowel finish could be obtained, producing a more durable wearing surface, and reduced the possibility of attack and corrosion of fibres near the surface by embedding them in the cement paste matrix
- Reinforced construction joints between pours and edge thickenings were eliminated and replaced with sleeper beams to achieve load transfer across the joints. This was expected to be cost effective, quicker and ensured free movement of the slab during shrinkage
- A base course of compacted limestone was introduced. This was expected to eliminate the need for cranes or pumps to place the concrete. It was decided to place all the concrete direct from the transit mixer. The benefits for the sites included protection of the subgrade from deterioration due to rain, unrestricted access around the site for concrete transit mixers and cranes and quicker concrete pours

A key concern and the general approach were to provide an economical pavement that was tough, wear resistant and durable. Ensuring that the slab was free from shrinkage cracking was seen as a key feature to sell to the Client.

#### Field confirmation of design assumptions

It was crucial to confirm the critical design parameters assumed for the subgrade early in the contract.

A local contractor was engaged to carry out extended Perth Sand Penetrometer readings to a nominal depth of 3m. The tests indicated a uniformly dense subsoil profile with

blow counts increasing with depth. Insitu subgrade compaction tests were conducted to determine the density of the subgrade prior to earthworks commencing.

The subgrade was trimmed to grades and compacted to a minimum of 90% Modified Maximum dry density (MDD), prior to a layer of Bidum A24 geotextile being placed and a layer of crushed limestone base course which was then compacted to a minimum of 95% MDD.

After compaction of the limestone was completed, the subgrade was exposed and the insitu density tested. It showed that the subgrade compaction had improved to some 93% MDD.

The critical parameter to be confirmed was the modulus of subgrade reaction 'K' of the base course. A testing bed was constructed from steel beams, with two testing plates, one 750mm diameter, being the standard required for the design and one (1500x1200 mm) calculated to be the footprint of the loader tyre, at basecourse level assuming a 45 degree spread of the load.

The test bed was set up on sleepers at various locations and loaded with concrete weights to approximately 50 tonnes dead weight. A 75 tonne jack with pressure gauges was used to apply a central load to the plates and deflection of the subgrade measured using two dial gauges accurate to 0.001 inches. (Plate 1)

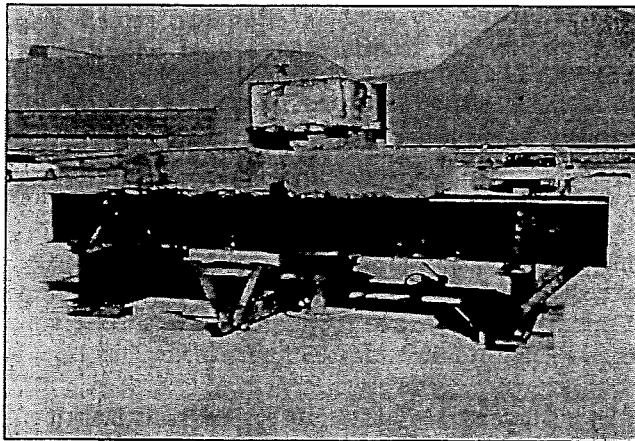


Plate 1: Test Bed

The maximum load applied equated to the full load of the loader at tipping point. The test plate was loaded and unloaded over several cycles to measure permanent deflections and rebound. A Geotechnical consultant (3) was engaged to interpret the results, which confirmed the design assumption of 'K'.

It was interesting to note that the 'K' values obtained from the larger rectangular plate were lower than that obtained from the smaller circular plate. This is attributed to the deeper zone of influence for the larger plate, but did not affect the design of the slab, which was based upon the 'K' determined from the circular plate.

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Confirmation of the design parameters fixed the slab thickness at 210mm, and the final design drawings were produced.

### **Field Installation of the Pavements**

The installation of the pavements proceeded as planned. Pour sizes varied between 800 and 1100 sqm. The entire floor area for the Bunbury Facility was completed in 5 pours.

With the subbase trimmed to grade and level, the edge beams were excavated with a mini excavator and hand trimmed. Along the edges abutting the wall foundations one side of the beam was poured, elsewhere the beam was poured insitu, without forming. The top surfaces were wood floated flush with the subbase to ensure that no lips were formed for the underside of the pavement to catch on.

With the sleeper beams complete, the edges of a slab panel were formed, with a section removed to allow access for trucks. Two layers of 200 micron plastic sheets were laid down and the edges lapped and taped. Finally screed rails were installed and leveled.

Concrete pours commenced early in the morning, and all concrete was poured direct from the transit mixer. After initial leveling, the concrete was compacted with 50mm immersion vibrators, following up with a vibrating screed passing at about 1.5m/minute. Surface evaporation retarders were used where appropriate, during leveling and screeding.

After steel trowelling of an area was completed, the slab was cut to a depth of 70mm on a 6m x 6m grid. This ensured shrinkage cracking at known locations. The surfaces were cured using a tilt panel bond breaker, formulated for concrete curing.

Forming and pouring of precast tilt up wall panels commenced the next day after the pour. Transit mixers were able to traverse the floor after 2 days.

### **Treatment of floor joints**

After erection of the wall panels, the joints were cleaned out using angle grinders, high-pressure water blasting, and wet vacuuming then allowed to dry. Inspection of the joints showed that the cracks had opened up approximately 1.5mm. This was less than the maximum of 2.4mm expected and attributed to the general increase in ambient temperature from winter to summer.

A low viscosity two part epoxy was then poured into the joints, and topped up until the cracks were full, as evidenced by residual epoxy in the bottom of the cut joint.

The following day, fine dry silica sand was brushed into the grooves and the epoxy added and topped up until the joint was full and the sand saturated with epoxy. The sand/epoxy mixture was left approximately 5mm below the finished surface.

### **Post inspection of floor joints**

In mid February 1998, after the Bunbury facility was in use, three 25mm cores were taken at random through the floor joints. Prior to coring, it was noted that no joints showed evidence of opening due to further shrinkage.

Where the cores intersected the shrinkage crack, significant penetration of the epoxy was in evidence. The cores were retrieved generally intact. It was noticed that some of the silica sand had not been completely saturated by the epoxy, these fines at the bottom of the cut groove had been lost during coring.

It was also noted that the perimeter footing had undergone shrinkage cracking as was evidenced by fine cracks at approximately 2m centres. The footings were tied to the slab to prevent sliding; as a result some of these cracks had propagated into the slab as hairlines. The length of these cracks in the slab was about 1m and not considered significant.

### **Discussion on the Comparative costs effectiveness of Fibre Reinforced Concrete and Conventional Reinforced Concrete Pavements**

The cost of a concrete reinforced pavement is determined by the cost of materials and by placement costs. Material costs are determined by the quantum of materials, which is defined by the pavement design, and the unit rate, which is influenced by the locality of supply. Placement costs are determined by the method of placement chosen and market plant and labour costs.

The design of a concrete pavement must satisfy various performance criteria including strength, toughness, permeability, durability, thermal and shrinkage movements and finished appearance. Cost effective design is achieved using an iterative approach to minimise total costs whilst achieving the desired performance requirements.

In any pavement design, there are diminishing returns, for example increasing the dosage rate of steel fibres or the strength of the concrete above an optimum will not result in a cost effective reduction in pavement thickness, or reduction in steel reinforcing content. Different steel fibres, dosage rates or concrete strengths will result in different pavement thickness. Spreadsheets can be an effective tool to optimise an effective design with relative ease and speed. An example can be seen in Table 4, below.

f'c	25 MPa		30 MPa		35 MPa		40 MPa	
	dosage KG/CM	't' mm	't' mm	\$/SQM	't' mm	\$/SQM	't' mm	\$/SQM
20	260	66.16	240	63.56	220	60.48	210	59.46
25	245	66.16	225	63.22	210	60.97	200	59.74
30	240	68.09	220	64.88	200	61.22	195	61.06
35	236	70.15	212	65.69	196	62.67	190	62.25
40	226	70.59	208	67.33	192	64.19	186	63.59

Table 4 : Evaluation of DRAMIX ® RC - 65/60 - BN fibre reinforced concrete pavements. Design loads as per Bunbury Port Authority facility.

In three localities that have been assessed by the author in Western Australia, steel fibre reinforced concrete pavements have proved to be cheaper, and quicker to install than conventionally reinforced concrete pavements of the same concrete strength( f'c trialed : 32MPa, 40MPa, 50MPa). Order of cost saving is about 10% order of time savings is 10% - 15%.

Translating these design concepts to other localities/states/countries will require iterative cost benefit approaches and similar costs analysis to that shown in Tables 2,3 and 4.

## CONCLUSIONS

### Tips and Tricks

Whilst the design and construction of the pavements proceeded generally as planned, the following are worth noting:

#### Tips

- Detail floor pours to maximise area per pour and minimise formed joints
- A firm subbase will ensure all concrete can be poured direct from the transit mixer. In addition, it gives easier early access for structural works. It will not increase the subbase 'K' value
- Wait as long as possible before filling the joints with epoxy
- Internal corners in the slab will still need re-entrant reinforcing bars
- Allow adequate mixing time in the transit mixer to ensure correct distribution of the fibres throughout the concrete
- For a good steel trowel finish, ensure that the vibrating screed is advanced slowly, to ensure fibres have a chance to settle below the surface
- Vacuum up the slurry from joint cutting operations immediately in a follow up operation, otherwise the slurry will flow back into the joint and harden, this will be difficult to remove at a later date

- K
- If filling the top of the cut joint with sand to bulk out the epoxy, use a coarse sand, as a fine sand will not allow epoxy to penetrate the full depth of the cut
  - An analysis of traffic patterns may allow refinement of the slab design, less repetitions translating to thinner floor slabs
  - Further analysis of performance requirements may allow deletion of the epoxy detail entirely, and substitute a flexible sealant

#### Tricks

- To apply the epoxy grout speedily, use a fine spout container and sit on a skateboard, moving backwards

#### Conclusion

Steel fibre reinforced concrete pavements can be an economic alternative to conventional reinforced concrete pavements, and have definite advantages in terms of speed and simplicity of construction.

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