

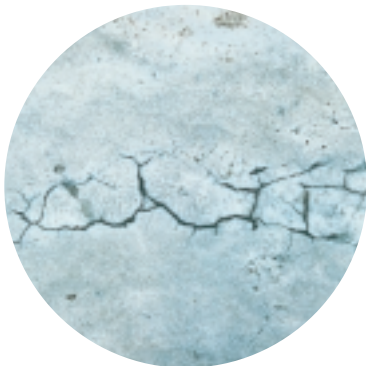
Industrial Floor Slabs: Patterns in Manufacture



Joint failure. Pallet stackers with solid tyres are causing the epoxy nosing to pull away from the adjacent 25MPa concrete.



Early thermal shock crack in exterior concrete slab. Note the slab run adjacent to the saw cuts suggesting the crack was present before the saw cutting operation.



Isolated crazed slab that is delaminating. Possibly lost surface type of delamination refer text for explanation.

A study of concrete floor slabs in industrial buildings, recently completed by CCANZ, aimed to identify consistent trends in the manufacture of successful and less successful examples.

The focus of this CCANZ research was on concrete floor slabs supported on the ground, used in industrial buildings. The aim of the study, which looked at samples from Auckland and Christchurch in order to establish whether there were differences in these two markets, was to identify any consistent trends between successful and less successful floor slabs, and then disseminate the information gained.

This article provides a short summary of the study's findings; a full copy of the study report is available on the CCANZ web site at www.cca.org.nz

The investigation was based on a pragmatic approach. The number of variables, the lack of some key information and limitations on research into some issues meant that a rigorous scientific methodology could not be adopted.

The approach taken was to survey the slabs, identify any defects and then examine whether there were common attributes associated with successful/unsuccessful manufacture.

Study Scope

Twelve industrial floor slabs were inspected in Christchurch, and 13 in Auckland. This is a small sample of the estimated 40 industrial buildings constructed in Christchurch per annum and 240 such buildings in Auckland. The Auckland slabs were predominantly constructed in 1999 and 2000, while the Christchurch study group consists of slabs constructed between 1995 and 2000.

The project selection process was based on data being available for the floor, and someone within the industry thinking that the survey team should look at it. While this non-scientific method of sampling does mean that there is likely to be some bias in the information gained, just looking at the 'interesting slabs' and disseminating the lessons learnt is of value to the industry.

The study identified the following trends:

- In Christchurch the most common defect was cracking. This defect is far more prevalent in Christchurch than it is in Auckland
- In Auckland the most common defect was delamination. This defect was rare in Christchurch.

Conclusions

The following points were concluded, accepting that the study has limitations in terms of scope (given the number of slabs and extent of examination):

1. A high quality concrete floor slab can be achieved with good design and construction technique.
2. Uncontrolled cracking is an issue that needs to be addressed particularly in the Christchurch market. It appears that the most common cause of cracking is restrained early thermal contraction, caused by lowering ambient temperatures during the first few days of the slab's life.
3. Early thermal contraction is not well understood, either by designers or constructors. There are a lack of guidelines about how to identify the risk of restrained thermal contraction cracking, and more research on this issue is required.
4. In the interim, until research can be conducted, it is suggested that precautions to prevent early thermal contraction cracking be taken if the slab is restrained and the ambient temperature is likely to drop more than 13°C over the 24 hours following finishing the slab.
5. Delamination appears to be a more significant issue in Auckland rather than Christchurch. However, delamination, when present, will typically be present in very isolated spots over an otherwise good floor slab. It has been estimated that only 0.05% of the surface area of all industrial floor slabs exhibit signs of delamination.
6. The potential for delamination appears to increase when the slab is poured in large areas, rather than in strips, and is finished using ride-on trowelling machines.
7. Greater care both in design and construction is required when the following variables are present. The greater the number of variables, the more knowledge and care required:
 - Low-bleed concretes;
 - Slabs poured in large areas rather than strips;
 - Slabs poured prior to erecting the building;
 - Use of ride-on trowelling machines;
 - Large day/night temperature variations.
8. The following probably increase the possibility of achieving a satisfactory end result:
 - A pre-pour meeting, with senior representatives from the designers, builders, placers, and ready mix suppliers present. The aim of the meeting should be to use the combined knowledge of those present to review the project, identify potential problem areas and develop a construction plan that minimises the exposure to risk.
 - If low-bleed concretes are used, specify the use of an anti-evaporator to reduce the potential for plastic cracking, surface crusting and commencing the trowelling operation too early.
 - Understand the importance of early age care, and take precautions to prevent early age restrained thermal contraction. These precautions might involve insulating the slab, the use of crack initiators or early entry saws.
 - Pour inside to eliminate some environmental variations.

A cartoon was developed for the report, to help visualise the variables associated with constructing a fit-for-purpose slab and their interaction. It is not exhaustive, but it does cover the main issues.



Hand trowelled section adjacent to the construction joint is considerably less durable than the rest of the slab. Bleed water/cement paste may have been mixed at edges.



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INDUSTRIAL FLOOR SLABS

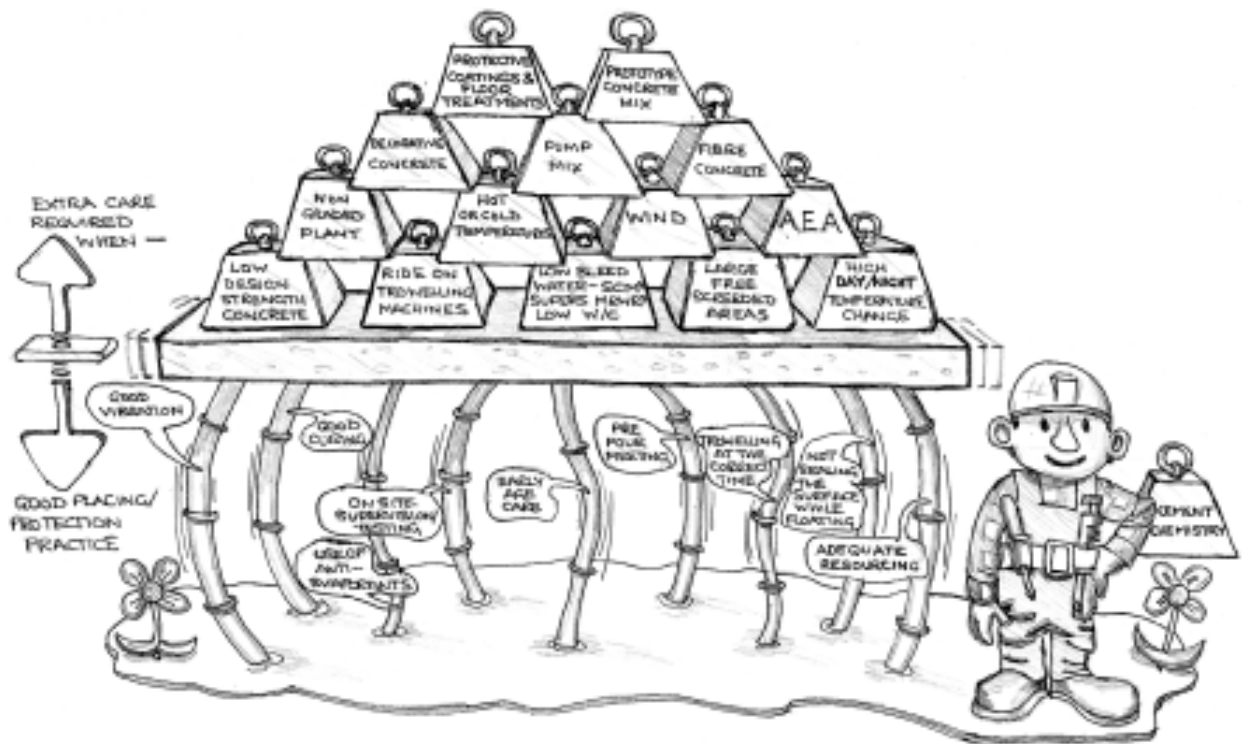
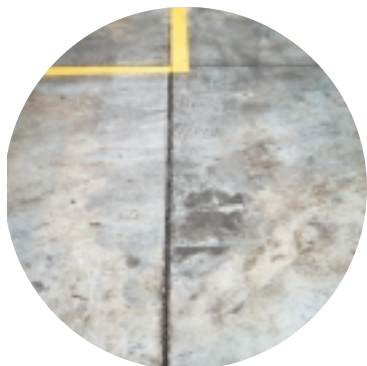


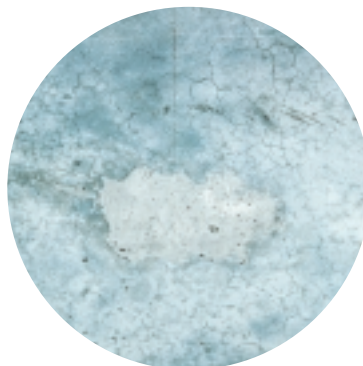
Figure 1 The variables that affect the outcome of the finished quality of a concrete industrial floor slab

The cartoon depicts a slab suspended on shaky poles. If the poles break, the slab falls - this is defined as a failure. A failure for a real slab might be unwanted cracks or a delaminating surface. We can prevent failure of the cartoon slab by making sure that the poles, which represent various placing and finishing practices, are strong enough. The strength of the pole is representative of the quality of the trade practice. Therefore, a strong pole equals good trade practice and a weak one, poor trade practice. The poles only have to be strong enough to support the weight of the slab, to ensure an adequate fit-for-purpose slab. If the weight is low, then a good end result might be achieved with less than perfect workmanship and with some of the less important poles missing. However, when the cartoon slab is heavy, all the poles need to be as strong as possible.

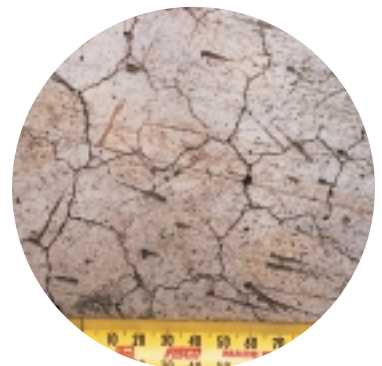
On the top of the cartoon slab are various weights. These represent conditions that impact on the probability of the slab failing. The weights are not necessarily undesirable, and in many instances there are good reasons for adopting them (such as economy and durability), but they do mean that additional care (stronger poles) will be required to ensure a good end result.



Grinding at slab edge to repair slab curl.



Area of delaminated slab which has been repaired.



Example of serious crazed cracking.

The weights are shown as equal size. The reality is that this is not the case. The relative importance of each weight will be project specific, but trying to show them as different sizes overly complicated the cartoon. The message is that those involved in the design and construction of the concrete floor slab must understand the significance of these variables. The report provides an explanation of how each variable affects the properties of concrete, and what additional care is required.

The report suggests that restrained early age thermal cracking is a significant cause of cracking in Christchurch. Figures 2 and 3 provide some explanation why this cracking is more prevalent in Christchurch than Auckland.

The figures show that the maximum daily temperature variation (Figure 2) and the monthly average daily temperature variation (Figure 3) are largest in Christchurch. There appears to have been little research conducted to quantify the critical temperature drop that will cause cracking due to restrained thermal contraction. It is a complex issue as wind chilling, creep characteristic of the concrete, soil temperature, curing technique, and temperature gradients in the concrete are all likely to be important variables. However, a rule of thumb often mentioned is that there is a risk of restrained thermal contraction cracking if the temperature drop exceeds 10 to 15°C in the 24 hours after finishing.

It is interesting to conduct some statistical analysis on the three years of temperature data. Assuming that the data is normally distributed, it is possible to calculate the annual probability that the daily temperature difference exceeds key values in Auckland and Christchurch. The following table summarises this analysis.

Table: Calculated Probability of Exceeding Daily Temperature Variation		
Daily Temperature Variation °C	Probability of Exceeding	
	Auckland	Christchurch
10	0.132	0.56
13	0.011	0.32
15	0.001	0.19

A crude interpretation of the above data would suggest that if the critical temperature to cause cracking due to early age restrained thermal contraction is between 10 and 15°C, we would expect to see 4 to 190 times greater number of early aged cracks in Christchurch than in Auckland.

Summary

The study, although pragmatic in approach, provided a good insight into the construction of industrial floor slabs in Auckland and Christchurch. It is recommended that those involved in this industry read the full report on the CCANZ web site. The study observed that a high quality fit-for-purpose slab can be achieved. The probability of a successful outcome is increased when all parties understand the required end result and the best techniques to achieve them.

Figure 2 Maximum daily temperature variation (1998-2000) by month for Auckland and Christchurch

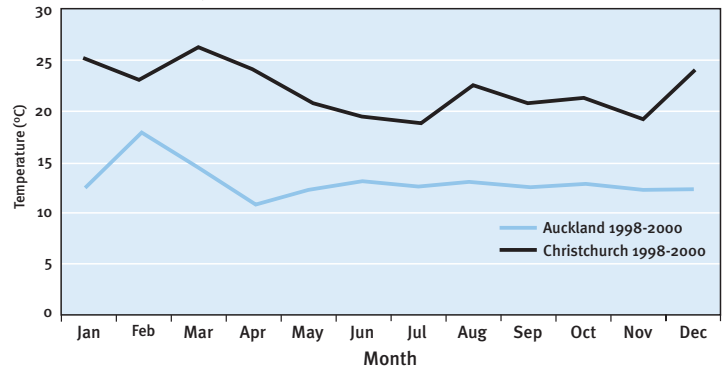


Figure 3 Average daily temperature variation (1998-2000) by month for Auckland and Christchurch

