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Cost factors affecting the design of ground-supported floors

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Abstract

The cost of concrete ground-supported floor slabs represents a significant proportion of the total capital cost of industrial projects. There are many structural design issues that impact on the concrete contractors’ method of construction. This is becoming more apparent with the use of new high-technology levelling and trowelling equipment, which has significantly increased the pour and finishing rates, resulting in much faster slab construction times compared with the traditional methods of construction. Selection of both the design and the construction methods exerts a large influence on the initial cost. According to the results of the research reported in this paper, it may be possible to save between 2-4 per cent of the building cost if high technology solutions are incorporated into the design and construction process. This paper investigates cost issues that impact on the design and construction of ground-supported floors for industrial buildings.

Keyword(s): Construction industry; Concrete; Design; Industrial design.

Introduction

In a study of technological advances in construction, Arditi et al. (1997) make the observation that a great number of productivity gains have been produced by improved construction equipment. The research investigated the development of new models of construction equipment over a 30-year period. The results of the work suggest that the technological changes now exert a large influence on the overall productivity of the construction process.

Arditi et al. (1997) argue that construction contractors are continually seeking more advanced equipment in an effort to increase their profits, and to differentiate themselves from other competitors. The research indicates that this group is driving a significant proportion of innovation in the construction industry. In addition, this places pressure on engineering designers to keep pace with the advances in technology used by construction contractors.

Many designers lack the experience to understand how the decisions they make will affect site operations. According to Jergeas and Van der Put (2001, p. 284), “they perceive contractors as ‘doers’ who would be unable to articulately contribute to the planning and design effort”. At the same time, many contractors are uncomfortable with office environments, and may be reluctant to contribute their ideas. As a result there appears to be a gap between the perceptions of designers and contractors in the design
and construction of industrial floors. The factors include (Jergeas and Van der Put, 2001):

- lack of mutual trust, respect and credibility between designers and contractors;
- traditional contracting practices that bring the contractors into the project only after the design has been completed; and
- lack of desire by owners to commit funds and resources to implement “constructability” processes.

The cost of industrial warehouse floor slabs typically represents between 11-13 per cent of the total cost of the building (Rawlinson, 2002), and a significant proportion of the cost is associated with the construction, location and length of the designed construction joints. The authors have been observing industrial ground slab construction techniques for over ten years. It has become obvious that the use of modern construction equipment has made significant changes to the manner in which slabs are poured and finished. The productivity gains have greatly reduced the time and cost associated with the construction process.

It was suggested by one of the interviewees for the research reported in this paper that labour savings of about one-third are possible due to improved construction efficiencies. According to Rawlinson (1994), the labour component represents 15-20 per cent of the construction cost of the floor slab. In addition, the reduction in the overall construction time can provide further knock-on cost savings, which may increase the total to 2-4 per cent of building cost. The authors acknowledge that the cost savings will vary for each construction project, however, it is believed that the cost-efficiencies of high technology floor slabs are significant.

Many concrete contractors in Australia have recently purchased, from abroad, a range of high-technology equipment; this has been to keep them competitive in their portion of the ground slab market. The selection and quantity of equipment necessary vary in accordance with the pour areas and finishes required in their market sector. Some of the high-technology equipment items include; ride-on-helicopter trowelling machines, vibrating truss-type screeds, pizza pan trays for early trowelling, and laser-guided automatic trowelling machines.

Further detailed analysis of a range of case study projects with varying floor areas with appropriate costing may in the near future provide some definitive answers to the issues raised in this paper. However, one contractor referred to the example of a warehouse slab constructed a few years ago, with a floor area of 6,000m². Poured in the long strip method, construction of the slabs over 23 pours took 28 working days. Current pour capability could now complete the same total floor area in four pours over an eight-day duration. This represents a reduction of 20 days (28 days – 8 days). The reduced slab construction durations are more significant for large warehouses with floor areas in excess of 20,000m². In addition, since the completion date of most industrial ground slabs is on the critical path programme for the project, substantial time-savings will result.

However, despite the improvement in construction technology there appears to be little change in the engineering design process. This suggests that engineering designs for
pour layouts may be trailing the innovations introduced by the contracting industry. This preliminary research has been based on interviews with engineers and contractors engaged in design and construction of ground slabs for large warehouse buildings. The aim of the research is to determine the factors that impact on the cost of the ground-supported floors, in order to identify the gap between the design and construction process.

**Existing engineering design considerations**

According to Garber (1991), floors are responsible for more complaints than any other building element except roofs. He suggests that good floors exist, but that they seldom occur by accident, and that good floor design requires equal attention to five factors; floor usage, structural strength, properties of the concrete used, cracks and joints, and properties of the floor surface.

Floors in industrial buildings, like warehouses, are typically very large and are most often ground-supported. These characteristics have created an environment where new construction equipment has significantly improved the concrete pour and finishing rates of the slab. As a result of better productivity the cost of the floor slabs can be reduced significantly, when modern equipment is used. However, engineering designers have been slow to appreciate the advances in construction technology. They are cautious about changing from their traditional design solutions, in particular the use of large bays that reduce construction joints and construction time. According to Garber (1991), there are essentially four ways (see Table I) to construct large ground-supported floor areas.

**Large bay and joint design**

Contraction joints are designed to induce the cracking of concrete in a planned manner. The effect of a joint is to concentrate large deformations in a localised region (i.e. the joint) and hence prevent the severe cracking that would otherwise occur (Rangan and Warner, 1996). It is generally not possible to construct large areas of concrete floors without any joints; however, joints are a potential source of trouble, due to deterioration (fretting) of the edges. Unfortunately, a probable alternative to the provision of joints is the formation of cracks. Thus the aim of most slab design is to reduce joints to a minimum. Apart from construction problems, there are significant disadvantages to the use of joints. These include (Rangan and Warner, 1996):

- increased construction time;
- increased construction cost;
- disturbance of visual homogeneity of slabs;
- expensive maintenance;
- decreased stiffness, leading to vibration; and
- increased permeability for gases and liquids.

Thus, according to Rangan and Warner (1996, p. 248), designers should always consider the feasibility of using as few joints as possible. However, from the engineer’s perspective, the more pour joints and more shrinkage control joints that are provided,
the better the crack control. Nevertheless, joints do add considerably to the cost and limit the area of slab pours.

In general the joint can be formed or can be saw-cut. Sawing can be cheaper than forming, but the incentive for sawed joints is that it produces a neater and more durable joint. Sawing is the better choice for floors that need to be flat, because it has virtually no effect on surface regularity. This is particularly useful for large industrial floors such as those in warehouses (Garber, 1991).

Take, for example, a typical warehouse with a floor area of 6,000m², 100m long × 60m wide.

The conventional long strip method of pouring (50m long × 6m wide) would contain approximately 960m of formed construction joints and 540m of saw-cut joints. The large area pour method (50m long × 30m wide) now favoured by the concrete contractors would contain approximately 150m of formed construction joints and 880m of saw-cut joints. Formed joints are reduced by 810m (960m - 150m), but the cheaper saw-cut joints increases by 340m (540m to 880m), the overall saving is still substantial. This represents a significant reduction in joint costs alone apart from the economies of other labour and time savings associated with large area pours.

The larger area pours have fewer of the expensive construction (pour) joints overall which can result in considerable cost savings. Similarly, typical large area pours contain a larger portion of the more economical saw-cut joints in the slab in both directions.

**Design and planning of joint locations**

With high storage racking the resulting point loads are likely to be a major factor in the design of the floor slab. It is of the greatest importance for the designer to have complete information on the anticipated moving and static loads on the floor. The load-carrying capacity of the concrete will be reduced if the point loads from the high racking are near the saw-cuts or formed joints. Thus the layout of the racking system needs to be known at the design stage for maximum economy in design (Perkins, 1993).

The ideal way to design a warehouse floor is to tailor it to the specific storage and material-handling system that will be used. This not only ensures that the floor will be fit for the purpose, but also keeps the cost down. The most costly component of the joint system can be confined to those parts of the floor that really need them. However, this is not always possible, because many warehouse users demand a degree of flexibility. It is often the case that the designer does not know the user of the building, much less the specific design loads (Garber, 1991).

The solution appears to be a load class system, which provides a way to standardise assumptions. There are four categories of loading; light, medium, heavy, and very heavy (Garber, 1991). However, the system deals only with the load and thus structural design, it does not address other important issues such as; joints and cracks, surface regularity, and wear resistance. Designers must still make judgements on these issues (Garber, 1991).
The structural design and detailing of joints and layout for industrial ground slabs have a significant impact on the cost of construction of ground slabs. However, there is doubt that engineering designers sufficiently investigate the factors that impact on the total cost of the slabs including joint formation and repair maintenance for large area industrial floors. Consequently, research into the economics of structural ground slab construction was considered to be an important area of research. The research question was to investigate “What are the factors that impact on the total cost of industrial ground-supported slabs?”

Data collection methodology

From past literature and from observations made by the authors it has become clear that many industrial ground slabs have not been designed with the use of modern pouring and finishing technology in mind. However, it was not clear if this was the result of issues related to the design or construction process. So it was decided that both engineering designers and concrete contractors should be interviewed.

Owing to the depth of information required in this research the use of interviews was considered necessary. Interviewing is often the best approach to obtain exploratory information, as the respondents can be probed more fully than other types of data collection process, e.g. surveys. Both semi-structured and unstructured interviews have been postulated as suitable techniques for obtaining preliminary information. In this case, semi-structured interviews were considered more appropriate for the research. The semi-structured interviews provided a useful method to investigate the impact of changing technology on the design and cost of industrial floor slabs.

During the interviews, each respondent group (engineers and contractors) was asked a similar set of questions, and then given the opportunity to expand and/or develop their thoughts on the factors affecting their decisions. This was considered the most appropriate mechanism for eliciting the knowledge of the experts. Interviewees were obtained from private contacts. A sample of six people was selected for the interviews. The participating organisations consisted of three construction contractors and three engineering designers. The results of the interviews are presented below.

Concrete pouring and finishing: the contractor’s view

Contractors stated that the last few years have seen major improvements in the standard of surface finish, and surface tolerances. In addition, the areas of slab that can be successfully completed in one day have been greatly increased. These major advances have been achieved with the use of this high-technology equipment and skilled operators for their efficient use. The major improvements that have direct cost implications for ground slabs include:

- uniform setting rates;
- consistent delivery times;
- reduced shrinkage characteristics;
- specialised mix designs for steel fibre reinforced concrete; and
- improved joint technology that reduces installation costs.
According to the contractors interviewed, there have been significant advances in concrete admixtures as well as improvements in the supply of the actual concrete product. Concrete suppliers can now provide concrete mixes with uniform setting rates and more consistent slumps. These items are crucial in allowing the concrete contractors to trowel and finish the slab surface to the hard burnish finish now required by the occupiers. The more economical larger pour areas (in excess of 1,200m²) could not be finished without uniform setting rates and consistent slump concrete.

Contractors indicated that better transport management and consultation with the concrete suppliers on the frequency of delivery have improved the erratic delivery times of the past. Consistent delivery times go hand-in-hand with setting and slumps rates. Mobile phone communication from contractor direct to the concrete plant and two-way communication with delivery trucks further assist delivery consistency.

Slab pour areas and the final panel sizes (determined by joint spacings) have been progressively increasing. As previously mentioned, the engineering concern is primarily to control random cracking from occurring within the individual panels caused mainly by concrete shrinkage. However, contractors believe that refined concrete mixes and the use of water-reducing or shrinkage reduction admixtures have lessened the shrinkage characteristics of the concrete, allowing the engineers to increase the joint spacings and thereby reduce joint costs.

Some of the advantages of steel fibre reinforced concrete ground slabs have been highlighted earlier. Contractors indicated that there seems to be a reluctance by designers to specify the specialised concrete mix designs that are required for steel fibre reinforced designs to gain their full advantages. Once plastic shrinkage of the concrete is reduced, it allows the joint spacings to be increased, thereby reducing joint costs even further. Detailed technical explanations of this concrete design are beyond the scope of this paper; suffice it to say contractors indicated that savings that are possible for large ground-supported floors are significant to the client.

According to the contractors interviewed, new joint hardware products have been introduced – such as flat plate dowels and diamond dowels – both of which have the potential to reduce overall slab costs by allowing the concrete contractor to pour larger areas in one day (for greater economy). These new hardware products provide a much-improved solution, where previous products were very site/labour-sensitive and inaccurate installation often exceeded the construction tolerances specified by the engineer. Contractors commented that this issue contributed substantially to joint failure and high repair maintenance costs. In addition, any reduction in maintenance costs is beneficial to the building owner.

Contractors said that they purchase high-technology equipment at considerable financial outlay, and this has meant that they are restricted to larger area pours for efficiency. These contractors do not generally like quoting for or constructing the smaller long strip-type pours, where their new equipment is not suitable or efficient. The next section of this paper considers the views of engineering designers.
The designers: the engineer's view

According to the engineers interviewed, the principles of structural design of industrial ground slabs has changed little over the past ten or so years. However, they commented that their repeat clients are questioning the increased thickness of ground slabs in comparison with their previous projects. This is due mainly to a newer but more conservative design guide (CCAA, 1997). Engineers believe that they are hindered in their design approach by:

- compliance with increasingly more conservative design guides;
- lack of accurate client design loads and racking layouts;
- not knowing the concrete contractor’s capacity with respect to slab pour area capability; and
- evaluation and acceptance of new joint hardware products.

According to the engineers interviewed, the recent construction of steel fibre reinforced concrete ground slabs, as an alternative to the more traditional steel fabric reinforced slabs, has been the most significant change. Specific steel fibre computer programs normally provide thinner slabs under the same load conditions. The reduced cost from the thinner slabs (typically from 200mm down to 150mm) from less concrete is, however, negated by the increased cost of the steel fibre reinforcement and the additional barrel-mixing time at the plant.

The engineers suggested that they face further problems in designing the optimum and most cost-effective ground slab design when developers are their clients and the loading conditions on the slab of the end-user are not known. A standard loading and design solution needs to be adopted and this does not produce the most economical solution. Developers often do not know the warehouse racking layout of the future tenant and joints normally located under the racking system are more likely to be located in trafficable, areas where maintenance costs of joints are high.

Often the engineer at the design stage has no indication who the successful concrete contractor will be on the project. This indicates that it is unlikely that the capacity of the successful contractor can be known, particularly in terms of their ability to pour and finish slabs. As a result, engineers said that they generally prefer to adopt the low technology long strip method of pouring slabs (see Table I), comprising areas of approximately 300m². This is well within the limits of most of the industrial concrete contractor's capability but, as described previously, is not the most economical layout for pours, particularly for the contractors with larger crews and better equipment.

Design of joints: the engineer's view

During the interviews engineering designers suggested that long-term maintenance costs of joints are rarely considered. A generalised slab design is often considered by engineers to be of minor significance in comparison to the total structural design package for typical warehouse buildings. This is particularly valid when property developers are the clients. Some joints may be given extra attention and detailing when specific floor loads and rack layouts are known.
All joint types can incur substantial costs associated with long-term maintenance. Joint repair techniques vary but the channel cut-out repairs, typically used where the edges of the joint have failed or broken away, are always wider than the original joint. These repairs invariably are a different colour from the original concrete surface and, with typical repair widths of 100mm or greater, look unsightly and detract from the building’s capital value. Future tenants or owners may downgrade the value of the building and consider that the slab has structurally failed, even if it has not.

According to the engineers interviewed, there is extreme pressure on them to reduce their design fees. Lower fees can lead to reduced site supervision, particularly for ground slabs. Formed construction joints are critical to the long-term performance of the slab and these joints are very sensitive to accurate set-ups and placement of reinforcement, as before described. There are several problems facing the engineer related to slab joint types, locations and costs, which including the quality control on-site that can lead to high repair costs.

The results above indicate that many of the high-technology solutions may not be appropriate at the time the design is undertaken. Engineers believe that it is possible that the traditional design-bid-build procurement arrangement limits construction innovation for industrial ground-supported floors.

**Conclusion**

This paper has highlighted some of the issues confronting both the design engineer and the concrete contractor in striving for the most economical solution for the construction of industrial ground slabs. Cost-effective solutions require co-ordinated input from all stakeholders involved in the design and construction phases. The research question investigated was “What are the factors that impact on the total cost of industrial ground slabs?”

The issues affecting the design and construction of industrial ground slabs have been discussed. The results of the interviews indicate that designers and contractors have divergent views in a number of areas. Some of the comments made indicate that a gap exists between the perceived role of the designers and contractors. Table II contrasts some of the typical views expressed.

This raises the question as to whether the design engineers are taking this into account in ascertaining the most cost-effective solution for the ground slab component. This research supports the work by Jergeas and Van der Put (2001, p. 286), which suggests that designers must “be willing to challenge the ‘tried-and-true’ methods, and try new approaches in the interest of achieving significant gains in project cost, schedule performance and safety”. However, it is obvious that some of the issues related to the efficiency of the design are outside the control of the engineering designers.

Nevertheless, it is clear from the results of the semi-structured interviews that the significant potential benefit in terms of productivity gains and cost savings is lost on many construction projects because of the gap between designers and constructors. One
of the main conclusions of this research is that this gap must be bridged by a closer integration of the above two groups. The use of “constructability processes”, suggested by Fischer and Tatum (1997) and Jergeas and Van der Put (2001), seems to have some merit and could form the basis of future research.

In addition, this research suggests that owners of industrial buildings have much to gain from forming alliances with contractors who have the ability to construct high-technology ground-supported slabs. This is particularly important for owners like supermarket chains, parts distribution companies and the postal service that are continually building large industrial buildings.

The owners of large industrial buildings should be willing to cast aside the traditional design-bid-build contracting philosophy in favour of an approach that brings the construction contractor into the design. This requires fostering close cooperation between the project participants with each pooling their knowledge and resources to achieve mutual trust.

### Table I: Construction methods for ground-supported slabs

<table>
<thead>
<tr>
<th>Bay and joint type</th>
<th>Reinforcement</th>
<th>Technology level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Conventional “long-strip” methods</td>
<td>Fabric</td>
<td>Low</td>
</tr>
<tr>
<td>2. Large bays with minimum joints</td>
<td>Fabric or bar reinforcement</td>
<td>Medium</td>
</tr>
<tr>
<td>3. Large bays with minimum joints</td>
<td>Randomly dispersed steel/polypropylene fibres</td>
<td>High</td>
</tr>
<tr>
<td>4. Large bays with minimum joints</td>
<td>Post-tensioning</td>
<td>High</td>
</tr>
</tbody>
</table>

### Table II: Typical comments by designers and contractors concerning the ground-supported floors

<table>
<thead>
<tr>
<th>Designers’ comments</th>
<th>Contractors’ comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>The successful contractor is not known at the design stage</td>
<td>Lack of appreciation of new pouring and finishing technologies</td>
</tr>
<tr>
<td>Conservative engineering codes discourage leading-edge designs</td>
<td>Concrete mix technology improves shrinkage characteristics</td>
</tr>
<tr>
<td>The rack design required by the occupier is often not known during the design</td>
<td>Reluctance to use bespoke designs for large-bay, ground-supported floors</td>
</tr>
</tbody>
</table>

### Table III: Typical comments by designers and contractors concerning the ground-supported floors
References


