INNOVATIVE CONNECTING SYSTEM FOR PRECAST CONCRETE PLANKS ON A MAJOR SPORTS STADIUM

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ABSTRACT

Close integration of supply and design enabled the delivery of major material and labour cost savings at Suncorp Stadium in Brisbane. An integrated documentation and construction contract format permitted the use of polystyrene voided concrete planks with reliable composite connections to supporting steel beams. This system was substituted for in situ concrete beams and slabs previously assessed as the lowest cost option by the project quantity surveyor. A development of technology previously used in bridge building, the "Clever Plank" system allowed the elimination of in situ formwork with its attendant time, cost and safety disadvantages. Robust linkages were achieved between the supplier and the central project participants. Confidence in the detailed design enabled the production of the planks to commence before full testing of the prototype for code compliance was complete. This project represents an example of efficiencies achieved by minimising "flow activities" and concentrating on value-added "conversions" in accordance with lean production principles.

KEY WORDS

Precast concrete, Composite connections, Innovation.

INTRODUCTION

The BRITE Project (Building Research Innovation Technology and Environment) was established by the Australian Cooperative Research Centre for Construction Innovation to foster the incidence and quality of innovation in the Australian Property and Construction Industry. The project seeks to redress industry scepticism about the benefits of innovation through demonstration and benchmarking activities. Case studies of successful innovations are recounted and this information is widely disseminated in the industry and the broader community. The case studies are intended to demonstrate best practice and contribute to the enhancement of industry capabilities. Among the six case studies produced in 2004 was one on the precast plank system used for the redevelopment of Lang Park, now known as Suncorp Stadium in Brisbane. This case study demonstrates an approach compatible with lean construction principles. Through the close integration of supply and design activity, savings were made in cost and time parameters while at the same time reducing the occupational health and safety risks associated with the construction. The form of contract and the strong linkages between the precast supplier and the other project participants enabled the adaptation of a technology previously used in bridge building for use in a sports stadium. The engineer's calculations and the supplier's experience enabled them to have confidence in the solution produced to the extent that they were able to commence production of the precast planks for the stadium before full testing of the prototype was complete. Construction time was shortened with no loss of quality or safety. Responsibility for monitoring the process was shared by the contractor, the supplier and the consultants. This enabled the lean construction principle of minimising flow activities while maximising value-

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added transformations to be put into practice (Alarcon 1997).

CASE STUDY

Suncorp Stadium is a 52,500 seat modern football stadium constructed as a redevelopment on the site of the rundown and inadequately serviced Lang Park football ground formerly known as "the Cauldron" in Brisbane, Queensland (see Figure 1 overleaf). The project was constructed by a private sector joint venture under a managing contractor. The procurement system was a two stage, document and construct contract with a guaranteed maximum price. As the name implies, a document and construct contract does not include initial design concept but does involve the full documentation of the project under the management of a head contractor. Such a contract allows the flexibility for new construction solutions to be introduced by the builder, who is not limited by the technical systems envisioned by the concept designer.

The stadium opened in July 2003 and was delivered on time and within budget. Both the organisational and the technological systems that were followed enhanced the need for innovative solutions. Risks and benefits were managed for a more equitable sharing than would have occurred through a traditional procurement process. This enabled the main contractor to develop innovative technical solutions not envisaged in the concept design which produced both cost and time economies.

INFLUENCE OF PROCUREMENT FORM

The traditional system of building procurement and the attitudes associated with it can form an impediment to the introduction of innovative ideas and products inhibiting the spread of lean construction principles. Both top down and bottom up innovations are hindered by the prevailing theory of construction (Koskela and Vrijhoef 2000). Top down innovation can be prevented by the split authority paths and lack of supply chain integration often seen in construction projects. Bottom up innovation can be stopped by lack of incentive for project based workers to produce gains from which they do not themselves derive benefit and by the failure to collect information learned on one project for use in future projects.

Contractual systems are being developed which address some of these difficulties an attempt to make the building delivery process more efficient. Currently a transition phase exists between the traditional contractual system with its competitive

Figure 1: Suncorp Stadium Photo Montage (Image copyright Ken Keefer provided by Arup)

and adversarial base and new hybrid procurement systems which attempt to share both benefits and risks more equitably (Pryke 2004).

The development of the precast plank composite construction solution for Suncorp Stadium arose in part from the opportunities for designer and contractor interaction inherent in the procurement system adopted for the project. Under the "Document and Construct" contract used, the joint venture contractors were encouraged to look for alternative forms of construction rather than being restricted by those envisaged by the concept designer. This is in contrast to the traditional lump sum fully documented type contract where generally all design decisions are made before the contractor becomes involved. In this case, the preliminary stadium design envisaged conventionally formed in-situ reinforced concrete beams and slabs. This had been assessed by the project's quantity surveyor as the lowest cost option. When the joint venture contractors were appointed they chose to pursue the idea of a composite steel beam and plank design based on the likely advantages related to construction time and risk management of the subcontractors. Consulting engineers investigated the feasibility of the composite approach and found that while the components were more expensive for the beam and plank composite construction, the savings resulting from the lack of formwork and scaffolding were considerable. It was this factor that eventually influenced the decision to adopt the composite system. The contractor's interest in achieving savings was driven by the form of contract which allowed for the sharing of the benefits if the project was delivered below its guaranteed maximum price. This contractual arrangement created an atmosphere where innovative solutions were explored and embraced.

CLOSE INTEGRATION OF DESIGN AND SUPPLY

The value adding and time savings that result from following lean construction principles can be illustrated through the Suncorp Stadium case study. The consulting engineers and the supplier worked closely together to produce a solution that met the performance criteria for the stadium by a means not previously used in such structures in Australia. The two main elements of this system—the polystyrene voided planks and the formed rebate detail—have only been combined to our knowledge on a few occasions globally in the building industry. The particular planks supplied for the project and the particular rebate detail designed by the engineer are unique to the Stadium project and have resulted in substantial benefits (Manley 2004). Discussions between the consulting engineers and the supplier resulted in a solution achieving considerable benefits over the use of in-situ reinforced concrete slabs and beams. The composite system chosen generated savings of A$260,000 in steelwork costs (equating to approximately 8% of the steelwork cost) and A$70,000 in labour costs when compared to precast concrete voided planks with conventional connections to steel beams. The use of these voided precast "clever planks" reduced the weight of the Stadium grandstand steel floor beams by approximately 25% due to the efficiencies generated by the composite connection between beams and planks. The connection detail enabled the concrete topping to be placed free of cracks and consequently removed the need for rework to repair cracks. The time savings made contributed to the successful delivery of the project on time and within budget after a two year documentation and construction program.

ROBUST LINKAGES

The integration of the supply chain achieved in this project provided significant dividends for all participants. The nature of the contract and the robust connections between consultants and suppliers enabled the production of a mutually beneficial solution and allowed a local Australian firm to become a global technology leader. Traditionally Australian construction industry supply chains have been fragmented and lacking in clear commitment to the success of the overall project. Often individual firms in the supply chain practise defensive blame shifting to minimise their own level of risk (Miller et al. 2002). This situation is widely perceived as unsatisfactory and supply chain integration is seen by several authors as a useful strategy for the construction industry (Arbulu et al. 2003; Briscoe et al. 2004; Dainty et al. 2001a; Dainty et al. 2001b; Hollingworth 2002; London and Kenley 2001; Nicolini et al. 2001; Palaneeswaran et al. 2003). In the case of Suncorp Stadium, the relationships between the precast plank supplier, the consulting engineers and the main contractor were sufficiently integrated to permit the exploration and selection of an innovative construction solution to the benefit of all concerned.

ADAPTIVE DEVELOPMENT OF BRIDGE TECHNOLOGY

A study of the steel and precast plank options identified significant potential savings if a reliable method of achieving a composite connection between the planks and beams could be found. There would be a considerable saving in the weight of the steel beams required and therefore their cost and associated supporting structure. Such systems were known to be used in bridge construction and after extensive research, the engineers devised an innovative rebate design for the planks which would enable a composite connection in the proposed structure. Formed rebates in the precast plank edge allowed for a solid and reliable connection to the supporting steelwork (see figs. 2 & 3). By extrapolating from available theory and existing codes the engineers calculated the theoretical capacity of the composite joints. They arranged for the testing of a full scale prototype of the system to verify the accuracy of their calculations. This testing was done by the School of Civil Engineering at Queensland University of Technology (Davies 2002). The exigencies of the construction program, however, necessitated that the manufacture of the planks should commence before the prototype testing was complete. As the designers were confident that the results would be positive, manufacture was commenced prior to the completion of the testing. Subsequent testing verified their confidence as has the performance of the planks and composite connections in operation in the stadium. There has been no evidence of movement, nor any need for rework to repair cracking in the concrete topping.

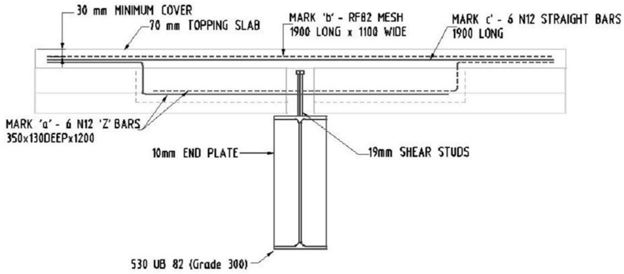

Figure 2: Detail of Composite Connection (Source S. Davies, Arup)

The testing of the prototype planks can be seen as a "flow" activity. Such "flow activities" do not necessarily add value to the project. As Ballard and Howell (2004) explain, flow activities can lead to "work waiting on workers" or "workers waiting on work". Progress can be impeded even if construction methods are adequate. Careful work scheduling is essential if potential savings are not to be lost. The confidence that the design engineers had in their own analysis of the structural performance of the composite system was

Figure 3: Precast planks being placed ready for composite connection (Source S. Davies, Arup)

such that they were able to take the risk of proceeding before full confirmation of the measurable performance of the prototype system was available. The decision to manage early production and prototype testing as parallel processes was a conscious effort to maximise the efficient delivery of the en product to the client. As Bertelsen (2004) points out "construction is a special kind of production" and that a change is afoot where construction is moving from an activity process to a system for delivering a product. This shift in focus is driven by more robust linkages between the various players in the construction process and by a need for the efficiencies that supply chain integration is able to produce (Love et al. 2004).

REMOVAL OF THE FORMWORK TRADE

Formwork for reinforced concrete is both material and labour intensive. The advantages of removing the need for formwork included a less congested construction site without the large number of workers required to produce in-situ formwork and the resulting reduced car parking and concrete truck access problems in an inner city location. In addition, the risk of concreter delays or disputes which could hold up the work of the following trades were minimised or eliminated. Past history of industrial action in the highly unionised concreting trades was influential in the decision-making process. The areas under the grandstands were able to be kept free of temporary propping necessary for formwork so later trades did not have to deal with restricted access caused by propping obstructions. Finally, in-situ concrete pours involve a relatively high level of occupational health and safety risk. The potential for formwork collapse during pouring is something that requires considerable input in terms of quality control and checking to ensure that reinforcement is correctly placed and plywood forms and supporting structures are adequately propped during the pour. Transferring large parts of the quality control issue offsite to a factory location where the precast planks were manufactured enabled easier and more satisfactory levels of control which enabled performance standards to be guaranteed by the supplier.

Of course such advantages could have been gained through use of precasting in a more conventional and non-composite construction

Figure 4: Stadium under construction (Source S. Davies, Arup)

system, but the consulting engineers looked beyond the possible savings in the formwork trades in response to the contractor's quest to achieve greater savings.

LEAN CONSTRUCTION

As defined by Alarcon (1997) "Lean Construction" involves project management to minimise "flow" activities or those which do not add value to the project while maximising those "transformations" which do add value. Lean construction principles grew out of the lean production theory initially developed by Ohno at the Toyota Motor Car Company (Ohno 1988). The Toyota Production System involved achieving continuous production flow through monitoring measures which reduced inventory and were capable of rapid response (Conte and Gransberg 2001). These ideas were applied to construction through the work of Koskela (Koskela 1992). Koskela emphasised the importance of production process flow and the need to characterise the process by its propensity to add value. Ballard and Howell have defined the four roots of a lean construction approach to be: the Toyota Production System; dissatisfaction with project performance; establishing a theoretical foundation for project management; and the discovery of facts that current practice finds impossible to explain (Ballard and Howell 2004). While the theory of lean construction has developed a significant following among construction academics and some practitioners it has yet to be thoroughly embraced throughout the industry as a whole. Where lean construction is occurring the principles of lean construction are often adopted implicitly rather than explicitly. The case study described in this paper is an example of lean principles being practiced without any explicit adopting of the theory by those involved in the construction process.

The experience on Suncorp Stadium serves as an illustration of the achievements that are possible in a lean construction atmosphere. While the participants did not set out to apply lean production theory to construction practice they have, nevertheless implicitly understood the need to minimise non value adding activities and maximise the kinds of transformations that deliver a satisfactory end product to the client. This confirms that lean production principles can be put into place without explicit adoption of lean construction theory. As Howell explains lean construction aims to meet customer needs while using less resources (Howell 1999). As such, it is entirely compatible with systems that aim to improve the quality of the delivered product to the consumer and the public generally.

The issue of the relationship between lean construction and human resource management has been raised by (Green 2002). He suggests that lean construction will repeat the mistakes of "previous instrumentalist improvement recipes" if it fails to give considered attention to this area. The construction industry has not tended to be an industry that encouraged suggestions and contributions from all levels of its participants. Its nature has been very largely hierarchical. Innovation theory, however, is making impacts in this structure and more construction companies are seeing the benefit of encouraging an atmosphere where new ideas are welcomed rather than suppressed (Bossink 2004; Gann 2000; Slaughter 2000). Such organisations are seeking a balance between production efficiency and human resource management. It would appear that there is no reason why lean construction principles cannot incorporate such a balance.

CONCLUSION

The Suncorp Stadium project is evidence of the significant savings in both labour and materials that can be achieved through the integration of supply and design. The procurement system adopted by the client enabled the consideration and incorporation of innovative construction solutions that were not part of the initial concept design. The joint venture contractor was not locked in to an inflexible design solution selected before they were able to have any input. The consulting engineers for the project were specifically asked to research alternative means of fabricating the grandstands in order to produce cost and scheduling efficiencies. The process led to an innovative composite construction system being developed to connect voided precast planks and steel beams. The system enabled a 25% reduction in the weight of the steelwork used to support the precast concrete planks with resulting cost savings over standard precast plank systems. It also meant the elimination of some of the complications of in-situ concrete work which was originally considered the most cost effective option. The composite precast system had quality control benefits and site organisation benefits which made it the preferred option and produced significant savings. Integration of the various members of the project team meant that they were confident enough to produce a new solution and to back that solution with there own expertise and reputation. To do so they needed to be assured of adequate quality control throughout the supply chain for the planks. The project required and demonstrated the value of a contractual system that distributes the benefits of cost savings to those who produce the savings, thereby providing the necessary incentive to find new solutions. As such the case study is an example of successful practice of lean construction principles if not an overt espousal of lean construction theory. Future projects are likely to benefit from the experience gained and from applying the principles and techniques of lean construction in a more systematic way.

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