Constructability Concepts in West Port Highway in Malaysia

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Abstract: This paper presents a case study of the applications and nonapplications of constructability concepts to illustrate, in a practical way, the impact that these concepts can have on a project's success. This case study, which conveys an important message with regard to the application of constructability concepts, was purposely chosen from among prestigious projects in peninsular Malaysia. The basic message, as viewed by the interviewees, is that applying these constructability concepts will enhance a project's constructability, consequently optimizing the schedule, cost, and quality of the project for the benefit of all the parties involved. The interviewees for the case study agreed that the applied constructability concepts were derived from their own experience and not based on any existing formal program. The absence of a systematic technique for transferring construction experience and knowledge to all the participants in all phases of a construction project is the reason behind the lack of constructability in our construction industry today.

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Introduction

Constructability is the optimum use of construction knowledge and experience in the conceptual planning, detail engineering, procurement, and field operations phases to achieve overall project objectives (CII 1986). Nowadays, the construction industry suffers from the lack of constructability, which causes many problems, such as increased cost and time required for constructing a project, reduced productivity of project personnel and equipment, and low-quality construction.

Some researchers in the developed countries have realized the seriousness of this shortfall and have suggested solutions to resolve it. In Malaysia, the problem of constructability has not been researched yet. Hence, this paper is considered one of the pioneer studies addressing this field in Malaysia. The paper presents and discusses the results of a case study carried out in the West Port project in Malaysia. The total construction cost of this project was more than 300 million Malaysian ringgits (about $120 million in U.S. dollars based on the exchange rate during the project's construction).

The case study discussed in this paper does not follow a traditional narrative presentation, but rather follows the sequence of the constructability concepts throughout the project phases for each case. The content of the compiled data from the interviews for the case study (the interviews were conducted with engineers with more than 5 years experience in design or construction or in both) shortened and edited for readability to depict the events chronologically. At the same time, the reader need only examine the sections related to the respective constructability concepts for the case study to begin making cross-case comparisons with the ideal constructability concept.

The entire format is tailored to the specific interests of the readers in the event that each reader may be interested in a different concept. The proverb "a picture is worth a thousand words" is often true. Accordingly, this case study is illustrated with nine figures, which include 20 panels. It is also relevant to mention that the principal writer of this paper is the head of the structural department of the consultant company for the West Port elevated highway. He was highly involved in the project during the construction phase to resolve site problems.

Methodology

The case study is an extremely flexible and most popular method of conducting research. It is considered an important approach for presenting information, describing the problem at hand, and prescribing solutions or treatments (Kirszner and Mandell 1992).

Zikmund (2000) stated that the purpose of the case study method is to obtain information from one or a few situations that are similar to the researcher's problem situation. He added that the primary advantage of the case study is that an entire organization or entity can be investigated in depth and with meticulous attention to detail. This highly focused attention enables the researcher to carefully study the order of events as they occur or to concentrate on identifying the relationships among functions, individuals, or entities.

As part of a comprehensive study of the application of constructability concepts in Malaysia by Nima (2001), it was determined that using the case study methodology in addition to questionnaires and interviews would further enhance the understanding of the current practices for design and construction in the Malaysian construction industry. This is supported by Yin (1989), who claims that the case study allows an investigation to

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retain the holistic and meaningful characteristics of real-life events. Another reason to employ case studies in research (Nima 2001) is to triangulate the results. Triangulated studies employ two or more research techniques: qualitative and quantitative approaches may be employed to reduce or eliminate the disadvantages of each individual approach while gaining the advantages of each and of a multidimensional view of the subject gained through synergy (Fellows and Liu 1997).

Constructability Concepts

Available literature on constructability (CIRIA 1983; O'Connor et al. 1987; Tatum 1987; Adams 1989; CIIA 1993; CII 1993; Nima et al. 1999; Nima 2001) defined the constructability concepts. Out of this literature, the writers formulated 23 constructability concepts in order to apply them in this study. The engineered construction process refers to the process of construction that contains the planning and design, that is, starting from conceptual planning to the end of construction and the start-up of the project. The phases of the engineered construction process are the conceptual design, final design, procurement, construction, and start-up. The 23 constructability concepts are listed below according to their relation to the engineered construction phases.

Concepts C1 to C7

Project constructability enhancement during the conceptual planning phase consists of concepts C1–C7:

- Concept C1: The project constructability program should be discussed and documented within the project execution plan through the participation of all project team members;
- Concept C2: A project team that includes representatives of the owner, engineer, and contractor should be formulated and maintained to take the constructability issue into consideration from the outset of the project and through all of its phases;
- Concept C3: Individuals with current construction knowledge and experience should carry out the early project planning so that interference between design and construction can be avoided;
- Concept C4: The construction methods should be taken into consideration when choosing the type and the number of contracts required for executing the project;
- Concept C5: The master project schedule and the construction completion date should be construction-sensitive and should be assigned as early as possible;
- Concept C6: In order to accomplish the field operations easily and efficiently, major construction methods should be discussed and analyzed in depth as early as possible to direct the design according to these methods; and
- Concept C7: Site layout should be studied carefully to perform the construction, operation, and maintenance efficiently and to avoid interference between the activities performed during these phases.

Concepts C8 to C15

Project constructability enhancement during the design and procurement phases consists of concepts C8–C15:

- Concept C8: Design and procurement schedules should be dictated by the construction sequence. Thus, the construction schedule must be discussed and developed prior to the design development and procurement schedule;
- Concept C9: Advanced information technologies are important in any field, including the construction industry. Therefore, the use of these technologies will overcome the problem of fragmentation into specialized roles in this field, thus enhancing constructability;
- Concept C10: Designs, through design simplification by designers and design review by qualified construction personnel, must be configured to enable efficient construction;
- Concept C11: Project elements should be standardized to an extent that will never affect the project cost negatively;
- Concept C12: The project's technical specifications should be simplified and configured to achieve efficient construction without sacrificing the level or the efficiency of the project performance;
- Concept C13: The project's capability for modularization and preassemblies for project elements should be taken into consideration and studied carefully. Modularization and preassemblies' design should be prepared to facilitate fabrication, transportation, and installation;
- Concept C14: Project design should take into consideration the accessibility of construction personnel, materials, and equipment to their required positions at the site; and
- Concept C15: Design should facilitate construction during adverse weather conditions. A good effort should be given to planning for the construction of the project under suitable weather conditions; otherwise, the designer must increase the project elements that could be prefabricated in workshops.

Concepts C16 to C23

Project constructability enhancement during the field operations phase comprises concepts C16–C23:

- Concept C16: Field task sequencing should be configured in order to minimize damage or reworking of some project elements, scaffolding needs, formwork used, or congestion of construction personnel, material, and equipment;
- Concept C17: Innovation in temporary construction materials/systems, or implementing innovative ways of using available temporary construction materials/systems that have not been defined or limited by the design drawings and technical specifications, will contribute positively to the enhancement of constructability;
- Concept C18: Incorporating innovation of new methods in using off-the-shelf hand tools, modification of available tools, or introduction of new hand tools that reduce labor intensivity or increase mobility, safety, or accessibility will enhance constructability at the construction phase;
- Concept C19: Introduction of innovative methods in using the available equipment or modification of the available equipment to increase their productivity will lead to better constructability;
- Concept C20: In order to increase productivity, reduce the need for scaffolding, or improve project constructability under adverse weather conditions, constructors should be encouraged to use optional preassembly;
- Concept C21: Constructability will be enhanced by encouraging the constructor to carry out innovation of temporary facilities;
- Concept C22: The work of good contractors, based on quality and time, should be documented so that contracts for future construction work will not be awarded based only on low bids, but by considering other project attributes, that is, quality and time; and

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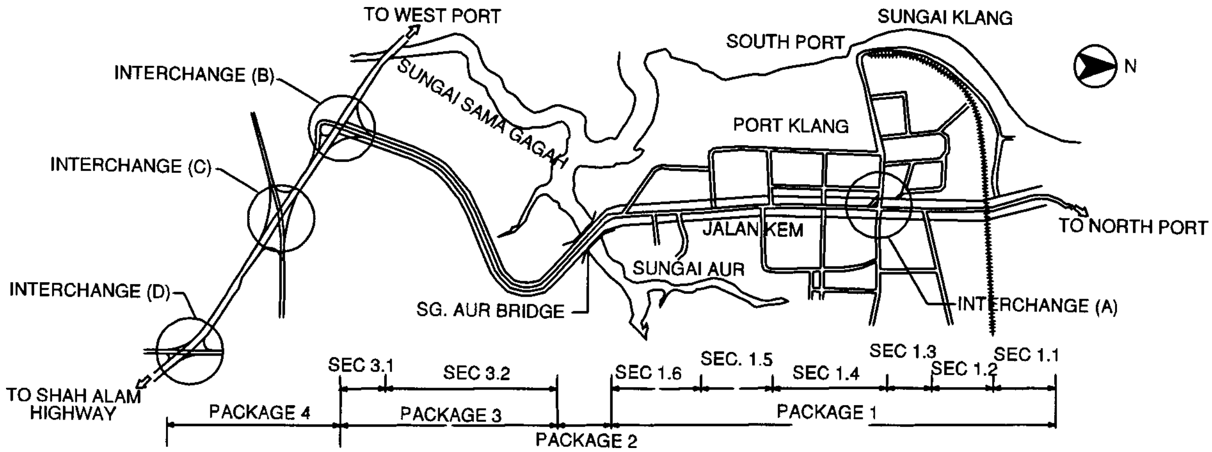

Fig. 1. Layout plan of West Port project, Malaysia

- Concept C23: Evaluation, documentation, and feedback regarding the issues of the constructability concepts should be maintained throughout the project to be used in later projects as lessons learnt.

Project Description and Background

The project selected for this case study was the construction of a highway connecting West Port to North Port-South Port inclusive of various grade separated interchanges at Port Klang, Selangor, Malaysia.

The construction cost was about $120 million, and the contract duration was 18 months, commencing in August 1997 and completed in July 1999 with a 6-month delay. The contract type is design/construct with a negotiated price. The Ministry of Finance selected the contractor for this project based on the contractor's previous performance.

This project was chosen as a case study for many reasons. First, it is one of the major and prestigious projects in Malaysia. Second, it is also a fast-track project with the detailed design carried out in tandem with the construction works. Third, the scope of construction work is very diverse, involving elevated structures, bridges, embankments, and traffic management; and fourth, the first writer was highly involved in the project during the construction phase to resolve site problems.

The government of Malaysia desired the development of Port Klang into a destination in a main commercial sea route in this region, able to operate and compete with other prestigious ports such as the Singapore port, especially in terms of cargo handling efficiencies. The infrastructure facilities at Port Klang need to be upgraded in line with the government's objectives to upgrade the port's capacity to cater to the commercial needs of the 21st century. The highway spanned from North Port Road in Port Klang through Jalan Kem, crossing Sungai Aur and ending at terminals at the West Port highway. The alignment covers a distance of approximately 4.3 km.

This project was divided into four packages: packages 1, 2, 3, and 4, as shown in Fig. 1. The design work for package 4, which covers interchanges C and D, has been completed, while the construction work would commence at a later stage. The scope of work for package 1 consisted of the construction of a new 2.2 km, two-lane dual carriageway viaduct on the existing North Port Road in Port Klang and Jalan Kem, upgrading the existing road to a full two-lane dual carriageway road and all related ancillary works. The scope of work for package 2 was the construction of a new 600 m, three-lane dual carriageway bridge over Sungai Aur, in addition to bridge approaches and all ancillary works. Package 3 involved the construction of a new 1.5 km, two-lane dual carriageway, trumpet interchange, and all related ancillary works from the Sungai Aur bridge approach to the West Port highway intersection. This project was initiated by the Port Klang Authority (PKA), who identified the alignment of the proposed road. In 1995, for implementation purposes, the PKA handed this project over to the Public Works Department (PWD). The government of Malaysia awarded the project to a Malaysian contractor as a design/construct contract.

In March 1997, the contractor appointed a consultant to undertake the design and supervision of the project. The consultants coordinated with various government agencies and authorities, such as the Klang Municipality Council, the PWD of Klang, Malaya Railway Limited, and relevant authorities for the design and relocation of utilities. The physical construction work commenced on August 1997, and by July 23, 1999, the main viaduct and bridge were opened to traffic; ramps C and D of the main viaduct were opened to traffic in December 1999, whereas the design for interchanges C and D, was completed and ready for tendering and/or construction, awaiting PWD instructions.

Constructability Concepts in Project

When the data for this case study started to be collected in November 1999, the project was in its final stages of construction. Accordingly, it provided an excellent chance to study the various facets of the constructability concepts.

Concept C1: Constructability Program and Concept C2: Project Team

The collected data show that there were no such things as constructability meetings or a constructability program in this project. Thus no constructability coordinator was involved in the project team, as required by the second concept. Consequently, the first two concepts could not be applied in this project.

Concept C3: Individuals

One of the major concepts of constructability from the viewpoint of the Malaysian engineers was the involvement of individuals

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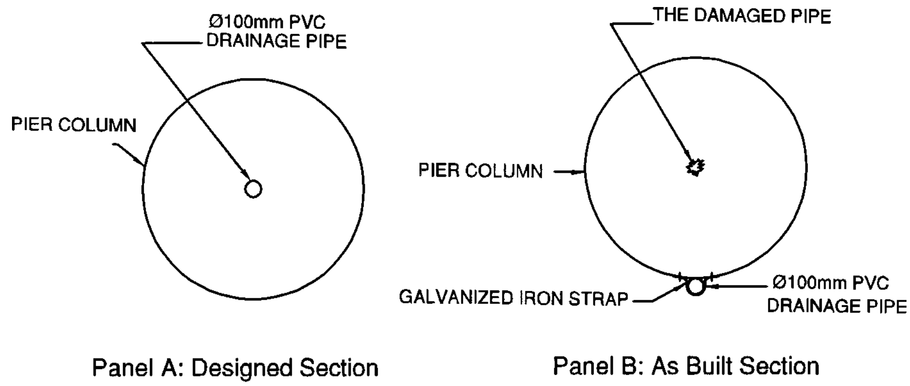

Fig. 2. Constructability problems in drainage system

with current construction knowledge and experience in the early design phases (Nima 2001). Their involvement might avoid major construction problems. As mentioned above, the contract type is a design/construct contract and has the potential to apply concept C3. In spite of this, the problems encountered during the construction phase, which are addressed later in this section, revealed that this concept was not implemented properly.

One of the problems that occurred during construction concerned the drainage pipes. Panel A in Fig. 2 shows that the designer, for aesthetic reasons, had used polyvinyl chloride (PVC) drainage pipes that were concealed in the piers. At the time of design the designer did not realize this and therefore did not specify the rate at which the contractor should pour concrete into the forms. Accordingly, he did not consider the pressure that the PVC pipes would be subjected to during casting. Therefore, all the PVC pipes were damaged in the course of concreting the piers. Solving this problem took a lot of time and money. All the drainage systems were changed to exterior pipes, as illustrated in panel B in Fig. 2.

Other construction problems were also encountered at the site and resulted in increasing the consultant's scope of work. For example, it was decided to maintain the existing level and pavement in Jalan Kem except for the parts that were going to be affected by the construction of the piles and the pile caps. During the design phase it was expected that an area equal to the area of the pile cap would be dismantled from the existing road. The consultant's expectations are illustrated in panel A in Fig. 3. While on the site, the pile subcontractor dismantled that area in addition to establishing drainage channels for the purpose of draining the water encountered during construction of the bored piles. Dismantling other areas of the existing road was necessary in order to relocate the existing underground utilities for construction purposes. The actual dismantled areas are illustrated in panel B in Fig. 3. As a result, additional construction work was needed to redesign and construct the road at grade below the viaduct.

Concept C4: Contracting Strategy

As stated previously, the Ministry of Finance selected the contractor based on the contractor's previous performance, and the contract was a design/construct negotiated contract. CII (1986) stated that construction knowledge and experience can be obtained if the selection of a design/construct contractor is made early enough to assist the owner during conceptual planning. On the other hand, Songer and Molenaar (1996) mentioned that owners select design/build because it establishes a single source of responsibility.

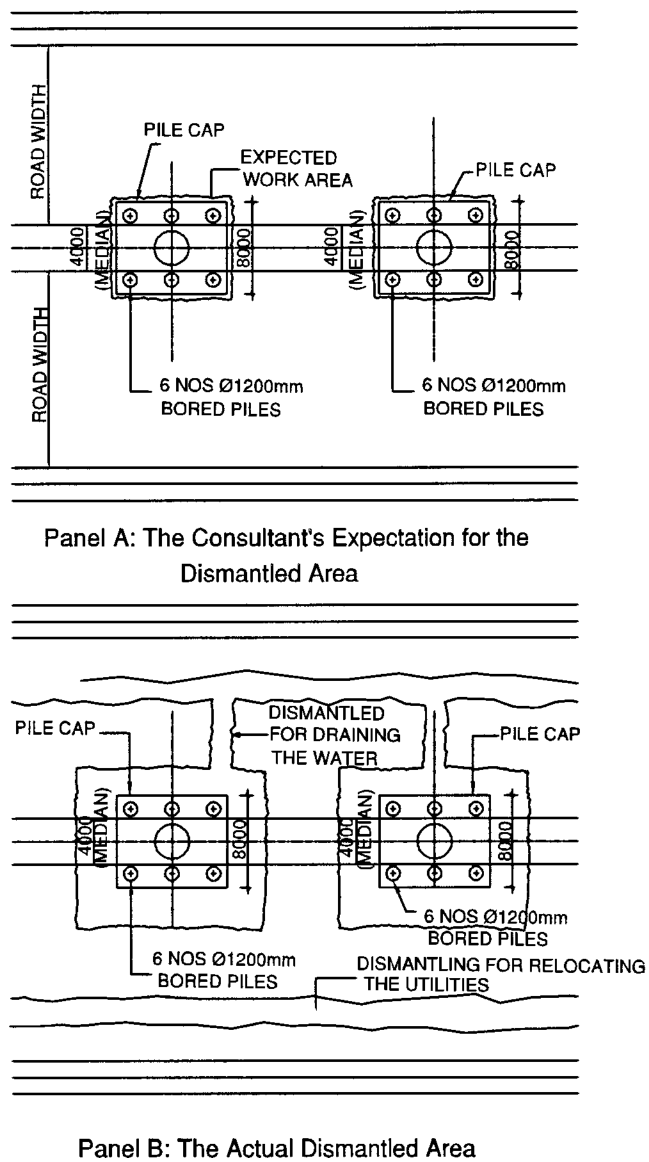

Fig. 3. Problem of pavement dismantling

At the time of data collection, the researchers did not know which method was followed by the owner in selecting the type of contract. Nevertheless, the general contractor, considering the different construction method required to carry out the construction work, applied this concept by selecting specialized subcontractors to construct many items of the main contract. Examples include

- Specialized precast, pretensioned girder supplier,
- Specialized bored pile subcontractor,
- Specialized international company for constructing the post-tensioned box-girder deck for the bridge over Sungai Aur,
- Specialized bridges' bearings supplier, and
- Specialized vendor for precast concrete drainage system.

In some cases the contractor may elect to construct some of these items rather than purchase them from suppliers. However, he or she must have the proper tools and equipment to be able to perform this work. It is very rare that a contractor is equipped to construct some items that make up a minor part of the project. Often it is more economical for the contractor to order specialist items from suppliers rather than investing in equipment that will be used only on a minor portion of his or her projects.

Concept C5: Master Project Schedule

Concept C5 encourages using the "backward pass" approach to planning. The West Port project was delayed by six months from its planned time of completion. However, the problems that occurred during the construction phase of the project, and which caused this delay, suggest that the schedule planners failed to produce a realistic plan. This can be attributed to underestimation of the importance of the planning process. If this had been understood earlier, the "backward pass" basis and tradeoffs with design and procurement schedules would have been used to arrive at a more cost-effective overall project schedule. Yet this did not happen, and the "backward pass" approach was never applied.

Concepts C6: Major Construction Methods and C7: Site Layouts

Concepts C6 and C7 are related to analyzing the major construction methods and site layouts, respectively. These concepts can be adopted easily in the design/construct contracts since the contractor's input can easily be obtained throughout the design and construction of the project. In spite of this, the contractor faced numerous problems during construction due to the nonapplication of these two concepts, which are illustrated together in this section, as the contractor encountered common problems due to the nonimplementation of both of them. Some cases will be exemplified here.

One major problem that faced the contractor was the difficulty of launching the girders. This problem was not properly dealt with during the early phases of the project, as the contractor faced big difficulties in launching numerous girders along the elevated structure. The elevated structure passed through Port Klang town, and the road reserve width inside the town was not similar to that outside the town due to land acquisition cost and some social reasons. Thus, the existing buildings inside the town hampered the lifting of the girders to their final position.

Fig. 4 illustrates the normal process of launching the girders. In contrast, Fig. 5 shows the site at which the contractor faced the problem. Panel A in Fig. 5 shows that the existing town market and its fence are very close to the elevated highway. Accordingly, there was not enough room for the cranes to launch the girders. In order to solve this problem, the contractor dismantled the fence,

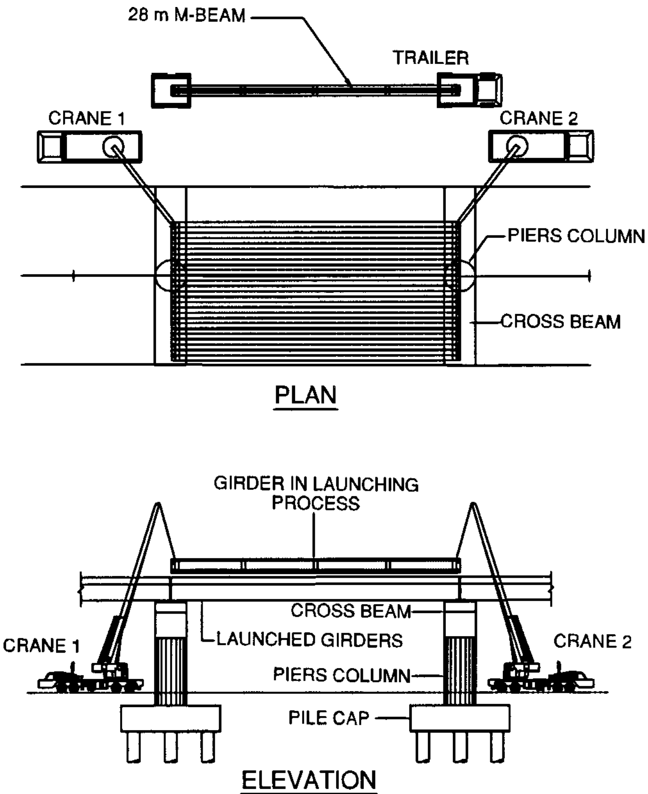

Fig. 4. Process of launching girder for elevated structure

launched the girders, and rebuilt the fence. Panel B in Fig. 5 shows a span in another location of the project, in which the launching was impeded by two buildings that could not be dismantled due to economic reasons and nonagreement of their owners. This problem was dealt with only after reaching the critical step of launching the girders. It was solved by transporting the cranes to the adjacent constructed spans, and from this position the launching was done after causing work schedule delays. The reason for this problem was that there was no construction input to the major construction methods and the site layouts during the conceptual planning phase.

The nonimplementation of concept C6 during the early stages of the project caused another problem, discovered at a later stage, that concerned soil and subbase compaction. Fig. 6 shows the plan and a cross section of a part of the elevated highway, and Fig. 7 illustrates the problem and the consequences of the difficulty of compacting the soil and subbase between two pile caps after the start-up of the project. This was due to the lack of enough space for traditional compacting equipment to do the compaction properly. Up to the date of the interview, this problem had not been solved.

As for the site layout, this project had a major problem. The structure had 44 posttensioned girders that are 35 m long to be used for the three intersections with the elevated highway. An adequate space was necessary for casting, prestressing, curing, and storing the girders until the time of erection. This requirement was not thought of until after the construction was resumed. The contractor was fortunate to find a vacant lot of land that was available for rent, adjacent to the construction site, which then was used for precasting and storing these members.

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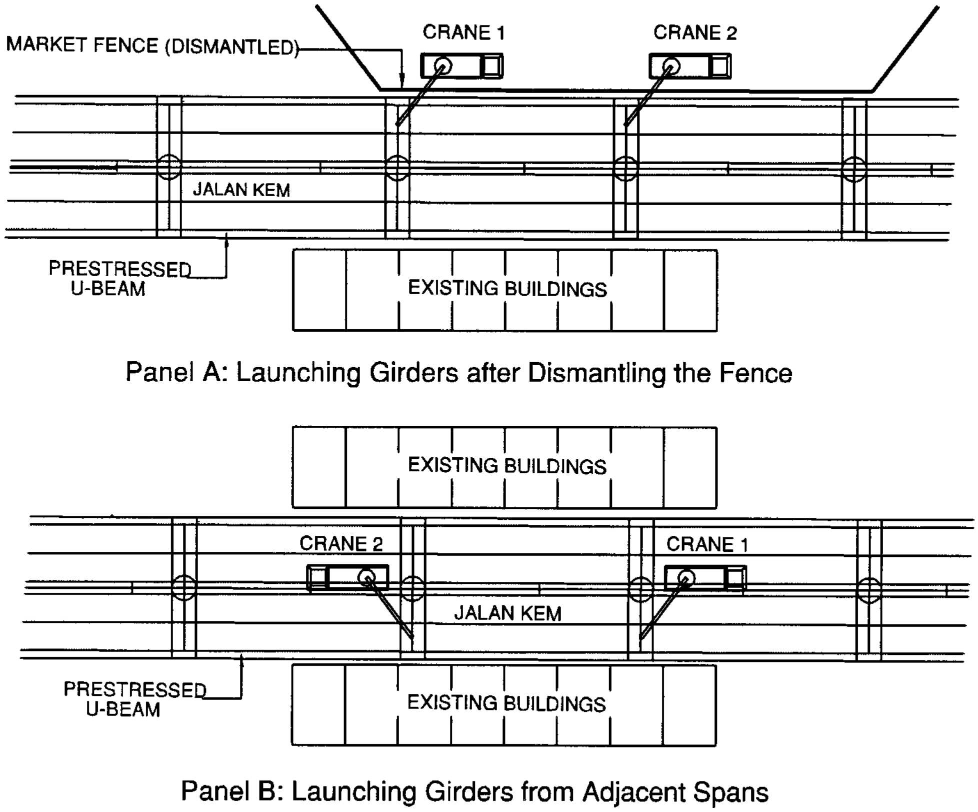

Fig. 5. Problems faced during launching of some girders

Concept C8: Design and Procurement Schedules

This concept suggests that the construction sequence should dictate the procurement and engineering sequences, and the plans should arrive in the field in advance of construction. Design/construct contracts and fast-track methods of construction provide the best opportunity for all the parties involved in the project to implement this concept easily during all the phases. In Kissinger's (1998) article about constructing Milwaukee's new convention center, he records the positive side of applying this concept. Kissinger wrote that the project team for Milwaukee's new convention center, of which he was a part, realized that the greatest strength of the design/construct approach had been their ability to make major changes much later in the construction process than they could have with traditional design/bid/build methods. This allowed their team to complete the first phase of the project without schedule delays or cost overruns.

By contrast, the consultant for the West Port project accelerated the design and produced the typical initial drawings for the purpose of saving time so that he could cope with the construction schedule. However, when this concept was tried, it was associated with a problem that was encountered later in construction. Panel A in Fig. 8 shows the typical crossbeam initial detail of the elevated highway's piers. The crossbeams as for the piers that carry the gantries had to be a different shape, as shown in panel B in Fig. 8.

During construction, the contractor followed the detail shown in panel A of Fig. 8 for all the piers. After casting the crossbeams, it was realized that the gantries could not be fixed on these typical crossbeams in accordance with the gantries' typical details. Consequently, the consultant was asked to solve this problem, and the selected constructed alternative is shown in Fig. 9. From this example it can be concluded that in order to implement this concept perfectly, the designer should spend enough time verifying the impact on the final product caused by acceleration in design that is carried out to match the construction schedule, so that problems like this will not occur.

Concept C9: Advanced Information Technology

This concept calls for applying advanced information technology and encourages the use of such technology to enhance project constructability. No examples for applying this concept were found.

Concept C10: Design Simplification

Concept C10 advocates design simplification. The implementation of this concept in this project was accomplished by simplifying the design of the piers and decks. This project had a good potential for detailing simplification because the major structure consisted of repetitive detailing. The consultant, based on previous experience with this type of structures, made use of this potential to prepare detailed construction drawings that minimized the number of components and elements of the structures.

Concept C11: Standardization

This concept supports standardization of the project's components. Because this project was a good candidate, this concept was implemented remarkably well. The consultant made good use of this by standardizing the majority of the project's elements. Examples include the piers, crossbeams, and decks.

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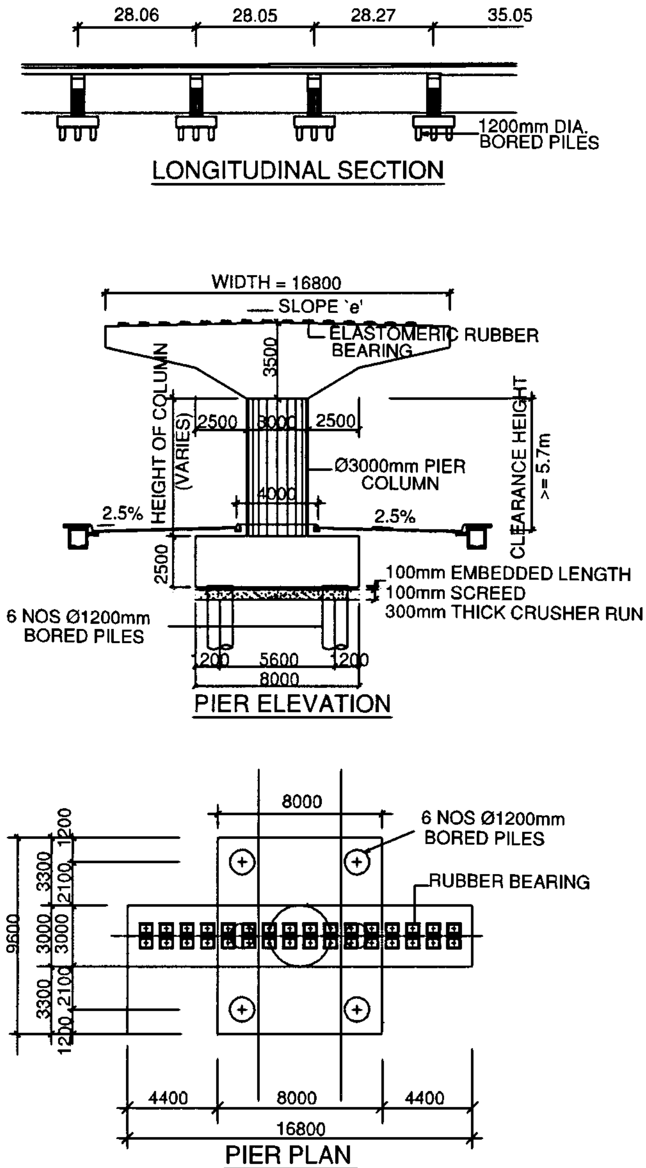

Fig. 6. Details of elevated highway at Jalan Kem, Port Klang

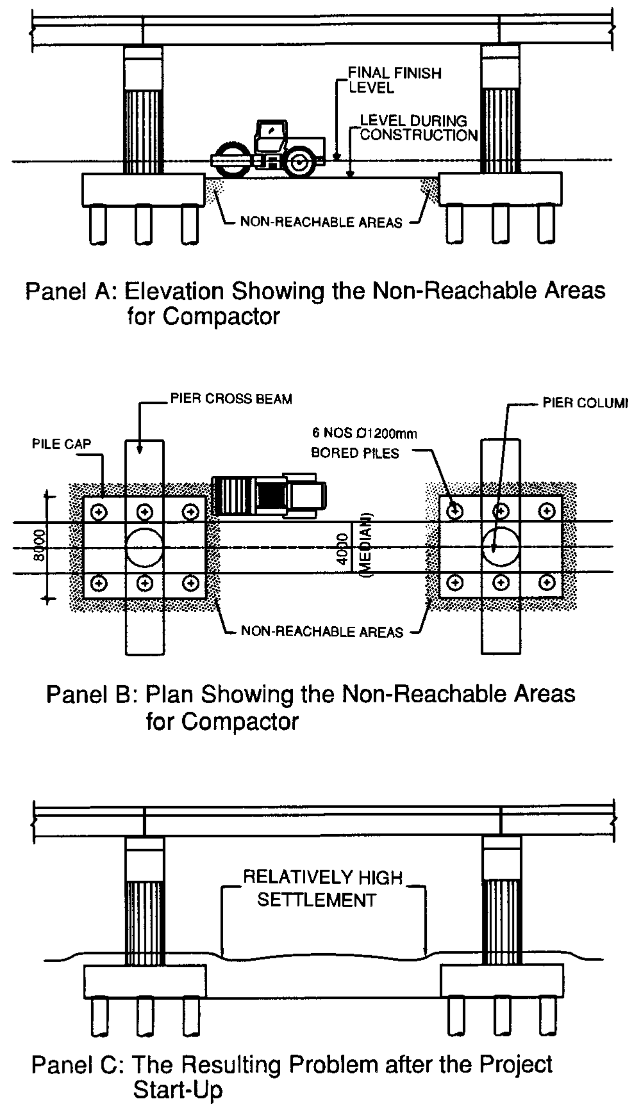

Fig. 7. Problem of compaction and results after project start-up

Concept C12: Technical Specification

As for this concept, the consultant prepared the specification according to the available materials in the market. Boyce (1991, 1994) proposed using the "performance type specification approach." This can be achieved by selecting a vendor with a good reputation and experience in the required specialization who will supply the item with a guarantee. This approach was used for many items in the project rather than implementing "gold-plated" off-the-shelf specifications that O'Connor and Miller (1994) considered one of the barriers to constructability implementation. The best example is the elastomeric bearing pads for the viaduct and the approach ramps and mechanical bearings for the bridge over Sungai Aur.

Concept C13: Modules and Preassemblies

Concept C13 advocated using prefabrication, preassembly, and modularization. This project had the potential of having its detailed design for the modules and preassemblies prepared so as to facilitate their fabrication, transportation, and installation. The major part of the project consisted of an elevated highway structure. In order to apply this constructability concept, the consultant used prestressed M-beams and U-beams for the spans that made up the elevated highway and posttensioned I-beams for the intersections with the town roads and railway tracks.

However, as O'Connor et al. (1987) warned, lifting limitations and delivery route restrictions should be studied when planning to implement this concept. Otherwise, the contractor will encounter the problems mentioned in this case study.

Concept C14: Accessibility

This concept highly promotes accessibility to enhance project constructability. The road reserve outside Klang town was wide enough so that there was no accessibility problem. But, as stated above, the road reserve width inside the town was narrower, which made the contractor face many accessibility problems that caused delays in progress and decreased productivity. Examples related to this concept were given in the discussion of the concept concerning site layout.

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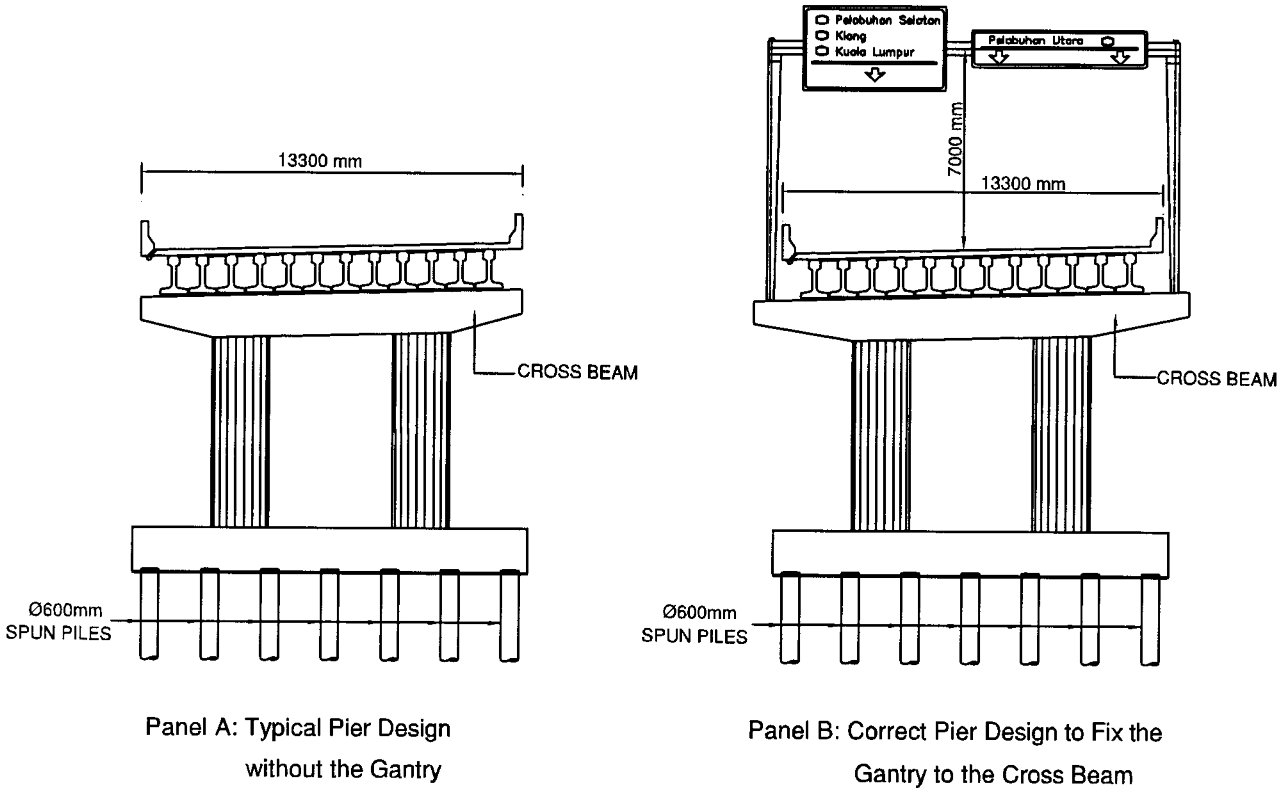

Fig. 8. Fixing gantries

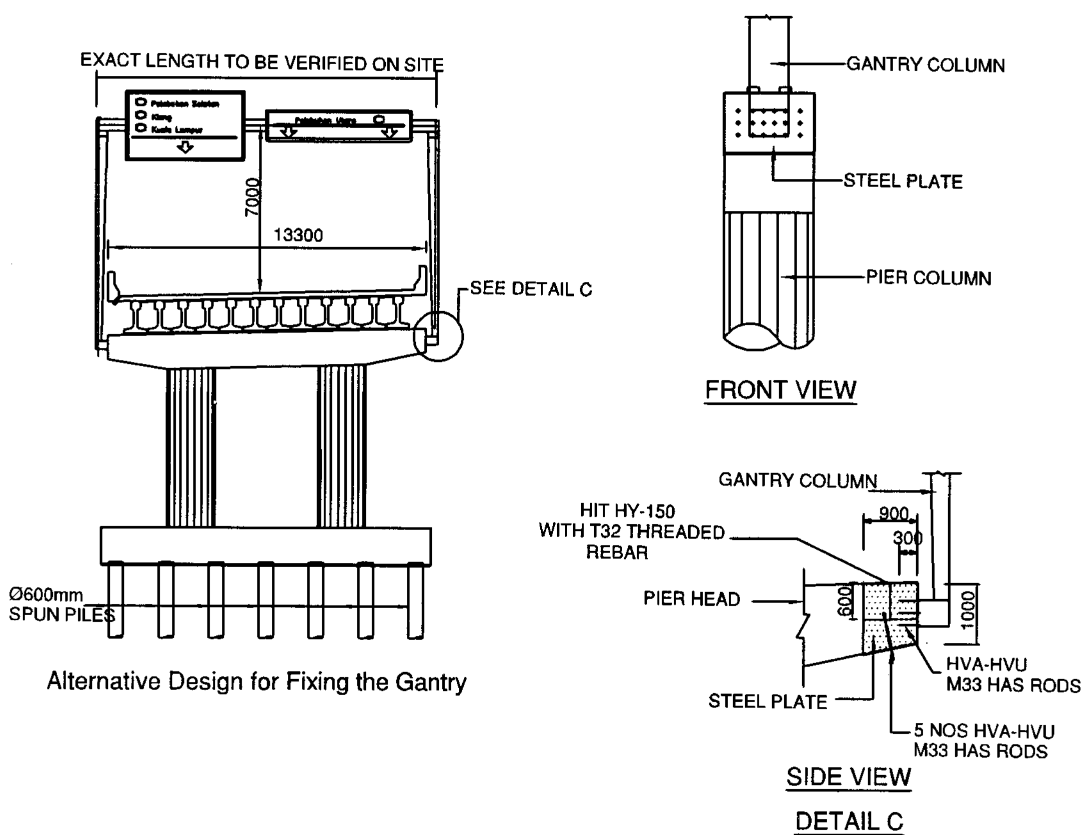

Fig. 9. Constructability problem of fixing gantries

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Concept C15: Adverse Weather Conditions

Concept C15 encourages facilitating construction under adverse weather conditions through design. This concept was practiced through using the precast units for the girders and drainage systems for roadsides and manholes. The precast elements were not damaged by rain when compared with the cast-in situ type of construction. Moreover, using the precast drainage systems helped in discharging rainwater during rainy weather.

Concepts C16 to C23

Concepts C16–C23 are related to the enhancement of constructability during field operations. The application of these concepts, according to the survey, was given the lowest priority. Only one example was found for the application of these eight concepts.

The contractor used concept C17, which advocated the innovative use of temporary materials/systems. The forms of the crossbeams for the piers, which are shown in Fig. 6, cannot be supported directly on the ground inside Port Klang town due to the constraints of existing city roads. Accordingly, the contractor following his own judgment decided to use a special type of forms that can be fixed to the pier columns and whose levels can be adjusted by using hydraulic jacks. Due to their extremely high cost, the contractor did not own this type of forms but rented them from a specialized equipment supplier, and their rental cost was calculated on the basis of ringgits per piece per day. Consequently, the contractor rented only three of them to perform the casting of the viaduct's piers, which exceeded 70 piers. In order to optimize the use of these forms, the contractor used an innovative construction procedure by modifying the concrete mix design of the crossbeams to make it reach the desired strength specified in the construction drawings and specifications in a shorter time. Hence the forms could be removed in a shorter time, and their usage was optimized.

Discussion and Conclusions

From the examples presented in this study, it can be perceived that out of the 23 constructability concepts adopted by this paper, only 7 were applied. This clearly dictates that there is a low level of application of the concepts in this project. The interviewed engineers agreed that they applied the concepts out of their experience and not based on any formal constructability program. Moreover, the engineers did not relate these concepts to any single principle. The interviews conducted for this case study revealed that the interviewed engineers had a good understanding of each constructability concept individually, but they did not link those concepts under one umbrella.

For example, the interviewed engineers showed a good understanding of the importance of standardization and consideration of accessibility for construction personnel, materials, and equipment to the site during the design phase and of innovation and documentation during the field operations. However, they did not realize that all these concepts are related to a common larger principle, which is constructability. In the West Port project, applying some constructability concepts apart from a comprehensive constructability program affected other concepts negatively and was the reason behind some of the constructability problems encountered in this project, as was illustrated in this paper.

In conclusion, any constructability concept should not be implemented at the expense of other concepts. Alternatively, the 23 concepts should be applied as a comprehensive formal program under the umbrella of constructability.

It is to be noted also that the 23 concepts should not be implemented unconsciously or individually. As in the case study of the West Port project, it is obvious that implementing some concepts by the consultant leads to problems related to other constructability concepts. On the other hand, in this project, some concepts are well implemented, while others are not. For example, concepts C1 and C2 were not applied due to the lack of awareness of these concepts.

The outcome of this study supports the main generalization of Nima (2001), which suggested that there is a lack of use of constructability concepts in the Malaysian construction industry. This problem should be addressed in proportion to its severity in the industry. Thus, further research is required to study the reasons behind this phenomenon so that the best solutions can be deduced to enable constructability implementation.

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References

Adams, S. (1989). *Practical buildability*, Construction Industry Research Information Association (CIRIA), Butterworths, London.

Boyce, W. J. (1991). "Designing for constructability." *Proc., American Association of Cost Engineers*, AACE, Morgantown, W.Va., b.1.1–b.1.7.

Boyce, W. J. (1994). "Design for constructability." *Hydrocarbon Process.*, 73(12), 81–85.

Construction Industry Institute (CII). (1986). "Constructability, a primer." *Publication 3-1*, Univ. of Texas at Austin, Austin, Tex., July.

Construction Industry Institute (CII). (1993). "Constructability implementation guide." *CII Special Publication 34-1*, Univ. of Texas at Austin, Austin, Tex.

Construction Industry Institute Australia (CIIA). (1993). *Constructability principles file*, Univ. of South Australia, Adelaide, Australia.

Construction Industry Research Information Association (CIRIA). (1983). "Buildability: An assessment." *Special Publication 26*, U.K.

Fellows, R., and Liu, A. (1997). *Research methods for construction*, 1st Ed., Blackwell Science, Boston.

Kirszner, L. G., and Mandell, S. R. (1992). *The Holt handbook*, 3rd Ed., Harcourt Brace Jovanovich, New York.

Kissinger, J. H. (1998). "Express design." *Civ. Eng.*, 68(8), 40–43.

Nima, M. A. (2001). "Constructability factors in the Malaysian construction industry." PhD thesis, Univ. Putra Malaysia, Selangor, Malaysia.

Nima, M. A., Razali, A.-K. M., and Saleh, J. M. (1999). "Evaluation of the engineer's personnel's role in enhancing the project constructability." *Facilities*, MCB Univ., U.K., 17(11), 423–430; see, ⟨http://haly.emeraldinsight.com/vl=2805357/cl=28/nw=1/rpsv~1170/v17n11/s3/p423⟩.

O'Connor, J. T., and Miller, S. J. (1994). "Barriers to constructability implementation." *J. Perform. Constr. Facil.*, 8(2), 110–128.

O'Connor, J. T., Rusch, S. E., and Schulz, M. J. (1987). "Constructibility concepts for engineering and procurement." *J. Constr. Eng. Manage.*, 113(2), 235–248.

Songer, A. D., and Molenaar, K. R. (1996). "Selecting design-build: Public and private sector owner attitudes." *J. Manage. Eng.*, 12(6), 47–53.

Tatum, C. B. (1987). "Improving constructibility during conceptual planning." *J. Constr. Eng. Manage.*, 113(2), 191–207.

Yin, R. K. (1989). *Case study research design and methods*, 2nd Ed., Saga, Beverly Hills, London.

Zikmund, W. G. (2000). *Business research methods*, 6th Ed., Harcourt, Orlando, Fla.

J. Constr. Eng. Manage., 2002, 128(4): 348-356