THE FEASIBILITY OF USING HYBRID CONCRETE STRUCTURES WITHIN THE CONTEXT OF COST AND TIME

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This paper is based on research conducted for the Reinforced Concrete Council on the feasibility of using hybrid concrete (combinations of in-situ and precast) in the UK. The main aim was to benchmark hybrid concrete construction against other types of construction within the context of building cost, operational cost and construction time. This is achieved through the direct comparison of hybrid concrete construction schemes with the M62C3 scheme (an in-situ concrete scheme used as a reference building) (Goodchild, 1993) for which cost and time models are already established. This research demonstrates that the perceived idea about hybrid concrete as being more expensive than in-situ and steel structures is in many cases untrue. In fact, some of the hybrid concrete schemes analysed in this study have been shown to be less expensive than their in-situ concrete equivalents which in turn are cheaper than steel.

In addition, this research clearly shows that initial costing of hybrid concrete construction is not the only factor to be considered when adopting this or any other type of construction technology. Other factors such as life cycle costing, construction time, procurement and process issues are as important. It is the holistic picture of the performance of hybrid concrete construction that needs to be addressed. The work on process performance, procurement and supply chains within the hybrid concrete industry is not within the scope of this paper. Barrett (1998) in another work package run in parallel with the work presented in this paper has documented his main findings in a report submitted to the Reinforced Concrete Council.

The research presented in this paper has been performed with the support of the project's industrial steering committee. A series of workshops and interviews were used to elicit knowledge and validate the results of the study.

Keywords: cost, hybrid concrete, feasibility, life cycle costing, time.

INTRODUCTION

The literature review has revealed that little research has been done within the context of establishing the feasibility of using hybrid concrete construction (combinations of in-situ concrete and pre-cast) within the context of cost and time. Previous work of some relevance to hybrid concrete included that of Hellers and Lundvall (1995) who addresses the issue of structural wood replacement with concrete hybrids. Goodchild (1995) compiles a good documentation of hybrid concrete schemes that could be used by the industry. Deskovich et al (1995) in their study of time dependent behaviour recommends the use of hybrid elements. Gentry (1994) describes a smart monitoring program for a hybrid concrete-steel building in Washington D.C. Bakery and Sunder (1990) suggests the use of fibre-reinforced concrete as opposed to plain concrete for modular bridge deck systems. Kobayashi and Cho (1982) describe the flexural

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characteristics of steel fibre and polyethylene hybrid reinforced concrete. However, none of the previously mentioned studies have dealt with the issue of hybrid concrete process modelling within the context of time and cost. This paper addresses these issues and present the findings achieved so far.

The main contribution of this research is a benchmarking model of hybrid concrete construction against other types of construction within the context of building cost, operational cost and construction time. The methodology adopted for this type of research is that of case studies. Model buildings were identified, costed and compared. The M62C3 building of the cost model study (Goodchild 1993, Baiche 1997) was used as a reference model. The main specifications for M62C3 building are: A three storey concrete building made of two rectangular parts (45 m x 15 m and 37.5 m x 15 m) connected by a central lobby area (18 m x 9.5 m); the height of each storey is 3.3 m; pad foundations; 300 mm concrete flat slab; steelwork roofing; brickwork cladding; naturally ventilated building. For other specifications refer to the cost model study by Goodchild (1993).

The building of the cost model study was compared with the hybrid concrete which are within the scope of this study: a) Scheme 1: hollow-core slabs without topping and transverse post-tensioned beams; b) Scheme 2: GRC permanent waffle formers: c) Scheme 3: precast inverted U frames and precast soffite slabs with void formers; d) Scheme 4: in-situ spine and perimeter beams with profile metal decking; e) Scheme 5: columns in precast shells and solid pre-stressed soffite planks with in-situ topping; and finally f) Scheme 6: tilt up wall panels (only scheme 5 is shown in Appendix A, other schemes are similar in dimensions, but different in materials). Conclusions were then drawn on the feasibility of using hybrid concrete as an alternative to in-situ concrete.

COST MODELLING

As mentioned before, this study mainly involves six generic Hybrid Concrete Schemes (Goodchild 1995, Tilt-up consulting services report 1997). This involves the costing of each scheme and comparing it with the Reference Scheme M62C3. The main task of this phase is the measurement of quantities for each scheme. In order to facilitate comparison a similar approach to measurement to that used for the Reference Scheme was used. The same types of items were used to a feasible extent. However, due to differences in the use of materials and types of construction, many new items had to be introduced. Further, the measurements were made using the guidelines provided in SMM7.

Major changes of design are in the elements of substructure and superstructure. However, due to difficulties in obtaining accurate and reliable cost data for very specialised PCC components the cost effects found can only be used as indicators in cost patterns. The figures below show schematic representations of the costing phase. Figure 1 presents an elemental cost comparison of the various schemes. All monetary figures are given in Pound Sterling. Figure 2 shows a comparison of total initial costing of the various schemes. Finally, figure 3 shows the ranking of the various schemes on a scale of 1-5.

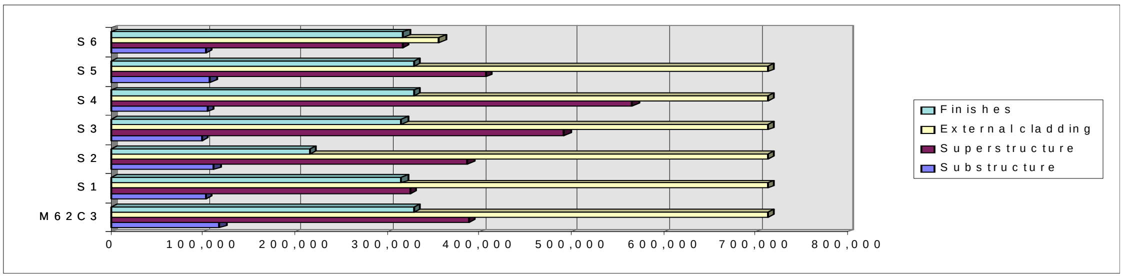


Figure 1: Elemental cost comparison

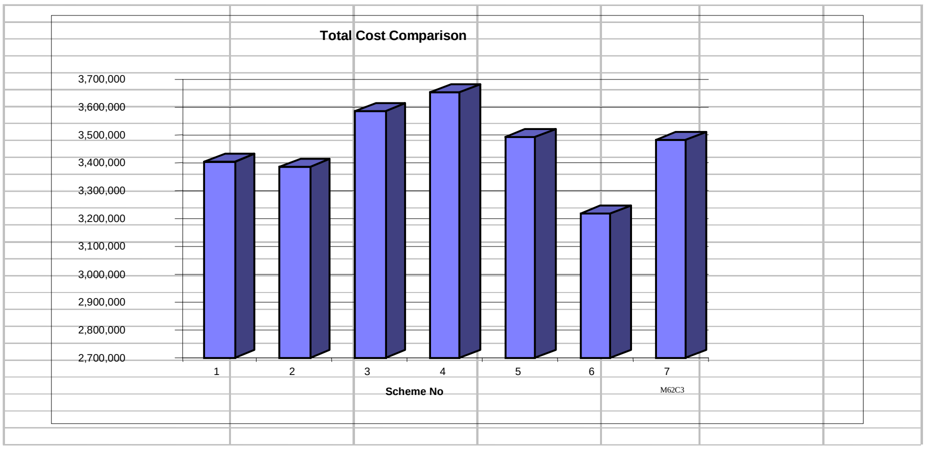


Figure 2: Cost comparison of the various schemes

The values shown above have been converted to a scale of 1-5. It is clearly shown that schemes 3 and 4 are the most expensive. Schemes 6, 1, 2 and 5 are competitive when compared with the in-situ concrete reference model.

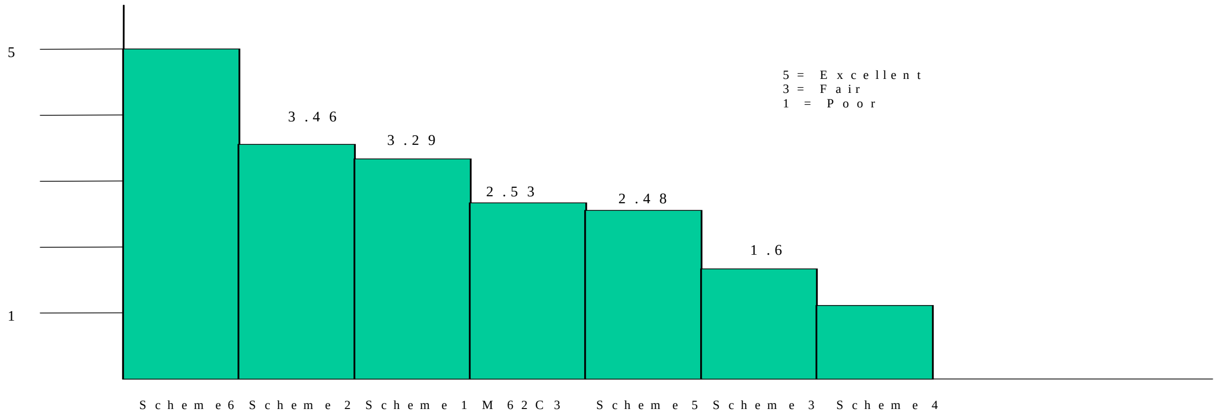


Figure 3: Ranking of the schemes by initial costing

It is clearly shown from the above figures that the tilt up (scheme 6) and waffle slab scheme (Scheme 2) are the least expensive. The waffle slab scheme is cheap because no suspended ceiling is required. However, this scheme may become the most expensive if services are to be considered. Discussions with experts in this area revealed that this type of scheme is ideal for car parks where services are not required. Once again, it has to be emphasised that it may be misleading for the hybrid concrete industry to just concentrate on the initial costing of concrete frames. This paper will reveal towards the end that Scheme 1 and Scheme 6 are front runners if we consider the overall picture (Schemes 2 and 5 are behind schemes 1 and 6). On this context, it will be seen that schemes 3 and 4 are behind and may prove problematic in some instances. The work then progressed to identify life cycle costing issues, and the establishment of the construction programmes for the schemes.

LIFE CYCLE COSTING

In performing life cycle costing analysis, various types of costs such as initial costs, energy costs, maintenance and repair costs and alteration costs need to be made available. Ideally, these costs will be drawn from facility managers, manufacturers and feedback based on previous experiences. This analysis is for the floor plan structural component of an office building. For this component, running costs are negligible over its physical life, which may extend to over 100 years. However, the design of floor can have various effects on other aspects of the building performance. In this study particular attention was paid to the extent, the proposed schemes may have an input on decoration/painting, maintenance, cleaning and energy costs. Five criteria that are normally used for life cycle costing analysis were identified as important in the evaluation. These are as follows:

1. Image/Aesthetics: internal decoration
2. Environmental comfort: illumination, spaces, relaxing environment, heating and air conditioning
3. Maintainability/Repairability of services: ease of maintenance and access to repair.
4. Cleanability
5. Space flexibility: space optimisation and changes in space use.

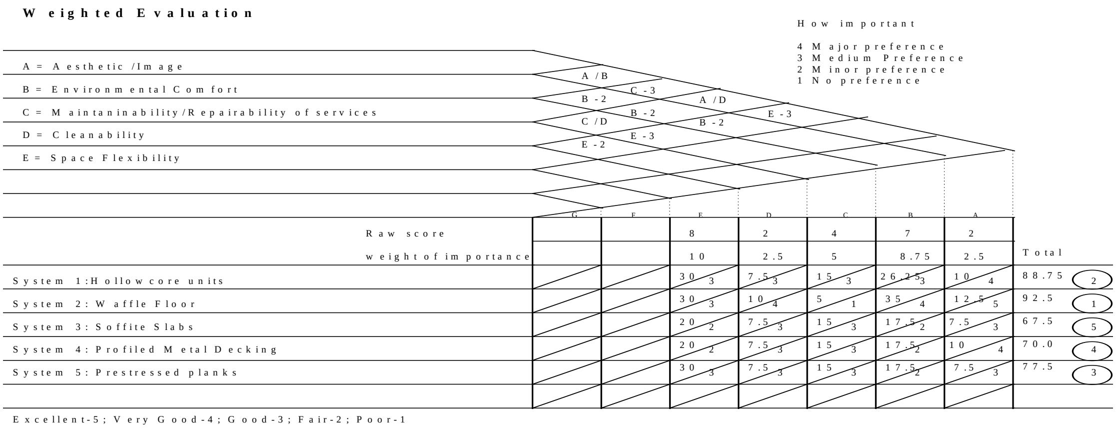


Figure 4: Weighted evaluation technique for ranking the schemes

The weighted evaluation technique (see figure 4) was used to rank the various schemes. Every factor is compared with the rest and given a value of importance. For instance if we take aesthetic and environmental comfort, they score equally (A/B) based on their equal importance to the party who is judging them. Now, if we take environmental comfort and repairability, the former scored higher with B2 indicating minor preference. We then counted the total number of A, B, C, D and E which are 2, 7, 4, 2, and 8 respectively and we converted them to a scale of 10. The next step was to score the various schemes according to the importance of the five criteria. Waffle floor scores 5 for aesthetic while it scores 1 for maintainability. The overall score was obtained by multiplying these scores with the values of A, B, etc on the 10 scale and the overall scores added together for every scheme. For Waffle slab (3x10 + 4x2.5 + 1x5 + 4x8.75 + 5x2.5 = 92.5)

Scheme 2 (Waffle floor) scored highest in terms of these non-monetary benefits. The score is very close to that of Scheme 1 (hollow core units). The remaining schemes have close scores indicating similar outcomes.

The waffle floor scheme is probably the only one that can be distinct from other schemes, merely because it does not need a ceiling. Having said that, this may present a problem regarding services. If services installations are designed inside the waffle floor and provided that easy access to these services could be maintained over the life of the building, this could be the preferred scheme. But if services will be above the floor, then obviously there will be a need to raise the floor level and as a consequence valuable height space will be lost. The initial cost would also increase and maintenance access must be ensured in the same way as to the previous scenario. As a result this scheme would drop back to third place behind schemes 1 and 5. Furthermore, the amount of reinforcement required for scheme 2 is more than double the amount needed for scheme 1, whereas it is not far away from the other schemes considering the added planks. As a result scheme 1 could be favoured if initial costs were taken into consideration. The figures shown in Figure 4 were converted to a scale of 1 to 5. Figure 5 shows the ranking of the various schemes according to life cycle costing.

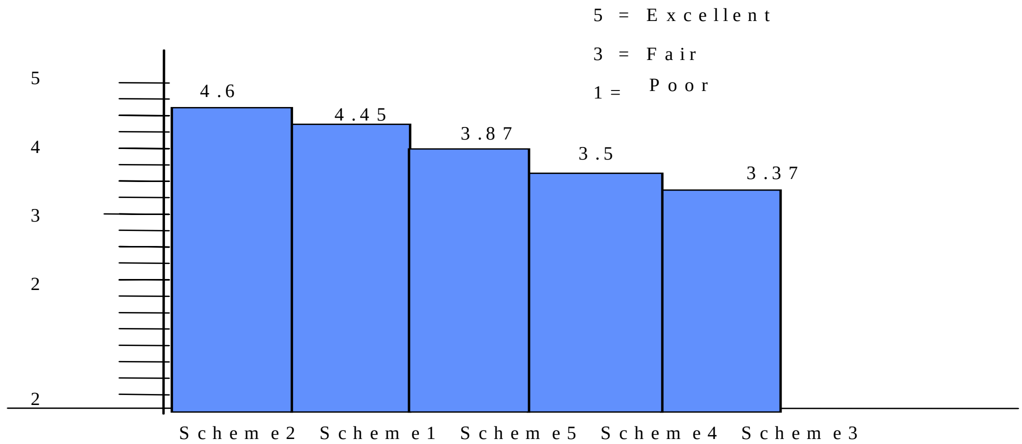
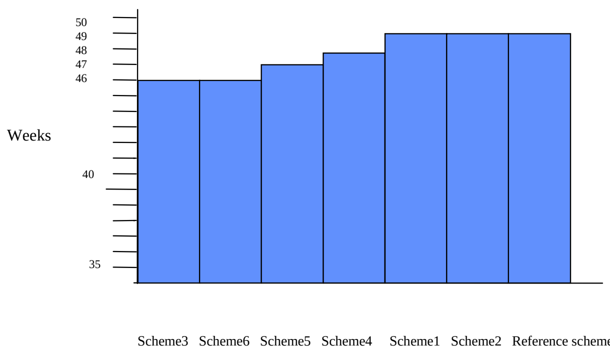


Figure 5: Ranking of the schemes according to life cycle costing

It is fair to say that these results were only indicative and were based on the subjective analysis of the research. In order to make a good judgement of the various schemes more information must be made available to allow for a more objective analysis approach.



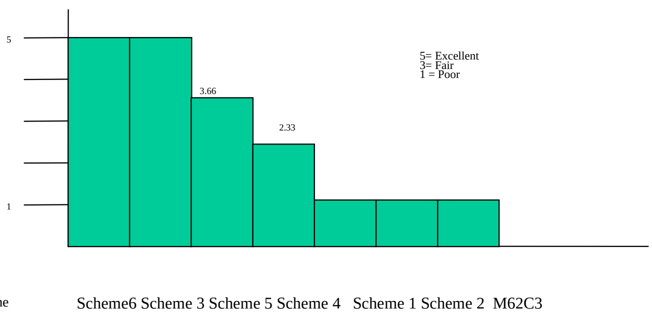


Figure 6 Ranking by total project duration **Figure 7** Ranking of schemes on a scale of 1-5

PROGRAMMING OF WORK

The schemes were compared in terms of the programming time required to construct the various schemes. The figure for the reference cost model was updated based on the assumptions for the resources made by the industrial collaborators of the project. The durations shown below are just indications of the time cycles. It is the overall sequencing of activities and the implications on the critical path which should be considered if proper analysis is to be performed. Leading periods of the various schemes can also vary drastically.

It is clearly shown that schemes 1 and 2 are similar to that of an equivalent of in situ concrete structure. Schemes 3 and 6 take the least time to be constructed. Figure 6 shows the performance of the various schemes on a scale of 1-5.

RANKING BY GENERAL PERFORMANE

This is based on interviews conducted with the steering committee members and a large contracting organisation (which deals with hybrid concrete structures) which was attended by the principal structural engineer, the chief planner and the chief temporary works together with a representative from the Reinforced Concrete Council. The discussion was a brainstorming exercise of the benefits and problems associated with the six schemes that are within the scope of this study. Issues such as initial costing, life cycle costing, buildability and programming and other issues such as procurement were considered when trying to rate the various schemes. The discussion has considered in particular design and build and PFI procurement systems. It was clearly revealed during the discussion that initial costing is no longer the issue. It is the holistic picture that should be taken into account when considering the various hybrid concrete schemes. The rating of the various schemes is shown below:

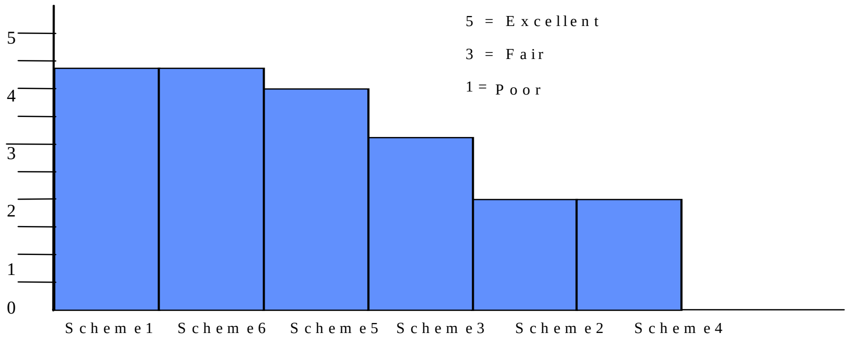


Figure 8: Ranking of the schemes

OVERALL RANKING OF THE SCHEMES

Table 1 shows the overall ranking of the various schemes by initial costing, life cycle costing, time and general performance.

Table 1: Overall ranking of the schemes

Ranking	1st position	2nd	3rd	4th	5th	6th	7th
By initial costing	Scheme 6	Scheme 2	scheme 1	Scheme ref	Scheme 5	Scheme 3	Scheme 4
By Life cycle costing	Scheme 2	Scheme 1	Scheme 5	Scheme 4	Scheme 3	=Scheme 6	
By time	Scheme 6	=Scheme 3	Scheme 5	Scheme 4	Scheme 1	=Scheme 2	= Scheme ref
General Performance	Scheme 6	=Scheme 1	Scheme 5	Scheme 3	Scheme 2	Scheme 4	

Assuming that scheme 6 performs as well as scheme 3 in terms of life cycle costing. The schemes will now be ranked according to their scores. A scheme in the 1st position will score 10, in 2nd position 8, in 3rd position 6, in 4th position 4, in 5th position 2, and in the last position 0. The overall ranking of these schemes is shown below:

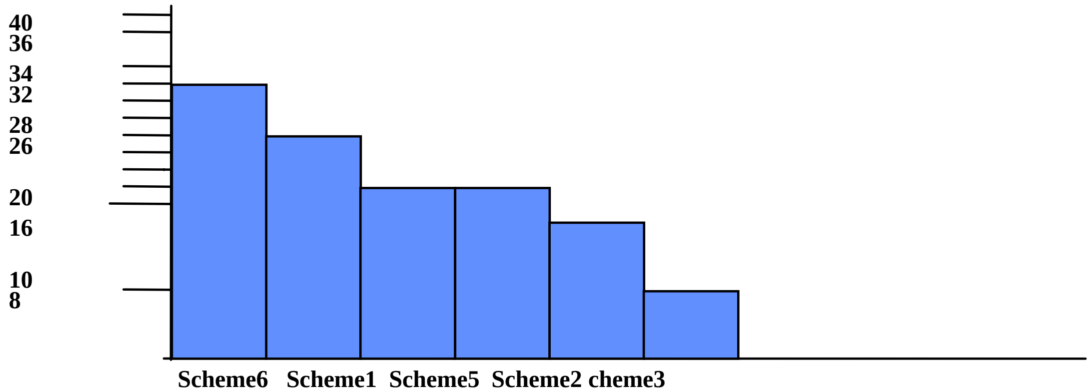


Figure 9: The overall ranking of the schemes

This ranking is based on the assumption that all the aforementioned evaluation criteria are of equal importance to the building client. Thus, greater importance of one criterion may sway the ranking in another direction. For example, if life cycle costing were 3 times more important than all other criteria, the best overall scheme would be scheme 2.

The main conclusions to be drawn regarding the ranking of the various schemes are as follows:

- Scheme 6 is a potential candidate for hybrid concrete. This scheme is popular in the USA. The UK hybrid concrete industry can benefit from this technology because of the many merits it can offer in terms of speed and the clear spans it can provide. In terms of initial costing, this scheme proved to be the least expensive when compared with other schemes. In terms of speed, it is amongst the fastest. Overall, this scheme was ranked to be the best. Surely, the issues of marketing of this scheme needs to be addressed if to be adopted by the hybrid concrete industry.
- Scheme 1 is the best scheme on the market. It is the most straightforward. A large proportion of people in the industry is familiar with it. In terms of initial costing, this scheme proved to be cheaper than that of the cost model building, but more expensive than that of scheme 6 and 2. If we consider the life cycle costing issue, this scheme scored to be the second best after scheme 2. In terms of speed, this scheme proved to be slower than schemes 6, 3 4 and 5. Overall, this scheme was ranked to be the 2nd best. Considering the current status of tilt up systems, this scheme would currently be considered as the best solution.
- Scheme 2 is the third potential candidate for hybrid concrete systems. However, it has to be taken into account that for this scheme it was assumed that no suspended ceiling was provided. This scheme may prove to be the most expensive if we take this factor into account. In terms of initial costing, this scheme was the second least expensive after scheme 6. The life cycle costing analysis gave this scheme the highest score. In terms of speed, it was amongst the slowest. Overall, this scheme can provide some benefits and was ranked third equally with scheme 5.

- Scheme 5 was ranked equally third with scheme 2. In terms of initial costing, it was more expensive than the cost model scheme. The life cycle costing analysis showed that this scheme lagged behind schemes 2 and 1. Overall, this scheme has potential benefits and should be considered as a solution for hybrid concrete systems.
- Scheme 3 offers some benefits in terms of speed as it is amongst the fastest. However, this scheme proved to be expensive in terms of initial costing and life cycle costing. Overall, this scheme was ranked to be second worst.
- Scheme 4 is the most expensive in terms of initial costing. This scheme also lags behind other schemes if we take into account life cycle costing and speed. Overall, this scheme was ranked to be the worst solution.

CONCLUSIONS

This paper presented the results of performance modelling, particularly within the context of initial costing, life cycle costing and time plans conducted within hybrid concrete construction. This study demonstrated that the perceived idea about high initial costing associated with the hybrid type of construction is sometimes misleading. This research has shown that in some instances hybrid concrete construction is less expensive that that of In-situ or steel construction. It is however worth mentioning that initial costing is only one of the many criteria that should be considered when assessing the appropriateness of a certain type of construction. It is the combination of time, cost, operational cost, buildability, type of procurement and other many factors which can determine which type of construction should be selected when faced with an array of alternatives. This research has demonstrated that Schemes 6, 1, 2 and 5 are front runners for hybrid concrete systems. Schemes 3 and 4 lag behind and the appropriateness of these schemes should be addressed within the specific process requirements. For instance, scheme 3 is amongst the best in terms of speed. The schemes adopted for this study should be used as guides. More schemes need to be studied and analysed.

REFERENCES

Baiche, B. 1997. The perception of hybrid concrete construction within the UK construction industry. Oxford Brookes University.

Bakeri, P.A & Sunder, S.S, 1990. Concepts of hybrid FRP bridge deck systems. ASCE, Boston.

Barrett, P, 1998. Hybrid concrete for the UK market: documentation of current business processes and desirable process improvement. Report submitted to the RCC, January 1998.

Gentry, R.T, 1994. Long term monitoring of civil structures using smart techniques. Structures congress XII, ASCE, New York.

Deskovich, N et al, 1995. Innovative design of FRP combined with concrete: long term behaviour. Journal of structural engineering, ASCE, New York.

Goodchild, C.H., 1993, Cost Model Study, A report on the comparative costs of concrete & steel framed office buildings, British Cement Association.

Goodchild, C.H. 1995. Hybrid concrete construction: combining structural materials for speed, quality and economy in buildings, British Cement Association.

Hellers, B.G & Lundvall, O, 1995. Light and strong as wood : the development of hybrid concrete elements. Materials and structures, Chapman and Hall, London, England.

Kobayashi, K & Cho, R, 1982. Flexural characteristics of steel fibre and polyethylene fibre hybrid reinforced concrete. Composites. Tilt-up consulting services. Report presented to the RCC, 1997 on tilt-up structures.

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APPENDIX A SCHEME 5