Economical use of concrete in tropical climates

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Abstract

With the introduction of new varieties of blended cement in Sri Lanka, the choices available for the structural engineers for the selection of concrete for large buildings and other structures have improved. This is further strengthened with the introduction of various types of admixtures and additives in the recent times that would allow a wide range of desirable properties for fresh and hardened concrete. In order to obtain the maximum advantage of the new developments, it is useful for the structural engineers to obtain a greater insight into such diversity possible.

Sri Lanka, being a tropical country that is experiencing some effects of global warming, there could be many additional considerations when the cement contents are high as for the high strength mixes. This paper will discuss some new developments in the cements, admixtures, additives as applicable to Sri Lankan scenario and would provide insight to economical selection of concrete grades and mixes to optimize the structural design of large buildings and structures to achieve cost savings while ensuring a robust and durable structure.

1. Introduction

Reinforced concrete can be considered as one of the most sought after construction materials in Sri Lanka. There are many reasons for reinforced concrete to be cheaper than the use of steel. One of the key parameters is the use of locally available ingredients to make concrete such as the sand mined from rivers and aggregates made with blasting of rock available in abundance. Until about 25 year ago, the supply of river sand has been sufficient. However, the introduction of various restrictions on sand mining has led to the increase in sand prices and also led to the widespread use of sand mined from lands that the sand obtained with sand mining from many rivers in Sri Lanka. Large scale sand mining and transportation over long distances have caused many other related problems as well.

Thus, the cost advantage that was available with reinforced concrete over steel construction has been lost to a certain extent and this has led to the introduction of steel buildings as an alternative. The use of steel could lead to reduction in construction times and also could result in light weight structures that will have additional cost benefits. Therefore, more advanced technology has been brought into the scene to maintain its competitiveness as a sought after material.

The use of precast technology and pre-stressing also could bring in many advantages in the use of concrete as a structural material. Even for these, the minimum usage of cement while obtaining maximum strength could have many cost benefits and also some environment related benefits. Since steel is manufactured only at commercial scale, generally, the prices of steel would reflect the environmental costs associated with the manufacturing process of steel. Due to the widespread practice of recycling steel by collecting steel as scrap metal has led to a significant reduction of environmental effects associated with the use of steel. In today's context, it is possible for any steel component bought in the market to have at least 25% recycled steel or sometimes going up to about 90%. This is a very healthy situation and it is ideal for such a situation to be created for concrete as well with the use of state of the art technology associated with cement, the additives that can be used and the proper use of admixtures.

With the use of such technology, it would be possible to improve the way concrete has been used in reinforced and pre-stressed applications. This paper will discuss such applications possible with special reference to the peculiarities pertaining to Sri Lanka.

2. The main objectives

The main objectives of the research presented in this paper could be highlighted as follows:

1. To highlight the types of applications of reinforced and pre-stressed concrete and the challenges that can be posed by the other alternative building materials
2. To device desirable strategies for obtaining higher strengths with the minimum use of cement, thus achieving cost economy while minimizing carbon emissions
3. To relate the problems peculiar to Sri Lanka and highlight the methodologies for overcoming such problems

3. Methodology

The following methodology has been used to achieve the objectives presented above:

1. The various uses of concrete in the form of reinforced and pre-stressed concrete have been highlighted with actual practical applications with special reference to buildings and highway bridges
2. The alternative methods and systems that can be used in a cost effective manner also have been presented in order to highlight the need for optimizations with respect to cost and carbon footprint
3. The state of the art advances available with additives and admixtures have been assessed to determine the changes that can be brought about to improve the applications
4. The special problems associated with the warm, humid tropical climatic conditions prevailing in most parts of Sri Lanka have been highlighted with the precautions taken and strategies that can be followed thus optimizing the use of concrete as a competitive building material

4. The various uses of reinforced concrete

Reinforced concrete can be used in all kinds of buildings. One of the key applications is in tall buildings where there could be large structural members such as pile caps, combined pile rafts, raft foundation and transfer plates that could pose a challenge to the structural engineer. In these buildings, pile caps that transfer the loads on to groups of piles of significant pile diameters such as 1.2 m to 1.8 m could pose a significant challenge with respect to the grades of concrete that is usually used. It is usual to use Grade 30 concrete for such large sections since the use of large sections itself indicate the possibility of the use of fairly approximate design methods for its structural design. Thus, the important question is whether it is worthwhile using a higher grade concrete such as Grade C35 or Grade C40 or even a higher grades.

The other member that needs attention is the transfer plates. The transfer plates can be either solid or cellular. The use of solid transfer plates is the usual practice [1,2,3]. However, a recent trend is the use of cellular transfer plates. The cellular transfer plates will consist of band beams. These band beams can be aligned with the shear walls and hence the moments induced in the transfer floor can be easily transferred to the cores. In addition, a band beam can be installed around the shear core at the transfer floor level. This will allow the effective transfer of loads and moments to the core without inducing stress concentrations at certain pockets that could be detrimental. Since the band beams could be subjected to torsion as well, it is useful to have a slab at the bottom of beams and the top of the beams. It is also possible to use the slab at the bottom level as a shuttering for the transfer floor. Hence, the thickness of this slab can be about 300 to 400 mm depending on the type of loads induced by the self weight of the band beams and the top slab that will be cast simultaneously. The thickness of the top slab can be about 200 to 250 mm.

The use of bottom slab is useful in another sense as well. That is resisting the additional moments induced due to staged construction. The construction sequence can increase the moment acting on the transfer plate by about 50-70% since the load will not be applied at once from above, but will act in a number of steps when each upper floor is constructed. Hence, the sagging and hogging moments in the transfer plate tend to be much more than that is shown by the static analysis. All these additional forces can be easily shared by the reinforcement in the bottom slab and also the reinforcement provided in the band beams. Once completed, a cellular transfer plate of this nature will have a much lower weight though it will still look like a solid slab of a considerable thickness. It will also allow the avoidance of many problems associated with large scale pores. The two buildings shown in Figures 1 and 2 have transfer plates that have been constructed as cellular with a significant saving in concrete and some saving in steel, while achieving thick plate behavior though most of the problems hot weather concreting have been avoided. Figures 3 and 4 show the SAP 2000 models of the whole building and the transfer plate of Sky-garden.

Figure 1:Sky Garden-Rajagiriya

Figure 2: Cinnamon Red-Colombo

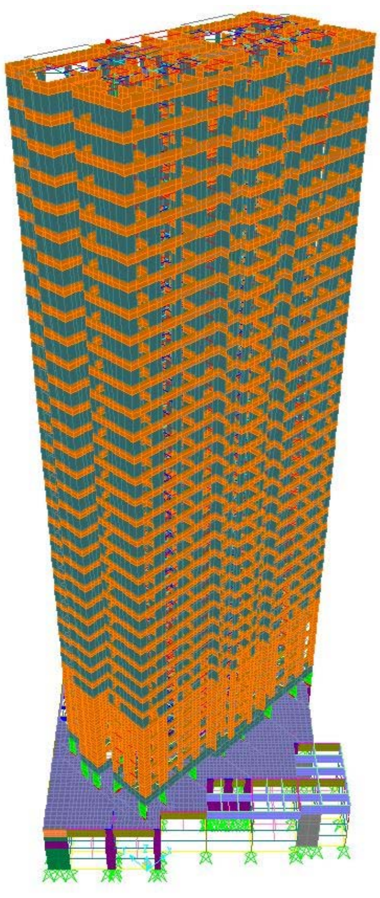

Figure 3: SAP 2000 analysis model of the Sky Garden Building

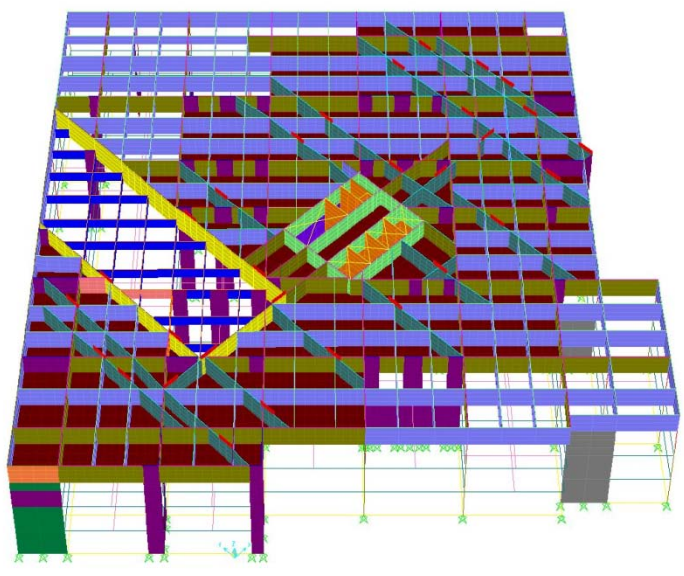

Figure 4: SAP 2000 model of the Cellular transfer plate of the Sky Garden Building

The effective use of reinforced concrete in bridges can be achieved by using an innovative beam slab system with precast elements hence avoiding the need for any kind of formwork or flasework [4]. This bridge stems from the premise that in reinforced concrete, the concrete below the neutral axis is cracked and hence would not serve much useful service except protecting the steel from corrosion. Though it is little difficult to avoid this ineffective concrete with in-situ cast slabs, it is possible to use precast techniques to implement a beam slab system as shown in Figure 5 where all the precast elements of beams and slabs could be combined and formed into one unit with the addition of in-situ cast topping which is adequately reinforced. A bridge of 110 m of length and 3.0 m of width constructed at a mere cost of Rs 7.5 million is shown in Figure 6 where the adoption of any other system for the construction of this bridge should have cost at least Rs 30 million for both the sub structure and the super structure. Another main advantage of this system is the ability of this beam slab deck to absorb support settlements without inducing significant cracking and hence allowing the use of simple foundations that might undergo a limited amount of differential settlements.

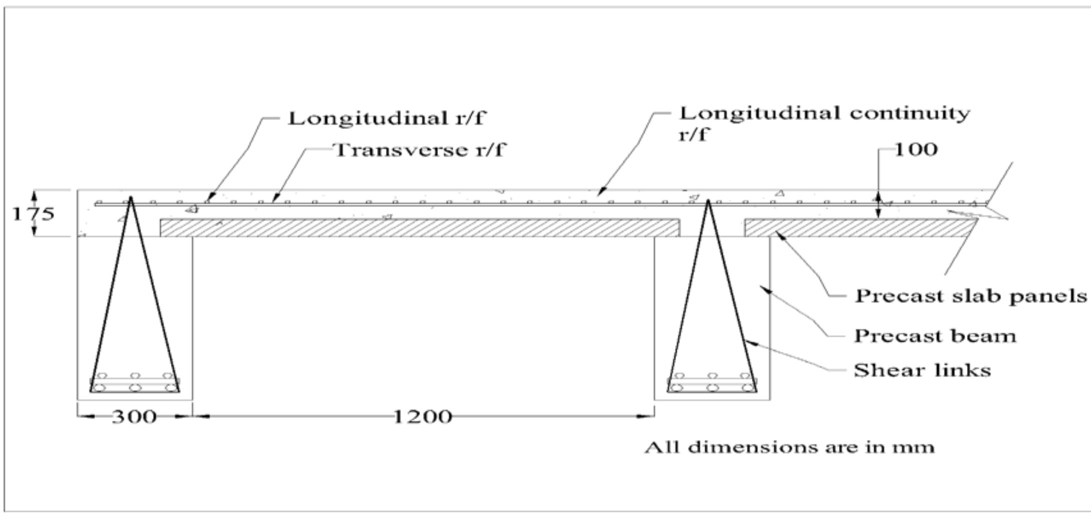

Figure 5: The cross section of the beam slab system

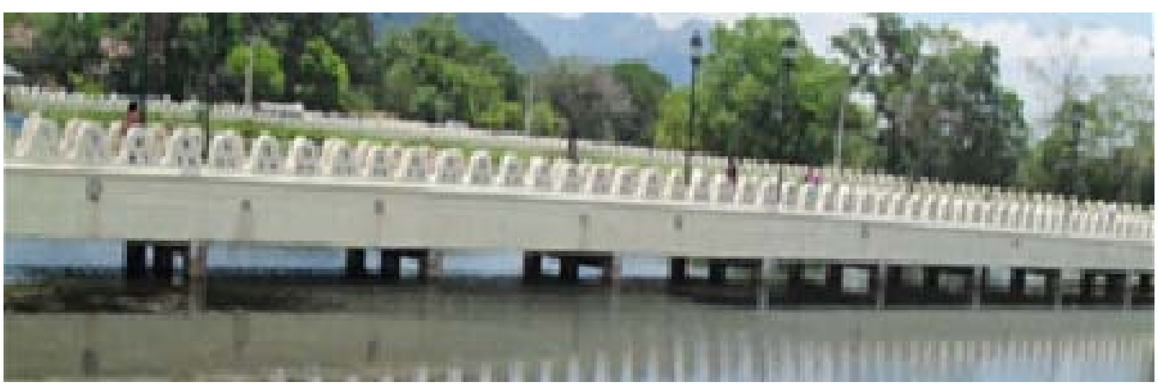

Figure 6: A bridge of 110 m of length and 3.0 m of width constructed at a mere cost of Rs 7.5 million

5. The various uses of pre-stressed concrete

Pre-stressed concrete can be used for many applications involving both precast products and in-situ cast structures. In Sri Lanka, it was usual to consider Grade C30 for post tensioned beams and to use Grade 40 for pre-tensioned precast products. However, it is possible to improve this situation by adopting Grade 50 or 60 concrete for pre-stressing thus improving the allowable stress in compression significantly; this will allow the optimum usage of the capacity of stressing steel and could be either be used to carry heavier loads or to make the sections even leaner [5]. For example, the allowable stress in compression in a Grade C30 concrete is only 12 N/mm^2 whereas the same for Grade 60 concrete is 24 N/mm^2. This means that when the strength of concrete is increased, the allowable stress range can be improved significantly thus resulting in noticeable cost effectiveness and also smaller members being used thus promoting a greater degree of sustainability.

The slab system shown in Figure 7 shows the use of prestressed concrete slabs made with Grade 50 concrete for a precast slab system supported on steel beams. These precast slabs have a span of 6.0 m and a thickness of only 90 mm thus giving a span/depth ratio about 66. This is an extremely high ratio and this was achieved by making the precast slabs continuous over the steel beams by using additional top reinforcement placed within the 40 mm thick screed concrete. This is a method borrowed from precast continuous bridges. The continuity required to transfer the compression was achieved by filling the gap between the two adjacent precast slabs by using construction grout since it will not shrink and also will give a strength comparable with the prestressed concrete. This means that the slab thickness can be reduced significantly without compromising the serviceability behaviours. As the strength was gained after the casting of the insitu topping with Grade 35 concrete, there was no tendency to induce vibrations though the span/depth ratios are beyond the usual range that is used.

The use of extremely strong concrete with high cement content and also having about 15% fly-ash can make the concrete to last a very long time without inducing carbonation thus ensuring that these slabs could last a very long period of time such as at least 100 years.

6. The alternative building materials available

There are many alternative building materials that can challenge the dominance of concrete. One is steel and the effective use of steel in conjunction with concrete to form continuous slabs with precast slabs is shown in Figure 7. Another alternative is Straw Panels called “Durra – the trade name” manufactured in Sri Lanka [6, 7]. This robust product has been fully utilized in the two storey house given in Figure 8 where the walls, floors and the ceiling are all out of Durra.

Figure 7: Pre-cast Pre-tensioned slabs spanning on steel beams with a reinforced in-situ topping on top

Figure 8: The two storey house with the walls, floors and the ceiling are all out of Durra.

Another application of cement in forming alternative material is cement stabilized earth [8, 9, 10]. These can be used as blocks or rammed earth. In the houses shown in Figure 9, the foundations and retaining walls have been out of cement stabilized rammed earth. The roof is out of micro concrete tiles [11]. The floors have been made on cement stabilized and compacted ground. Thus the use of traditional masonry and concrete have been minimized as much as possible and sometimes have been completely avoided. These show that unless some innovation is brought into concrete to make it as cost effective as possible, there is a risk of concrete becoming a material that is not very much sought after.

Figure 9: The tiered houses with cement stabilized rammed earth foundations, retaining wall and cement stabilized earth blocks

7. The use of additives and admixtures for improved usage of concrete

The use of additives like fly ash and silica fume has gained popularity worldwide. In Sri Lanka also, with the starting of coal power generation, fly ash has become a very cost effective cement replacement material. Some cement companies have even developed blended cements with 15% and 25% fly ash. Silica fumes at 5% to 10% can give massive benefits when the concrete grade exceed C60 [12]. However, the use of Silica fumes is still not widespread due to higher cost.

The other technique for obtaining good concrete is the use of super-plasticizers that can lower the water cement ratio (W/C ratio) to be around 0.33 and high grade super-plasticizers that can still lower it to about 0.23. Such very low W/C ratios can give high strength concretes with significantly low cement contents. The only drawback is the cost of these admixtures, especially the high grade super-plasticizers. Nevertheless, the additional cost can be offset to a certain extent by reducing the cement content that can also be useful in preventing the Delayed Ettingite Formation in large concrete sections [13]. Some possible concrete mixes for high strength concrete with high grade super-plasticizers could have cement contents as low as 350 kg/m^3 even when Grade 50 concrete is needed.

8. The problems associated with warm humid climatic conditions

The warm humid climatic conditions that prevail in most parts of Sri Lanka except the hill country could result in placing temperatures rising to about 32^{o}C to about 36^{o}C. Such high placing temperatures would be detrimental in large sections. The strategy is to control the placing temperature of concrete with the use of flaky ice and also cooling down the aggregates by wetting. Even such strategies might not work in certain circumstances and hence DEF can occur. Thus, some easy to refer guidelines have been prepared and presented in chart form for easy reference during early design stages. Three such charts are given Figures 10-12 [13].

These charts indicate that the presence of fly ash can make a significant impact on the peak temperatures reached. For example, when the thickness of the section is 1000 mm, with 350 kg/m^3 of cement, the peak temperature reached is 75^{0}C and it runs the risk of forming DEF in the presence of moisture. However, when fly ash is used to replace 15% of cement, the same section thickness will induce only a peak temperature of 70^{0}C and the use of 25% fly ash can give a peak temperature of only 65^{0}C. This indicates the use of fly ash could reduce the risk of DEF occurring or completely eliminate that. On the other hand, the same effect can be obtained by using high grade super plasticizers as well. Thus, such possibilities must be actively pursued by the industry to make the large concrete pores safer and also to reduce the cement contents used even with high strength concretes. Such approaches can also assist with reducing the carbon foot print of products that use a particular grade of concrete.

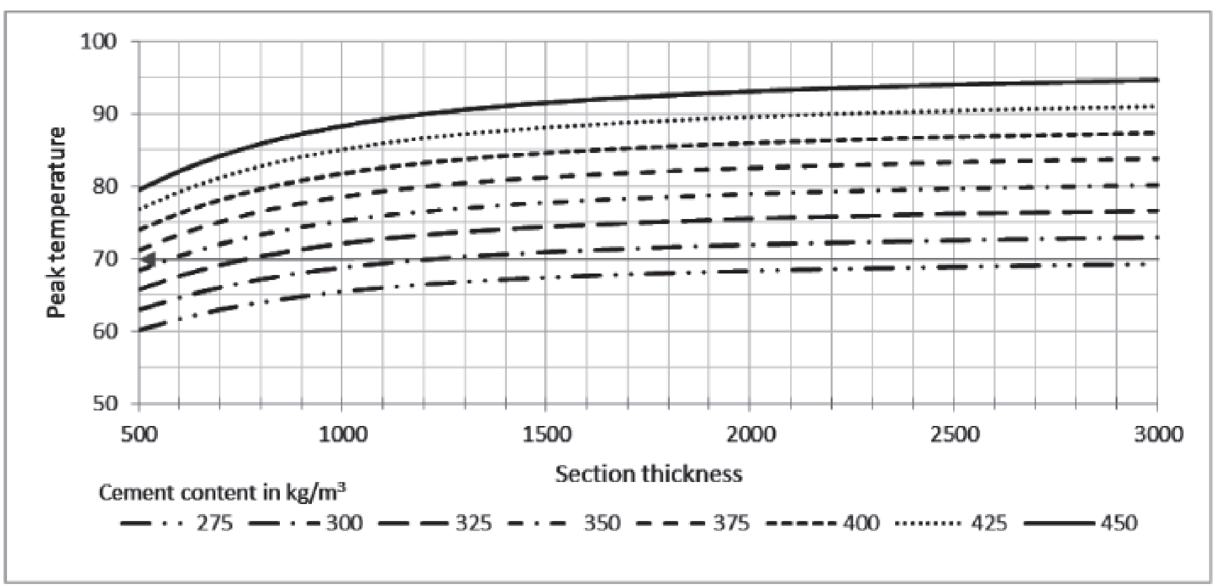

Figure 10: Peak temperature variation of various concrete mixes with a placing temperature of 32^{o}C and 0% fly-ash

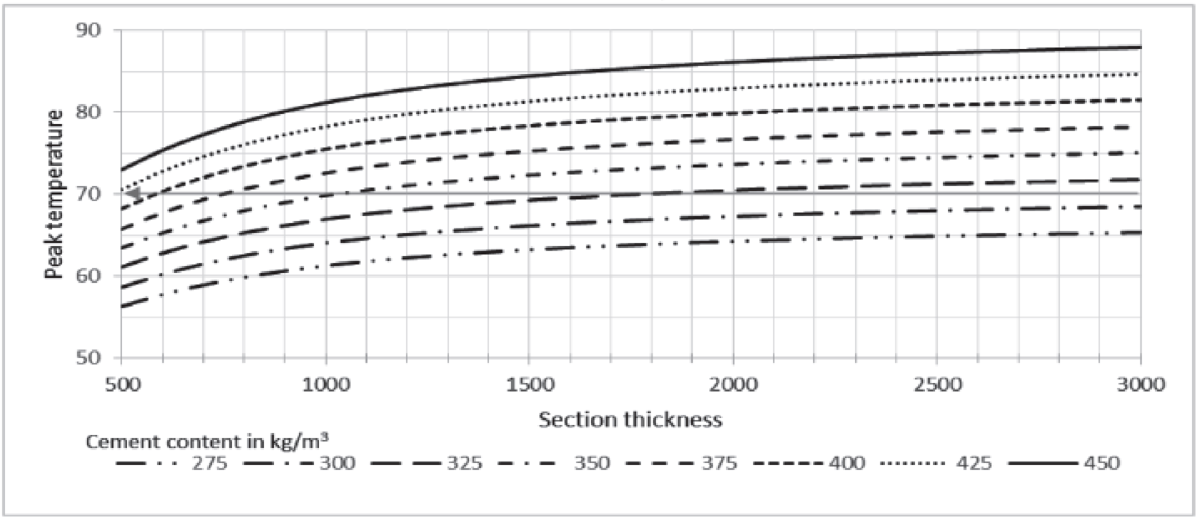

Figure 11: Peak temperature variation of various concrete mixes with a placing temperature of 32^{o}C and 15% fly-ash

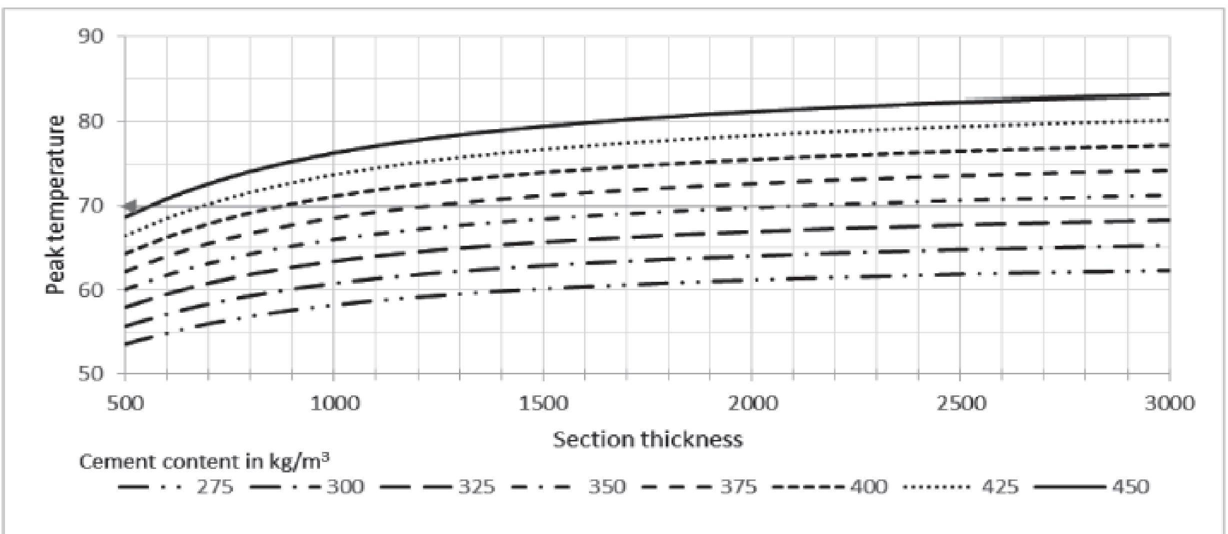

Figure 12: Peak temperature variation of various concrete mixes with a placing temperature of 32^{o}C and 25% fly-ash

9. Conclusions

Sri Lanka is a tropical country and most parts of the island have warm humid climatic conditions. Hence, it can pose considerable challenges and some of the latest techniques such as additives and admixtures available can be effectively used to overcome such difficulties. The following points can be highlighted:

1. The use of reinforced concrete will need a quantum change in the approach where an attempt should be made to make use of higher grade concrete while achieving it with

minimum cement content while using additives like fly-ash to ensure the long term gain in strength

2. The use of concretes of higher grades such as C40 and C50 for reinforced concrete should be made viable for smaller sections where the development of early thermal cracks could be easily prevented with the use minimum steel ratios
3. The same is applicable for prestressed concrete as well and hence the use of Grades C 50 and C60 should be of common occurrence
4. The use of such high concrete grades will result in the production of leaner precast prestressed concrete sections thus reducing the section sizes and the prestress required
5. The use of light weight, but of high durability materials like Durra could be strongly recommended to be used as partition materials thus minimizing the weight of partitions and hence the impact on foundations could be reduced

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