Energy conservation in construction through concrete demand management in an Egyptian context

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Abstract: *Energy shortage is becoming a major impediment to the sustainable development of Egypt. Energy intensive industries, such as steel and cement which directly feed into the construction industry, take a heavy toll on the country's energy balance. This paper identifies reasons of material overuse in mainstream construction. Although the construction industry is governed by building codes and overseen by regulatory bodies, quality control remains inadequate, leading to material misuse. The paper also proposes institutional and organizational actions to rationalize the use of cement. The requisites and approaches for implementing the recommended actions are addressed, their impact on energy consumption presented, and the parties involved in undertaking these changes identified. The successful implementation of these interventions will have a direly needed positive impact on Egypt's energy balance and help the cement industry meet growing demand for construction reducing the need for new capacities.*
Keywords: Egypt, construction sector, energy shortage, demand-side management.

Introduction

A critical energy shortage is currently facing Egypt and its economy. Construction, being one of the most dynamic industries in Egypt, has a definite impact on the energy demand as most energy intensive industries such as cement, steel, bricks and ceramics feed directly into this industry. In order to reduce the energy consumed to produce such materials, measures such as production process energy efficiency, utilization of alternative fuels and reduction of specific energy consumption have been already proposed. These measures effectively reduce energy consumption, but might not yield quick results as they likely require additional investments, significant plant changes and up-grading or creating infrastructure.

Conversely, the focus of this paper will be on the demand management of cement and the prospects of improving the energy profile of reinforced concrete (RC) structures both in terms of composition and dimensioning. It does not aim to introduce alternative products or innovative materials that offer substantial energy and material savings[1]. Rather, it will examine ameliorating the current practices with established solutions as these offer more timely implementation and results and are already governed by codes, standards and practices.

Cement is the most energy intensive component of concrete. The Egyptian market is primarily reliant on local cement production capacity rather than imports. Excess production used to be exported but recently the exports have significantly dwindled. Natural gas (NG) has the lion's share in the local energy mix for cement production with heavy fuel oil being the secondary

[1] Even though alternative products may be far more consequential in terms of energy savings; they need a considerable period of time to become common practice.

fuel. In 2012, 51.2 billion cubic meters of natural gas were consumed nationally of which roughly 10% was consumed in the cement sector.
The energy profile of cement per se is proposed to be improved through clinker substitution. Moreover, the improvement of design and site execution practices could reduce the use of cement as part of the RC system.

Overview of Cement Types and Clinker Substitution

Cement, the binding component of concrete, is primarily composed of clinker and a variety of other constituents depending on the type of cement. The compositions of the different cement types are set by the Egyptian Standards 4756-1 (2009) which take cue from the European standards EN 197 – 1. However, the Egyptian Standards and the Egyptian Code of Practice 203 – 2009 ban specific cement types for use in RC structures such as limestone cement, blast furnace slag cement (with substitution percentages greater than 36%) and composite cement as shown below. In comparison to Europe, the US and Canada, the variety of cements in Egypt is relatively limited.

Table 1: Cement types as per the European Standards and their allowance for use by the Egyptian Code in reinforced concrete (RC)

Cement Type	Cement Designation	Percentage Substitution	Co-constituent's Local Availability	Allowance in Egyptian codes and standards in RC
CEM I	Portland	None, 100% clinker	√	√
CEM II	Portland - slag	6% to 35% Ground Granulated Blast Furnace Slag (GGBFS)	√	√
	Portland - silica fume	6% to 10% Silica fume(SF)	X	√
	Portland- pozzolana	6% to 35% Pozzolana[2]	√	√
	Portland - fly ash cement	6% to 35% Fly ash (FA)	X	√
	Portland - burnt shale	6%to35%Burnt shale-BS	X	√
	Portland - limestone	6% to 35% Limestone	√	X
	Portland - composite	6% to 35% GGBFS, SF, Pozzolana, FA, BS, Limestone	X	X
CEM III	Blast Furnace Slag	35% to 95% GGBFS	√	X
CEM IV	Pozzolanic	11% to 55% - Pozzolana	√	√
CEM V	Composite	18% to 50% Pozzolana, FA	X	X

Limestone cement presents the most promising option due to limestone abundance in Egypt, possible high substitution percentages in blended cement, easy grind-ability and convenient access to limestone quarries. Consequently, focus will be on limestone cement.

Limestone substitution

Portland - limestone cement (PLC) is produced either by inter-grinding limestone with clinker or blending it with ground clinker. It is used for general purpose concrete and masonry in non-aggressive and moderately aggressive environments (1). It is not recommended for use in aggressive environments and building foundations. PLC is already produced in Egypt by two cement companies for use in plain, ordinary concrete, mortars and screeds. Bagged PLC currently bears a warning that it should not be used in RC.

[2] Pozzolana is categorized as either natural or calcined. While the former is not locally available the latter can be produced from thermally treating oil shale.

Overview of International Norms and Specifications

PLCs have a long history of use in Europe in applications that do not require sulfate resistance[3]. Spanish standards permitted up to 10% limestone in 1960 (raised to 35% in 1975), French standards adopted provisions for use of up to 35% limestone in 1979, and German standards for PLC were adopted in 1994, although cements with up to 20% limestone were manufactured for specialty applications in Germany as far back as 1965 (2). More recently, the European specification EN 197-1, formally adopted in 2000 by members of the European Committee for Standardization (CEN), sub-divided PLC into two categories according to the total organic carbon (TOC) content[4]. In 2008, the Canadian Standards Association (CSA) allowed for inter-grinding up to 15% limestone and forbade its use in sulfate-prone environments[5]. While in the US a 5% limestone substitution in cement was allowed under the American Society for Testing and Materials (ASTM) standards, a new standard - ASTM C595- was released in 2012 allowing for up to 15% limestone substitution.

Previous studies on PLC

Egypt, as a potential late-comer, can benefit from studies already undertaken and experience and knowledge acquire over the last 20 years to formulate the current cement product mix in Europe. Studies covered study the various aspects of using PLC from the economic, environmental, physical and chemical perspectives.

The economic benefits come down to the possibility of obtaining a type of cement having a strength development similar to that of Portland cement at reduced production and investment costs per ton of cement. The cement content, as with other cement types, is determined by the desired strength and consequently the water/cement (w/c) ratio. Environmental benefits are due to reduction in fossil fuel consumption and CO_2 and NO_x emissions from fuel (3). On the physical front, it instigates better packing of the cement's granular skeleton and a larger dispersion of (clinker) cement grains (4).

In 2009, the European Cement Research Academy (ECRA) (1) under the Cement Sustainability Initiative (CSI) studied the energetic and practical impacts of producing and using PLC. The study stated that using PLC may lead to better concrete workability and lower alkali-silica reactivity, reducing the energy required to remove high alkali-containing kiln dusts from the kiln bypass system. Yet, for PLC to give the same strength as OPC, it has to be more finely ground. The study also claimed that during cement hydration, limestone reacts with calcium aluminate producing a mono-carbonate that does not contribute to strength formation. However, Bonavetti et al. (2003) (3) stated that using PLC increases early

[3] Sulfates are present in sea water (marine and coastal environments) as well as in some soils and ground-waters. http://www.understanding-cement.com/sulfate.html

[4] The provision for TOC content of the limestone is related to freeze-thaw performance of concrete. Such provision is irrelevant to climate conditions in Egypt

[5] CSA A3001

strength[6], limits bleeding in concrete with low cement content, and has low sensibility to the lack of curing.

Using limestone in cement may compromise on the resistance to acids, sulphates and the freeze-thaw cycles. Hence, the proportion of limestone in cements has been limited to a maximum of 25 to 35% by mass (1). Alunno-Rossetti and Curcio (5) found increased chloride ion penetration[7] in concretes produced with PLC with 20% inter-ground limestone as opposed to similar OPC concrete. However, Tennis et al. (2011) (6) stated that increased chloride ion penetration may take place in PLC concrete produced at the same w/c ratio as OPC concrete. However, OPC and PLC concrete are expected to present similar performance when proportioned to give the same compressive strength at 28 days. On the same note, the British Standards BS 8500 considers that at the same strength class, PLC has equivalent resistance to chlorides as OPC. Similarly, PLC is restricted for use in design chemical classes 1 and 2 in BS 8500 just like OPC, but with different limits on water/cement ratio and cement content.[8]

Another factor affecting concrete durability and correlated with PLC is Thaumasite Sulphate Attack (TSA)[9], which leads to an overall loss of concrete strength. Following an extensive review of research, Irasser (2009) (4) concluded that the risks of TSA are minimized with low w/c ratios, sulfate resistant cements, and sufficient cement contents[10]. While current studies indicate that PLC has higher vulnerability to TSA than OPC concrete, supplementary cementitious materials[11], when combined with PLC, may be able to reduce the risk of TSA. (4) Hooton and Thomas (2002) (7) stated that PLC should not be used beyond Class I sulfate conditions (i.e. when SO_4 content of groundwater exceeds 0.4 g/L).
The British standard BS8500 recognizes that for PLC and OPC concretes of the same strength class, PLC has a resistance to carbonation[12] equivalent to that of concretes containing other cement types in all carbonation exposure classes.

These studies and experimental works show various results. Concern regarding vulnerability due to the presence of limestone in cement to chloride penetration and susceptibility to sulfate attacks is an area of contention. On the other hand, PLC offers improved strength development, workability, reduced ‘bleeding’ and reduced costs and CO_2 emissions.

[6] Limestone enhances the hydration rate of cement compounds, contributing to strength development
[7] When chloride ions reach the steel they de-passivate the region surrounding the steel and hence in the presence of air and/or water, steel starts corroding. As the volume of corrosion products increase relative to the original steel, re-bars expand and concrete begins spalling.
[8] Lafarge TARMAC. PLC Datasheet. March 2014
[9] Concrete exposed to sulfates at lower temperatures (5 °C) is subject to thaumasite form of sulfate attack (TSA) especially when the concrete contains a source of carbonate ions. Such low temperatures are only reached in Egypt in limited areas for limited times of the year.
[10] Put differently, established sulfate resistant concrete practices minimize the risks of TSA
[11] For example; silica fume, ground granulated blast furnace slag and fly ash.
[12] The reaction of carbon dioxide from air with the calcium hydroxide in concrete to form calcium carbonate, reversing the chemical process of the calcination of lime that took place in a cement kiln. It causes corrosion.

Thermal and electric savings

The reduction in clinker content directly reduces the fuel used in the kiln. Moreover, the manufacturing of PLC is less electricity consuming due to the fact that limestone's grind-ability is higher than that of clinker[13]. According to ECRA (1), the savings are as follows.

Percentage Substitution	25%	35%
Thermal Energy Savings	0.22 GJ/t	0.6 GJ/t
Electricity Savings	12 kWh/t	23 kWh/t

The investment cost ranges between 8 and 12 million Euros per plant, accounting for the extra storage capacity and handling equipment (1). However, savings and costs need to be assessed based on individual plants.

In terms of thermal energy savings in Egypt, substituting 25% of the clinker with limestone, 25% of the thermal energy required to produce clinker will be avoided. In other words, if PLC production reached a total of 40%, about 1 % of the total national NG consumption will be avoided[14]. Such savings potential are certainly worth achieving.

Using limestone cement for reinforced concrete in Egypt

Limestone properties in Egypt are compatible with European standards for use in PLC. Most limestone quarries in Egypt have good separation between clay and limestone[15], and thus have high quality limestone with limited TOC and clay content. PLC production entails minimal investment costs at the cement plant which essentially includes more silos and conveyors.

Previous Local Efforts

Around two years ago, Suez Cement (Italcementi Group) proposed to extend the use of PLC to reinforced concrete structures in Egypt to the Egyptian Organization for Standardization and Quality (EOS) and the Housing and Building Research Centre (HBRC), thus saving energy while maintaining production levels. One concern was that openly providing to the market a product dissimilar to OPC, with its own application limitations, before proper design and execution practices are established, structural strength and durability could be compromised. Another is the possible corrosion of steel reinforcement. However, on the letter point, previous studies show that corrosion only occurs in coastal and humid areas while Egypt is not generally characterized with high humidity (except for coastal areas).

Although the previous efforts have not concluded in concrete steps yet, the current ban might be reconsidered in the RC Code revisions within a year[16]. As presented, the existing infrastructure for PLC production already exists and governing codes and standards are

[13] Electricity consumption will be reduced even if the PLC's grain size is reduced.

[14] The specific energy consumption for local OPC is 3,781 MJ/ ton clinker. Assuming 40% of the cement produced in Egypt (20,374,000 tons) is 25% limestone PLC and consequently 0.945 GJ/ton thermal savings; 20,858,693 GJ will be saved. Put differently, 0.51 BMC of the 51.21 BMC of NG consumed annually is saved. 40% savings present the most conservative figure as PLC use will exclude mass concrete (e.g. in bridges) applications. The eligibility of using PLC for mass concrete is not fully agreed upon in different PLC's product specifications.

[15] Personal communication

[16] Personal communication

established and hence problems are not related to production. Rather, as with any cement type, the water requirements and cement contents should be set as to achieve the required strength and overcome any attacks on concrete. Accordingly, the bulk of effort for the extensive use of PLC needs to be done downstream, in real cooperation with contractors and engineers to fully assimilate the difference between OPC and PLC. The final section of this paper will further discuss this point and will put forward recommended actions in this regard.

RC common design and use practices

The Egyptian Code, 203-2007, includes two RC structures design methods, the Working Stress (WS) and the Ultimate Strength (US). Although the US method is most commonly used in Egypt and world-wide, Egyptian senior engineers are still more familiar with the WS Method. The US Method was calibrated in the Egyptian Code to yield results similar to that of the WS Method[17]. The Egyptian code takes cue from international codes but is bound by the local quality practices. Some parameters are thus modified; for example, the values of the factors of safety used in the US design load combinations are 1.4 for dead loads and 1.6 for live loads in the Egyptian Code while in the Euro Codes they are 1.35 and 1.5 respectively. Higher factors of safety lead to heavier RC sections and reinforcement as compared to European construction, and thus more energy consumed in building materials (8).

The Egyptian construction industry, despite being well-established, suffers from a number of critical drawbacks. Many construction companies have lax quality control and testing measures. Contractors are registered at the Federation for Construction and Building Contractors (FCBC) where they are classified according to competence. However, not all Class (A) contractors have formal quality control systems; only those operating internationally do. The industry practice to delegate work to cascading sub-contractors further complicates quality assurance and control. The lack of solid collaboration, understanding and trust between the site and design engineers is also a determining factor To avoid the risk of structural failure, poor onsite execution is addressed by structural engineers through over-designing RC structures beyond their calculated dimensions according to an already conservative code.

With the above considered, structural elements can be increased up to a total of 30% more than the calculated design to overcome the risk of poor on-site construction quality including poor concrete quality. This is especially true when concrete is mixed on-site rather than acquired from ready-mix plants. However, even for those, it has been reported that for large-scale projects such as power plants and bridges, a number of the ready mix plants are not short-listed as their concrete quality is not ensured[18].

On a similar note, some structural engineers claim that the Egyptian seismic design code is too conservative which also lead to material overuse. Moreover, structural engineers who lack the competence to design according to seismic design code often arbitrarily overdesign to

[17] Personal communication
[18] Personal communication

overcome any uncertainties. Overdesign in all cases is formalized through structural design reviewers who do not reject the structural design as long as it is safe even if over-designed. This is a logical result of the reviewer's role as it feeds into the decision related to insurance required as part of the licensing process.

Moving further on, concrete is commonly overused onsite beyond design. For example, slabs are executed as 15 cm even when the design drawings indicate a smaller thickness. This is attributed to the difficulty of bending steel reinforcement for 10 cm or 12 cm slabs. As for the supply of concrete, some ready-mix plants upgrade the concrete strength grades (and hence increasing the cement content) to ensure that their trucks are not rejected on-site. Poor gradation of aggregates also influences the workability and the cement content in concrete and is a function of the quality control on the site.

Although there is no official census on building collapse and reasons behind them, the concern regarding structural failure due to poor site execution and the risk aversion of design engineers seem justified. In 2008, Abdel–Latif (9) collected case-studies of buildings in Egypt whose reasons for collapse[19] are known over the period from 1955 to 2005. Of the 30 case-studies, only 3 building collapses were attributed to poor structural design while 8 collapses were attributed to poor site execution, 8 collapses were due to faulty renovations and 11 collapses were due to an increase in the building stories that had not been designed or accounted for. Other factors include gas explosions, failure of neighboring buildings and excessive loading. In 2009, HBRC (10) studied the main reasons behind faults and cracks in 530 buildings over the period from 1985 to 2005. It was found that 52% of the cracks and faults were due to poor site execution while 19% were due to poor structural design.

Future Outlook

Material overuse seems to boil down to the root cause of poor quality control, which resonates in the Code where factors of safety are high and in general practice where RC sections are increased beyond their calculated design. The use of PLC is also hindered by poor quality control as there is a concern regarding its appropriate use on-site. Accordingly, improvements in quality control can significantly lower the thermal energy intensity of building construction[20]. The figure below shows the 'base-case' thermal energy consumption of cement production extrapolating the demand for construction from actual data from 2002 to 2011. It also shows the future energy consumption if PLC represents 40% of the local cement consumption resulting in roughly 10% decrease in thermal energy. If overdesigning beyond the code is reduced to half, an additional 10% production and thus the thermal energy consumption will be reduced. It is well understood that quality control and assurance is not a measure to be undertaken instantaneously and swiftly. However, in addition to energy conservation, it is a desirable labor-intensive process given the current unemployment levels.

[19] Excluding collapse due to natural disasters (e.g. floods, earthquakes and fires)
[20] The repercussions of using less concrete not only entails less cement but also less steel and less energy for handling and for transport.

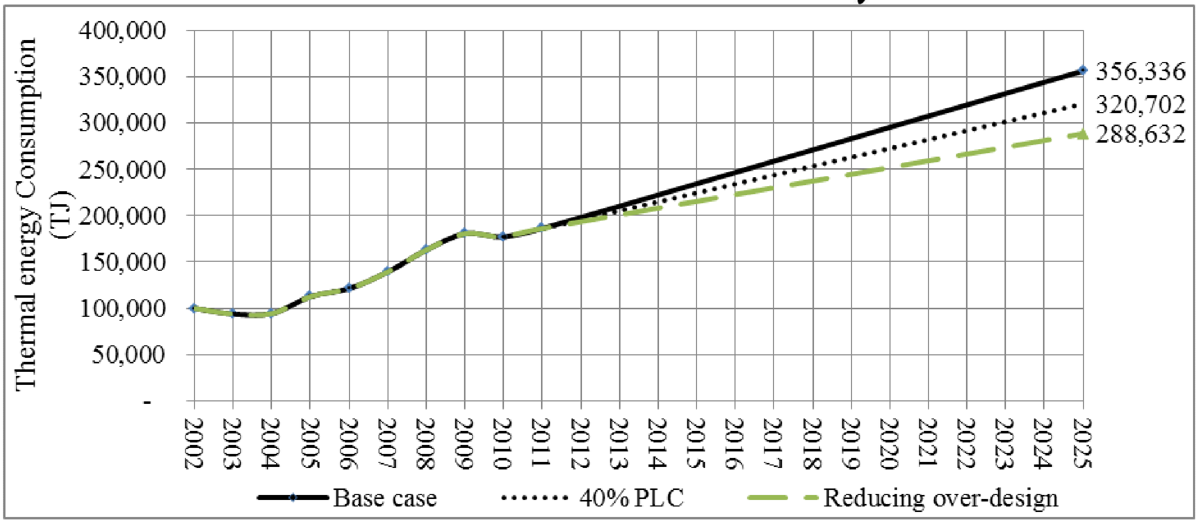

Figure 1: Projected thermal energy consumption for cement production

Recommendations and Future Actions

Proposed actions in this section benefit from suggestions of interviewees[21] but formal consultation with the major stakeholders should be undertaken prior to implementation for refinement and 'buy-in'. The current situation offers an opportune time to undertake these actions; as interviews revealed that the deterioration of construction quality has become a point of concern for both the construction industry and the State.

Limestone cement market penetration

OPC is the most common and dominant cement type in the Egyptian construction industry, which knowledge has been passed over from one generation of workers to the next. Hence, in part, the concern is that the mainstream construction industry would be reluctant to use a new type of cement with which they are not familiar and that has a different behavior than OPC in terms of strength development, slump, consistency, water requirement and setting time, etc. Moreover, PLC being not recommended for use under-ground and in coastal areas will likely add to the suspicion and uncertainty of the construction community. The complementary concern is that PLC is improperly used, given inappropriate adaptation from the industry.

Accordingly, a controlled and gradual diffusion approach, starting from the upper end of the market then slowly moving down to lower levels, is of utmost importance for the successful penetration of PLC in the construction sector. First, the Code should sanction the use of PLC in RC. To minimize resistance, this should clearly be coupled with an action plan regulating its gradual introduction to the market. It is suggested that PLC should first only be supplied through ready-mix plants. In other words, it will only be produced in cement companies having their own ready-mix plants[22]. In the following stage, all cement companies could produce PLC but its use in concrete will still be restricted to ready-mix plants, whether owned by cement companies or not, thus facilitating its quality control[23]. Accordingly, for the first years, PLC will only be supplied in bulk.

For contractors to use PLC, they will be required to obtain a proof of training of their relevant personnel from the FCBC stating that they fully understand the terms and conditions of using

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[21] See acknowledgement below.

[22] The total ready mix plants form 10% to 15% of the Egyptian concrete market.

[23] HBRC has a long experience is monitoring the process and testing the product of ready-mix plants

PLC in reinforced concrete. This will confirm the contractor's legal responsibility to abide by the terms of PLC use. FCBC is in a position to provide training to contractors' relevant personnel. It could use training centers of major contractors to provide 'hands-on' experience with PLC, its use restrictions, strength development and workability as compared to OPC.

The design engineers should clearly state the recommended mix proportions on the construction drawings and not only the required compressive strength, as is currently the case. They would thus need to gain full knowledge of the concrete mix design using PLC. This can be secured by the Syndicate of Engineers in cooperation with cement plants and/or HBRC.

Suggestions regarding quality control improvements outlined below will also smooth the introduction of PLC in the market. After sufficient confidence is gained, the momentous leap would be to supply it to the rest of the market. Until then, PLC already produced in bags should continue to bear the warning stating that it should not be used in RC. It is of chief importance to set the price of PLC competitively with OPC to create a strong market pull. This will be in the interest of producers as it should increase the share of ready mix plants in the concrete production, and regulators as it facilitates the quality control of concrete.

Construction industry regulation

The FCBC is well-positioned to upgrade the quality control performance of contractors according to their different classes. As a first step, formal quality control system for the construction industry in Egypt should be formally required from the most competent contractors. The required system should take cue from high-end contractors who already have well-established quality control systems. This will gradually move to class (B) as well as class (A)'s sub-contractors. Having the government set operational quality systems as an eligibility condition for contractors to undertake any of its construction projects provides an effective competitive advantage and would encourage other contractors to follow suit.

In order to decrease the risk perceived by design engineers, the relation with the supervising engineers should be clearly regulated and defined. A legislative document should be drafted by the Syndicate of Engineers to regulate the relationship between the two parties to be incorporated into the Housing and Building law. Accordingly, this will be reflected in the terms of registering consulting engineering firms at the syndicate of engineers. Moreover, only licensed contractors should be allowed to do construction works, irrespective of the building complexity. As part of the licensing process, licensor bodies should ensure that buildings are not over-designed just as insurance companies ensure the building's safety.

Finally, it should be put into perspective that the informal building sector in Egypt represents more than 50% of the private buildings and is, by definition unaffected by a change in laws or regulations. However, it is surely influenced, although on a longer term, by dominant, formal sector practices.

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