Developing knowledge-based computational tools using MATLAB – Novel applications in Concrete Materials Technology

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Abstract

The development of intelligent computational tools provides new opportunities to exploit various potentialities of computers. At present, automated computing is the main means for the application of engineering knowledge. The growth and development in the application of computing tools and technologies, and the development of new paradigms has been incremental and linear. Many fields have taken significant advantage of the recent advancements in computing technology to adapt, apply and enhance the way people learn these fields.

In this paper, a framework for developing efficient knowledge-based computational applications is presented with an actual case study of concrete mixture proportioning. Recommendations are also developed targeting the possible employment and application of latest computing technologies in concrete engineering. The presented case study comprises of developing a computer application for a recently developed novel mix design method for Pakistan based on empirical results established as a result of a detailed testing program. The experimental testing details and results for development and validation are presented in a separate study. Design flowchart and necessary calculations are implemented in a Graphical User Interface (GUI) in MATLAB R2009a environment which is designed as a self-explanatory program providing an easier and friendly platform to compute constituent quantities, adjust various trials and understand the art of mix design.

The interface is developed in a simple and interactive manner for convenient visualization of complete step-by-step process of mixture proportioning, aiming not only to provide an easy tool for what-if analysis, but also to generate a learning attitude among the end users. The interface is also equipped with necessary help notes, attractive and self-explanatory interactive graphics and description for each dialog box. A parametric study attempting to comment on the effect of changing various desired characteristics on recommended constituent quantities is also carried out using this program and is also presented.

Keywords: Computational Tools, Mix Design, MATLAB, GUI

1. Introduction

In engineering and other technological fields, the growth and development in the application of computing tools and technologies, and the development of new paradigms has been incremental and linear. The old learning paradigm was about what software/tools can do while the new paradigm is all about what users can do (Shneiderman, 2002). Often the developments which are going on, in various fields related to computing software and hardware are done independently with a particular focus. The wide spread use of internet, intranet and more recently cloud computing is changing the way computers are being used, and information is being shared and stored (Anwar et al, 2011). The availability of latest computational platforms, simulation tools, analysis packages and World Wide Web have now changed the way engineers deal with real life problems by helping them become actively engaged in collaborative work via various computer-supported processes.

2. Emerging Technologies and Tools

Many fields have taken significant advantage of the recent advancements in the technologies related to computing and communications which are happening in an exponential manner, especially when considered along with their reduction in cost per feature or capability. Traditional computers including desktops and workstations are being replaced by laptops, notebooks, smart pads, and tablets. Development of wide range of delicate instruments and sensors (accelerometers, inclinometers, light sensors, noise sensors and many more) integrated with attractive 3D displays may prove to be very handy for field civil engineers.

Information and data sharing, access and transfer has gone through a revolutionary change with the emergence of modern mobility, wireless connectivity devices and access technologies over the last few decades. Social media have made it possible to get in touch with work groups around the clock, no matter where you are. Online journals, blogs, newsgroups, digital libraries and search engines are available to find the relevant information in abundance. In the computing field, Artificial Neural Networks (ANN), Fuzzy Logic, Genetic Algorithms (GA), Optimization etc. are some important and powerful tools applied to solve difficult problems with a different and appealing approach. Remarkable efforts are being done in various walks of life to absorb this innovatory change and to make best use of the modern computing technologies and devices (Anwar et al, 2011).

3. Computational Paradigms in Structural Engineering

Modern computing techniques and devices are now playing their role in various structural engineering fields. With the increasing interest in building information modeling in the industry, various model-based applications have been introduced to facilitate the professionals. Currently most of the structural engineers are using the traditional computing programs and techniques to solve their problems especially while designing structures and it is very difficult to visualize the results or output of the analysis carried out on structures (Edward, 2000). Sometimes even after a successful analysis, it is difficult to present the output in an understanding way. For this purpose visualization techniques are now being applied to communicate the message by creating images, diagrams or animations.

With the development in computing industry, a wide range of software is developed for structural engineers to help them out in various tasks. Now, with the help of computing software, it is possible to perform various computing activities in a shorter period of time including preliminary designing for initial sizing of members, modeling and analysis, graphical representation and visualization of the analysis output, generating Building Information Model or BIM to present and visualize building components, construction sequences, resource allocation and other disciplines of construction process in a virtual environment. ETABS, SAP2000, STAAD Pro, SAFE, Auto CAD, ANSYS, ABAQUS, PERFORM 3D and much other software serve the above mentioned purposes. On the other side, open source tools and frameworks like “OpenSees” (Open System for Earthquake Engineering Simulation) allows users to create object-oriented applications for simulating the response of structural and geotechnical systems subjected to earthquakes.

Similarly, with the evolution of mesh-less methods for structural analysis, various other advancements in finite element analysis and performance-based design procedures, the importance of high-speed computing and enhanced processing units has increased exponentially. On the other side, the development of integrated sensors, radio-frequency identification (RFID), global positioning system (GPS), wireless and other technologies are being used for real-time monitoring of the structural response, both for ambient conditions and during events such as strong winds, earthquakes, moving loads, temperature and moisture changes etc. These sensors can also be employed to track and monitor the time dependent phenomena such as shrinkage, creep, concrete aging, degradation, ionization, chlorine attack and link these inputs to the structural models to produce meaningful response that can be communicated to the owners, public and researches in real time (Anwar et al, 2011). Material behavior simulation has now become more demanding with the advent of smart materials including piezoelectric and magnetostrictive materials, shape-memory alloys, temperature-responsive polymers, chromogenic systems (electrochromic and thermochromic and photochromic), self-healing materials and dielectric elastomers (Wenwu, 1999).

4. Computer Aided Mix Design of Concrete – A Case Study

Concrete mix design is the science of deciding relative proportions of ingredients of concrete, to achieve the desired properties in the most economical way (ACI 211, 2005). With the advent of high-rise buildings and pre-stressed concrete, use of higher grades of concrete is becoming more common. Mix design of concrete is becoming more relevant in this scenario. The overall objective of proportioning can be summarized as “selecting the suitable ingredients among the available materials and determining the most economical combination that will produce concrete with certain minimum performance characteristics”. An obvious constraint is that within a fixed volume, one cannot alter a component independent of others. For example, in a cubic meter of concrete, if the aggregate component is increased, the cement paste component decreases. The task becomes complicated by the fact that certain desired properties may be oppositely affected by changing a specific variable. For example, the addition of water to a stiff concrete mixture with a given cement content will improve the flowability of fresh concrete but at the same time will reduce the strength. In fact, workability itself is composed of different components [i.e., consistency (ease of flow), yield stress, cohesiveness (resistance to segregation) and viscosity], and these tend to be affected in an opposite manner when water is added to a given concrete mixture. The process of mixture proportioning, therefore boils down to the “art of balancing various conflicting requirements”.

A very few commercial software packages are available covering various aspects of concrete mix proportioning and trial mix adjustments coupled with experimental data. Employment of intelligent systems and genetic algorithms in concrete materials technology may provide a solid platform for development of efficient computing tools. A case study program for a recently proposed empirical method (Najam et al, 2012) of mix design based on local materials of Pakistan is developed and presented here. It is developed in the form of a Graphical User Interface (GUI) in MATLAB R2009a environment. MATLAB is both a computer programming language and a software environment for using that language effectively. Its interactive environment allows the user to manage variables, import and export data, perform calculations, generate plots and develop files (William, 2003).

4.1 Graphical User Interfaces (GUI) and its Elements

A GUI provides a pictorial interface and a point of contact between the user and the computer program (Hanselman and Littlefield, 2005). It provides a convenient environment with the help of its components, figures and callbacks. Keyboard inputs or mouse clicks are referred to as events. The code executed in response to an event is known as callback. The components used in presented GUI include push-buttons, edit boxes, pop-up menus, frames, and text fields (figures 2 to 5). The developed case study application responds to each event and implements the functions of each graphical object on the figure window. Flowchart along with some figures elaborating some of the features of this application are shown in figures 2 to 5.

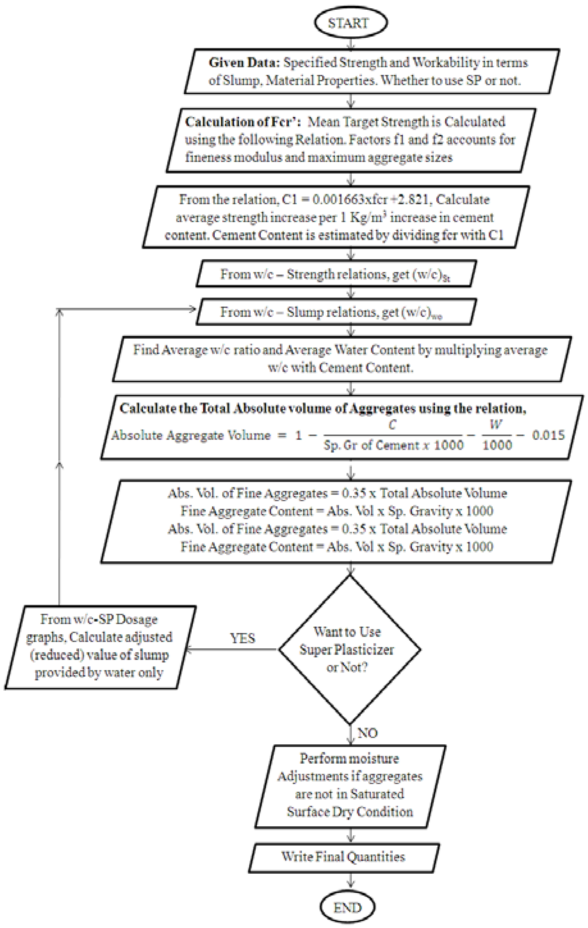

Figure 1: Flow Chart for the proposed Method

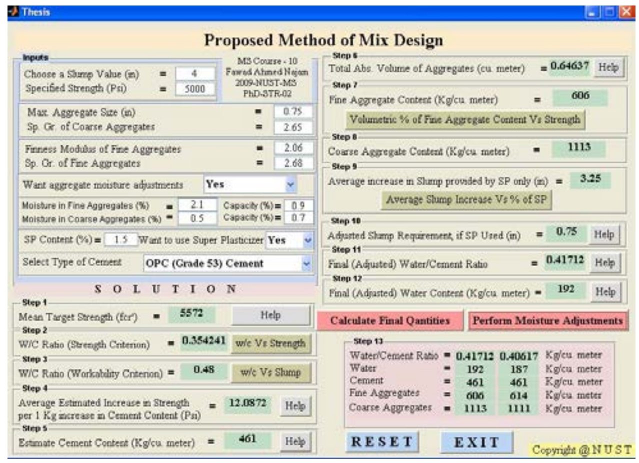

Figure 2: Main Interface

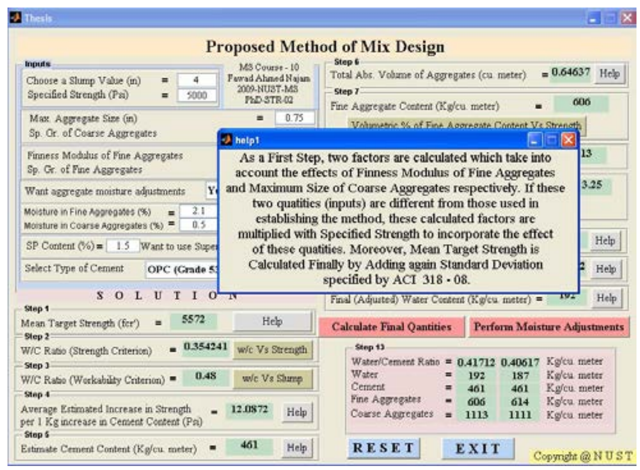

Figure 3: Using "Help" Buttons

The code sets in the callbacks include the regression equations, input and output commands, and other necessary calculations. The program consists of following two types of files (Patrick 2003).

a) A FIG-file, with extension .fig, that contains a complete description of the GUI layout and the GUI components, such as push buttons, axes, panels, menus, and so on. The FIG-file is a binary file and user cannot modify it except by changing the layout in a GUI development module of MATLAB known as GUIDE.

b) An M-file, with extension .m, that initially contains initialization code and templates for some callbacks that are needed to control GUI behavior.

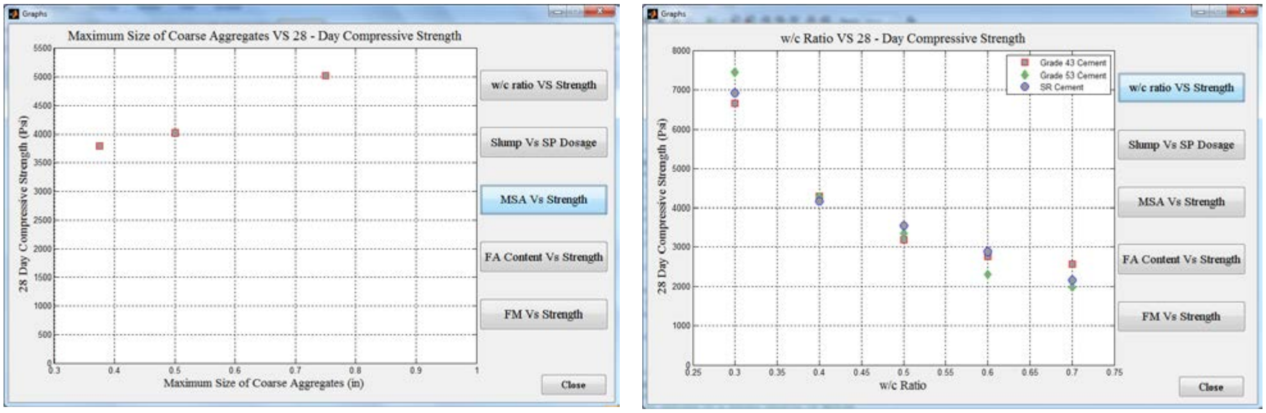

Figure 4: Views from graphical relationships module

Explanatory notes are also provided as help files to guide the user on decision-making. The program is capable of giving the material constituent of concrete for the first trial batch from given performance criteria. The main calculating functions and formulae are embedded in two Popup Menus i.e. "Selection of Super plasticizer" and "Selection of Cement Type".

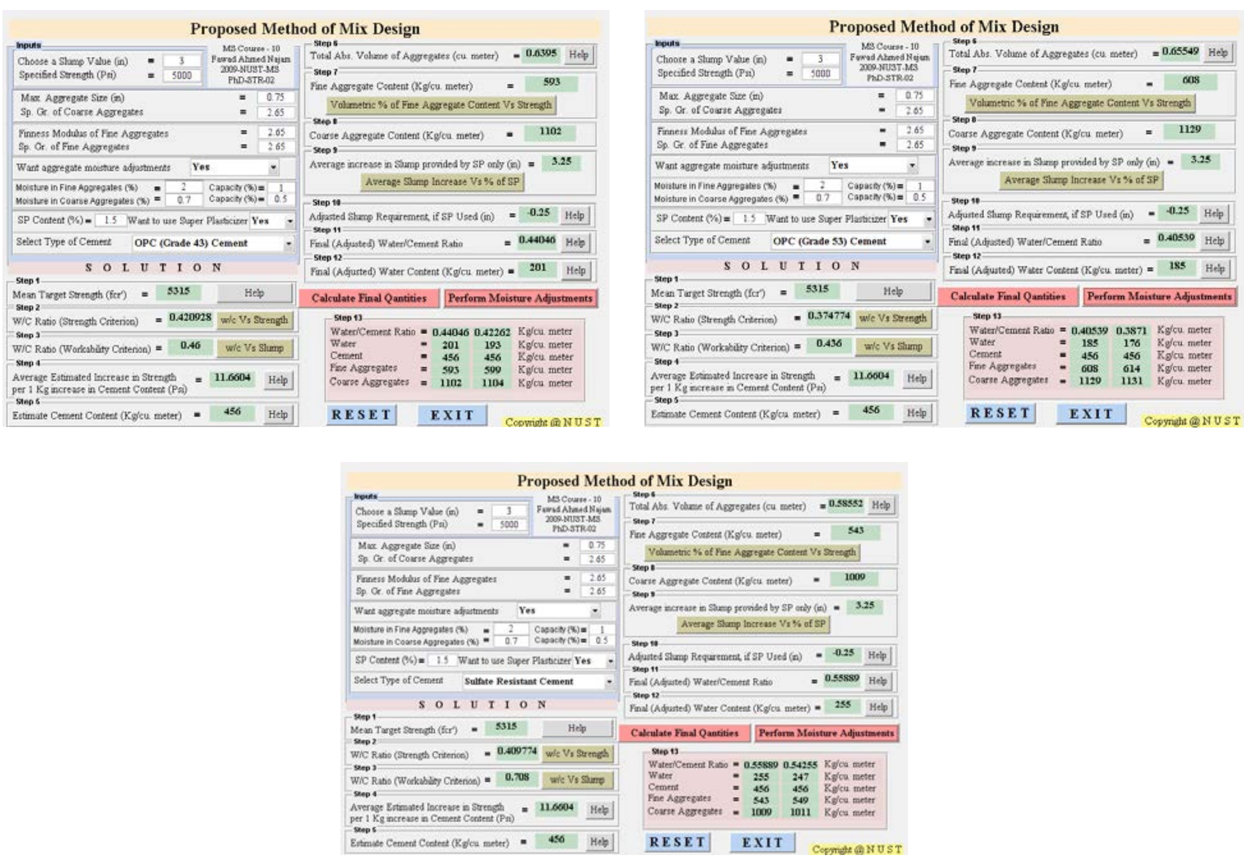

Figure 5: A complete example solved using (a) OPC Grade 43 (b) OPC Grade 53 (c) Sulfate Resistant cement type

4.2 What-if analysis and Parametric Study

In order to examine the effect of varying desired characteristics on proposed constituents, a parametric study is carried out. An example is explained below which comprises of employing the proposed method with varying slump and strength requirements. Slump value is varied from 1 inch (25.4 mm) to 4 inch (101.6 mm) while using 1.5% of superplasticizer content (by weight of cement) and constant desired compressive strength of 6000 Psi (41.4 Mpa). Desired strength is varied from 3000 Psi (20.7 Mpa) to 6000 Psi (41.4 Mpa) with a constant slump requirement of 3 inches (76.2 mm). Sample aggregate properties and other data are kept as given below.

Maximum aggregate size	=	0.75 in
Specific gravity of coarse aggregates	=	2.65
Fineness modulus of fine aggregates	=	2.65
Specific gravity of fine aggregates	=	2.65
Moisture in fine aggregates (%), as stored	=	2
Moisture capacity of fine aggregates (%)	=	1
Moisture in coarse aggregates (%), as stored	=	0.7
Moisture capacity of coarse aggregates (%)	=	0.5
Superplasticizer content (%)	=	1.5

Figure 6 shows the effect of varying required slump and 28 day compressive strength on recommended constituent quantities. Increase in cement content with increasing target strength and increase in water demand with increasing slump requirement can be observed. However relative proportioning of coarse and fine aggregates in both cases is supposedly accounting for constant slump and compressive strength respectively. Similar relationships between other quantitative parameters such as aggregate-to-paste ratio and various desired characteristics can be developed for more understanding and sensitivity analysis. It should be noted here that convenient use of mix design method as well as any parametric study is only possible due to availability of presented program and is almost impossible using cumbersome manual calculations.

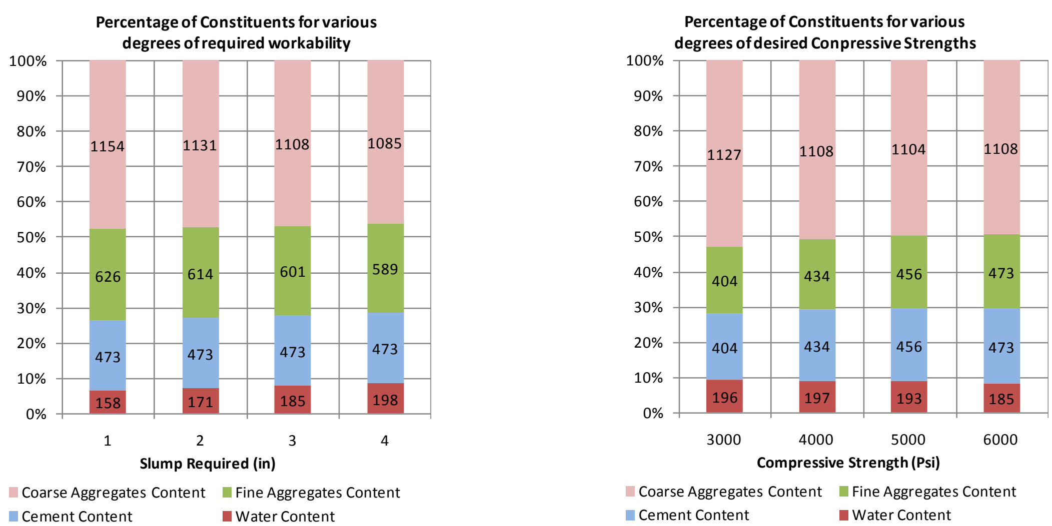

Figure 6: Constituent quantities for various degrees of required slump and strengths

5. Conclusions

Introduction of modern computation methods and devices in concrete materials engineering can be very handy and useful, resulting in amazing ease for construction engineers in terms of solving complex nature problems. It is need of the hour to embrace modernized computing tools and devices, not only to generate and provide answers to ever increasing real life problems but also to match up with the pace of technology development booming around us. This paper has presented some of the areas where the concrete engineering profession and the academia can make use of the new developments in the computing tools and technologies to improve the use the computers for better understanding of core engineering concepts.

In this paper, an actual case study application for concrete mixture proportioning is presented. Target areas in civil and construction engineering for possible employment and application of latest computing technologies are identified and highlighted. The presented case study makes use of Graphical User Interface (GUI) module in MATLAB R2009a environment and is designed as a self-explanatory program providing an easier and friendly platform to compute constituent quantities, adjust various trials and understand the art of mix design. Other enhanced compilers and rapid development frameworks can also be employed for similar nature of problems especially in those areas of concrete engineering where field or test observations require complex data analysis and simulations.

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