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Interactive and Educative Software for Designing Concrete Mixtures Utilizing Saudi Building Code

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ABSTRACT. The main objective of Saudi Building Code (SBC) is the minimum requirements, and investigating public health and safety through stability of buildings and facilities and the protection of life and property from hazards associated buildings. The quality control systems of concrete are gaining great importance to ensure the successful application of SBC for concrete structures, and it is necessary to be aware of its requirements and to highlight the benefits of it. It was difficult to follow the procedures of code by most of engineers or engineering students because of huge number of charts, tables and equations. This research aims in spreading the culture of design by code utilizing e-learning. This computer-aided design software has to go through uncomplicated steps until reaching the design values of concrete mixture proportions. This software is a first phase begins with designing concrete mixtures, evaluating the test results of hardened concrete and quality control of the implementation of new projects. This research shows the role of Qassim University in serving and developing the community. The Saudi Building Code was first issued in 2007. It consists of 13 main volumes, among which is SBC301 which is the loading and forces requirements. Design of concrete mixtures is a requirement in the Saudi Building Code. It was essential to develop an interactive software with an easy graphical user interface to be brilliant solution to design problem. This software goes through uncomplicated steps until reaching the values of concrete mixture proportions and the evaluation of test results.

Keywords: Saudi Building Code, Concrete mix design, Evaluation of concrete, Computer-Aided Design.

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1. Introduction

Reinforced concrete is considered one of the versatile materials that used in building constructions. One of the reasons for its versatility was the availability of its ingredients (Coarse aggregates as gravel and crushed stone, fine aggregate as sand and manufactured aggregates, water and cement) in many countries and the availability of reinforcing bars. The construction of concrete requires simple skills and can give different shapes of casting. The construction of concrete is considered an economic construction compared with other forms of construction. It can be used for many purposes as elevated, ground and underground concrete constructions and it also can be used for construction of water structures.

The tremendous developments of the desktop computer stimulated the development of graphical user computer-based standards that make it easy to use complex standards in efficient manner and reduced the probability of errors. This will help the designer and engineering students to design concrete mixtures and will help in the evaluation of concrete characteristics in accordance with SBC [1-2].

The building code can be defined as: "A collection of regulations adopted by a city to govern the construction of buildings" [3]. More research is needed about coding of various building codes. SBC is a set of scientific, technical, and administrative systems related to building design in Saudi Arabia. It also includes reinforced concrete structure design utilizing methods and equations which are indirect and complex. User design interface is the user interface software that designed to follow a specific process and/or application [4]. There was a lack of uniformity and utilization of outdated references in the design practice of many buildings in Riyadh that required an urgent action for the utilization of SBC [5]. Alsayed *et al.* [6] highlighted on the importance of applying SBC on the evaluation of both local and imported construction materials and its effect on the life cycle of the infrastructure. Al-Hazmi *et al.* [7] proposed a text book for the design of reinforced concrete structures in accordance with SBC. Al-Shaalan *et al.* [8] provided guidelines for the design to conserve energy of buildings in KSA by computer simulation utilizing simulation tool of quick energy.

At the beginning of the twentieth century, many software packages for applications of civil engineering such as PLAXIS, SAP 2000, ANSYS, AUTOCAD Civil 3D were developed and have been widely used on the professional level. The issues about these packages are the higher level of these software than undergraduate students in civil engineering and these packages didn't take into considerations the provisions of local building codes. The International Building Code (IBC) was coded and published by Satti and Krawczyk [9]. This code is enforced and used in 44 states in the architectural field. They made tools for code analysis for the current building code and a computer-aided program for design which helps professional designers.

Tang-Hung and Eric [10] outlined an integrated framework by the investigation of a 3D computer-aided-design for a system of building design that checks the compliance of building code automatically. A framework for automated code compliance to examine the role of BIM for building code checking for Indian National codes was presented by Raninder and Hardeep [11]. Bikramjit *et al.* [12] developed a code checking system that helped in reducing the risk of non-compliance. The developed code also improved the efficiency in building code checking process. Certain stages are commonly passed through in most design projects. Each stage of design is determined by its requirements. The sequence of stages varies depending on the importance and the purpose of the project. The stages may extend from a simple building to an existing one. Each stage of the design is defined and related to the building code requirements [13].

During the typical design stage, the proportions of concrete mixtures should be determined and technical issues should be taken into consideration. The trials of the concrete mixture should be done. The test results should be checked against locally adopted building code before preparing the acceptance of the proposed concrete mixtures design [14-16].

The concrete mixture design and quality control of concrete are considered important issues before and during construction process. Hamoud *et al.* [17] proposed a statistical analysis to examine the quality of utilizing basalt as coarse aggregate in the production of normal strength concrete by using Chebyshev's theorem and the Statistical Empirical Rule method. Ahmad and Alghamdi [18] proposed an approach for optimizing the concrete ingredients based on experimental data. Reinert [19] developed a computer software for the evaluation of concrete properties and to optimize the percentages of ingredients of concrete mixture.

The utilization of interactive data and web based are considered as a guide for easy way to use the building codes. An interactive internet database of aerodynamic loads was presented by Zhou *et* *al.* [20]. This database obtained from the high-frequency base balance as a guide for the preliminary design of tall buildings. Aye *et al.* [21] proposed an interactive web-GIS tool that aimed in the analysis of risks, impacts and consequences of a specific natural hazard event. Pratihast *et al.* [22] developed an interactive web-based forest monitoring system to support good forest management based on geographic information services.

This paper presents an interactive software that helps the designer to use the equations and regulations of the code to design concrete mixture in accordance with SBC. It will be a good effort in the participation in the developing of e-learning throughout Qassim University and College of Engineering. The first phase of the proposed application will be for concrete mixtures design, frequency of testing and evaluation of hardened concrete test results.

2. Interactive Software

The interactive software comprised of three parts. The first part includes the frequency of testing which gives the number of required concrete samples, the second part includes the acceptance criteria for the results of laboratory tests of the concrete and the third part includes the design of concrete mixture in accordance with Saudi Building Code provisions.

2.1 SBC - 304

The (SBC 304) [1] for Concrete Structures, includes minimum requirements for the design of concrete structures. SBC 304 governed all issues related to design and construction of concrete structures. Since the design of concrete mixtures in Saudi Arabia, should conform SBC 304 specifications. It is very difficult to follow each item in the code to design a concrete mixture or to evaluate the compression test results for quality control.

Many sections from Saudi Building Code were used to construct the first part of the interactive software. Frequency of testing (SBC 304 - 5.6.2) [1] which is related to samples for compression tests. Evaluation and acceptance of concrete (SBC 304R - 5.6) [2] which is related the acceptance criteria for concrete mixture proportions. Water-cementitious materials ratio (SBC304 – 4.1) [1] which gives the maximum water to cementitious materials ratios. Sulfate exposures (SBC 304 – 4.3) [1] which define the category of concrete exposed to sulfate-bearing groundwater or soils.

Required average strength (SBC 304 – 5.3.2) [1] for concrete compressive strength in addition to margin for mixture design.

2.2 Programming language

Detailed flowcharts were created for the integration of the selected provisions in the SBC that used in the code of the proposed software; the needed entry data, variables, and output results. The software code was written utilizing the ASP.NET MVC and C# computer languages which is used for the internet web pages' design. The front page of the developed interactive software is shown in Figure (1).

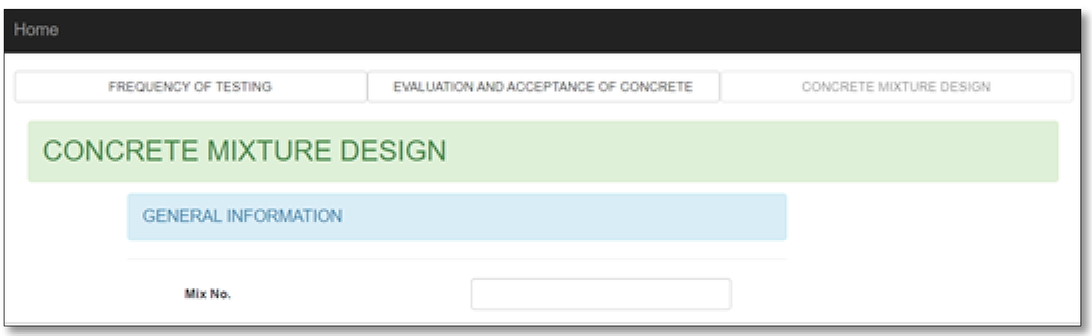


Fig. (1). Interface of the software code

2.2.1 First Part (Frequency of Testing)

The detailed flowchart of the first part (Frequency of testing) of the integrated software is shown in Figure (2).

The software will request to enter the number of casting days and to choose the type of concrete element from drop list that consists of ((a) Reinforced Concrete Slab, (b) Reinforced Concrete Columns, (c) Reinforced Concrete Walls, (d) Isolated Footing and (e) Raft foundation). The screen will appear with different options according to the chosen concrete element from previous option. The user should enter the required data. The number of samples is calculated according to provisions of SBC 304 - section 5.6.2. The final result will appear as the number of samples.

2.2.2 Second Part (Acceptance Criteria for Concrete)

The detailed flowchart of the second part (Acceptance criteria for concrete) of the integrated software is shown in Figure (3).

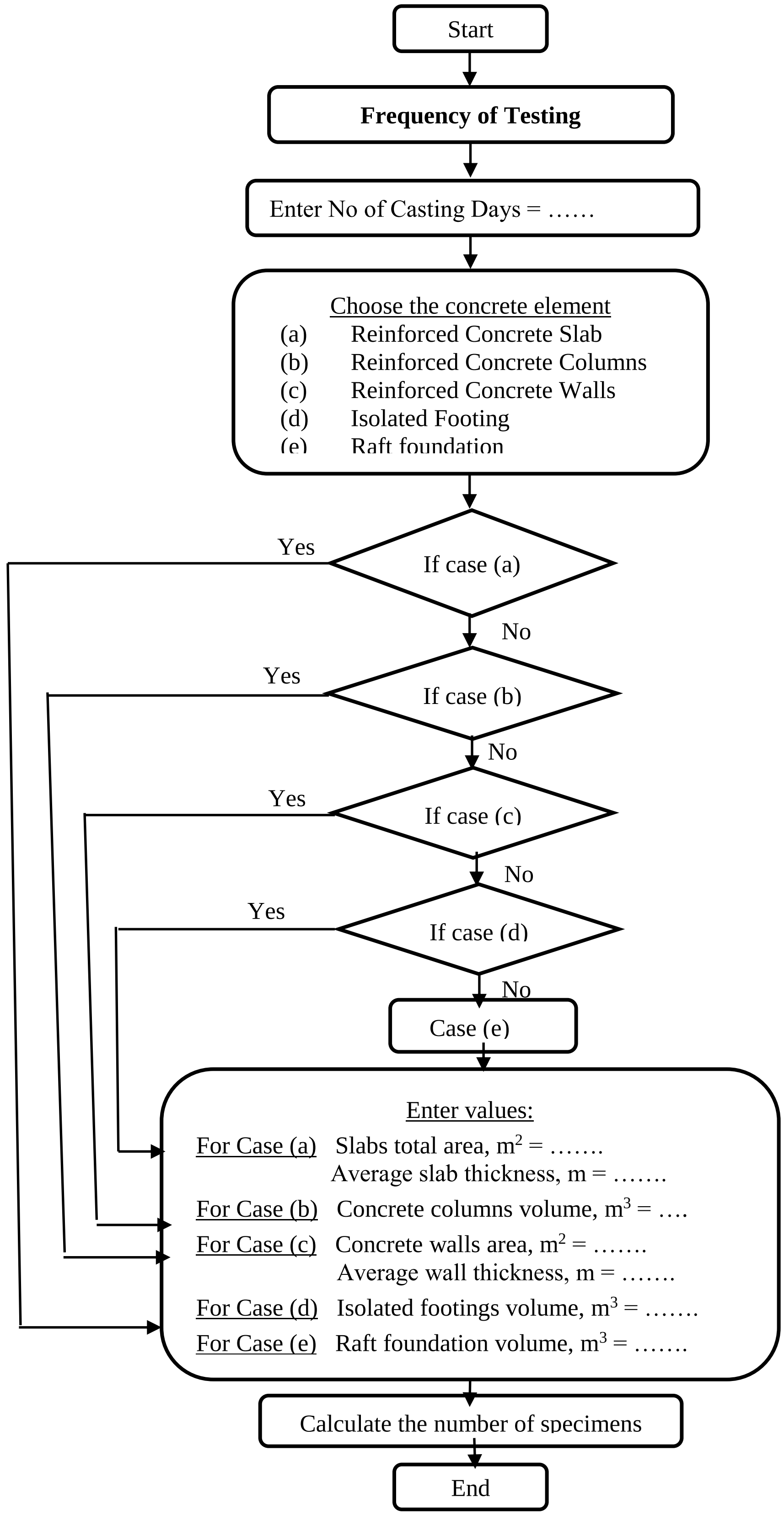

Start
Frequency of Testing
Enter No of Casting Days = ……
Choose the concrete element
(a) Reinforced Concrete Slab
(b) Reinforced Concrete Columns
(c) Reinforced Concrete Walls
(d) Isolated Footing
(e) Raft foundation
If case (a)
Yes
No
If case (b)
Yes
No
If case (c)
Yes
No
If case (d)
Yes
No
Case (e)
Enter values:
For Case (a) Slabs total area, m2 = …….
Average slab thickness, m = …….
For Case (b) Concrete columns volume, m3 = ….
For Case (c) Concrete walls area, m2 = …….
Average wall thickness, m = …….
For Case (d) Isolated footings volume, m3 = …….
For Case (e) Raft foundation volume, m3 = …….
Calculate the number of specimens
End

Fig. (2). Flowcharts of the first part (Frequency of testing)

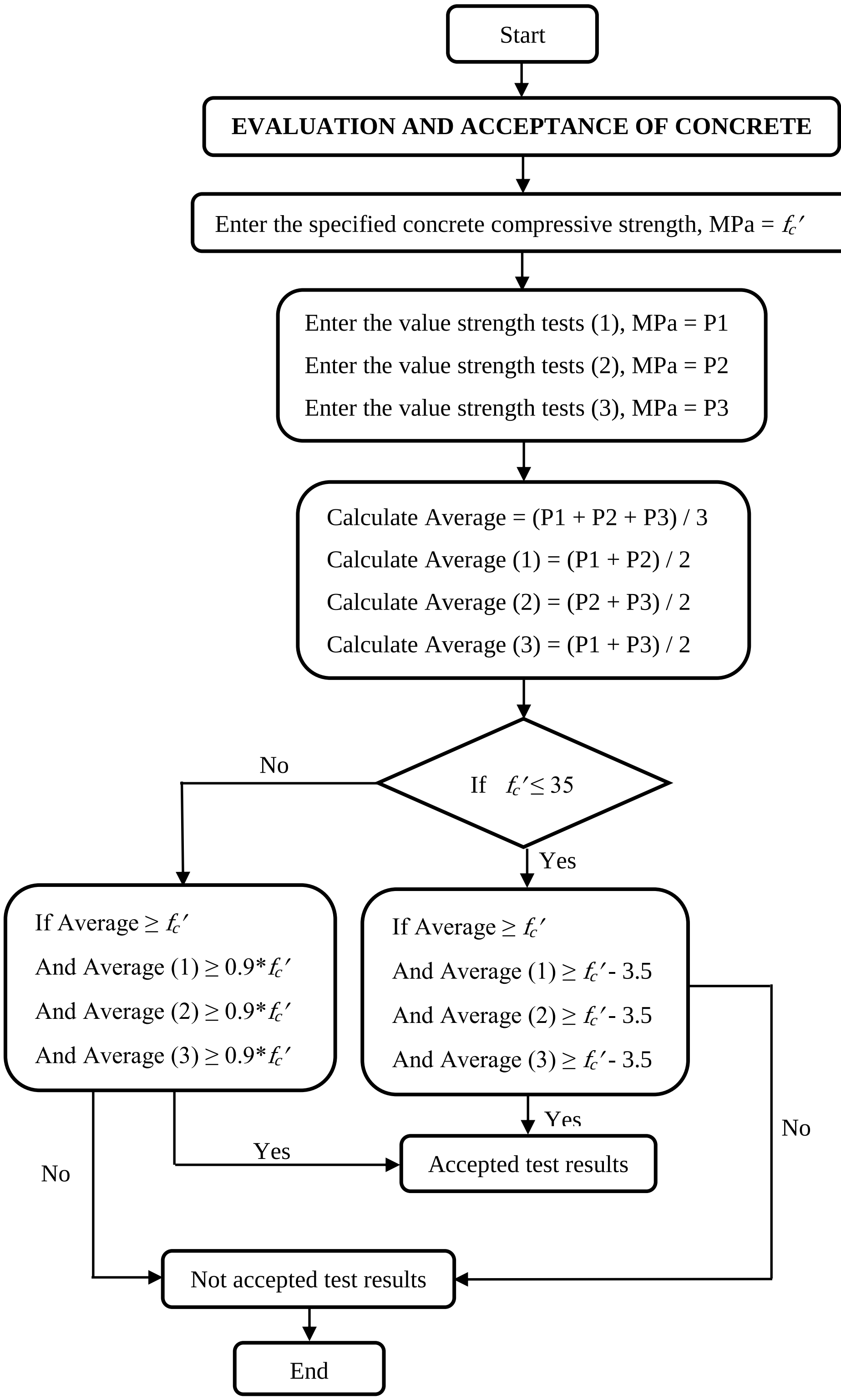


Fig. (3). Flowchart of the second part (Acceptance criteria for concrete)

The software will request to enter the value of specified concrete compressive strength and the results of three consecutive strength tests. Based on the acceptance criteria according to SBC 304R provisions (5.6) and based on the value of specified compressive strength of concrete, the final result will be (Accepted) or (Not Accepted Test Results According to SBC).

2.2.3 Third Part (Concrete Mixture Design)

The detailed flowchart of the third part (Concrete mixture design) of the integrated software is shown in Figure (4) and Figure (5).

The user will follow the following steps:

1- Entry of the general information (Mix No., Date, Engineer name, Institute).

2- Choosing of the type of construction from drop list.

3- Choosing the category of sulfate exposure according to Table 4.3.1 [1] from drop list.

4- Data entry (Concrete Compressive Strength at 28 days, Standard Deviation (If it is available for the user) and required slump value from drop list).

5- The software will request to enter the properties of concrete ingredients.

Steps of Solutions:

The following steps shows the calculations procedure:

1- Calculation of f_{cr}' from Table (5.3.2.1) and Table (5.3.2.1) [1].

2- Calculation of water/cementitious materials ratio (w/c) by using the value of f_{cr}', and make check for the maximum allowable value obtained from Table (4.3.1) [1].

3- Calculation of free water content (w), kg/m^3 by using the maximum aggregate size and the slump value.

4- Calculation of cement content (C) (kg/m^3), and check the minimum value obtained from Table (4.3.1) [1] and choosing of the type of cement according to the category of sulfate exposure in Table (4.3.1) [1].

5- Finding the value of plastic density (kg/m^3) by using the maximum aggregate size value.

6- Finding the Bulk volume of coarse aggregates V (m^3) by using the value of maximum aggregate size and fineness modulus of sand.

7- Calculation of coarse aggregates content, total aggregates, and fine aggregates content in (kg).

8- The final results will be the summary of mix design (Amount of coarse aggregate, Amount of fine aggregate, Cement type, Amount of cement and Amount of water) for one cubic meter.

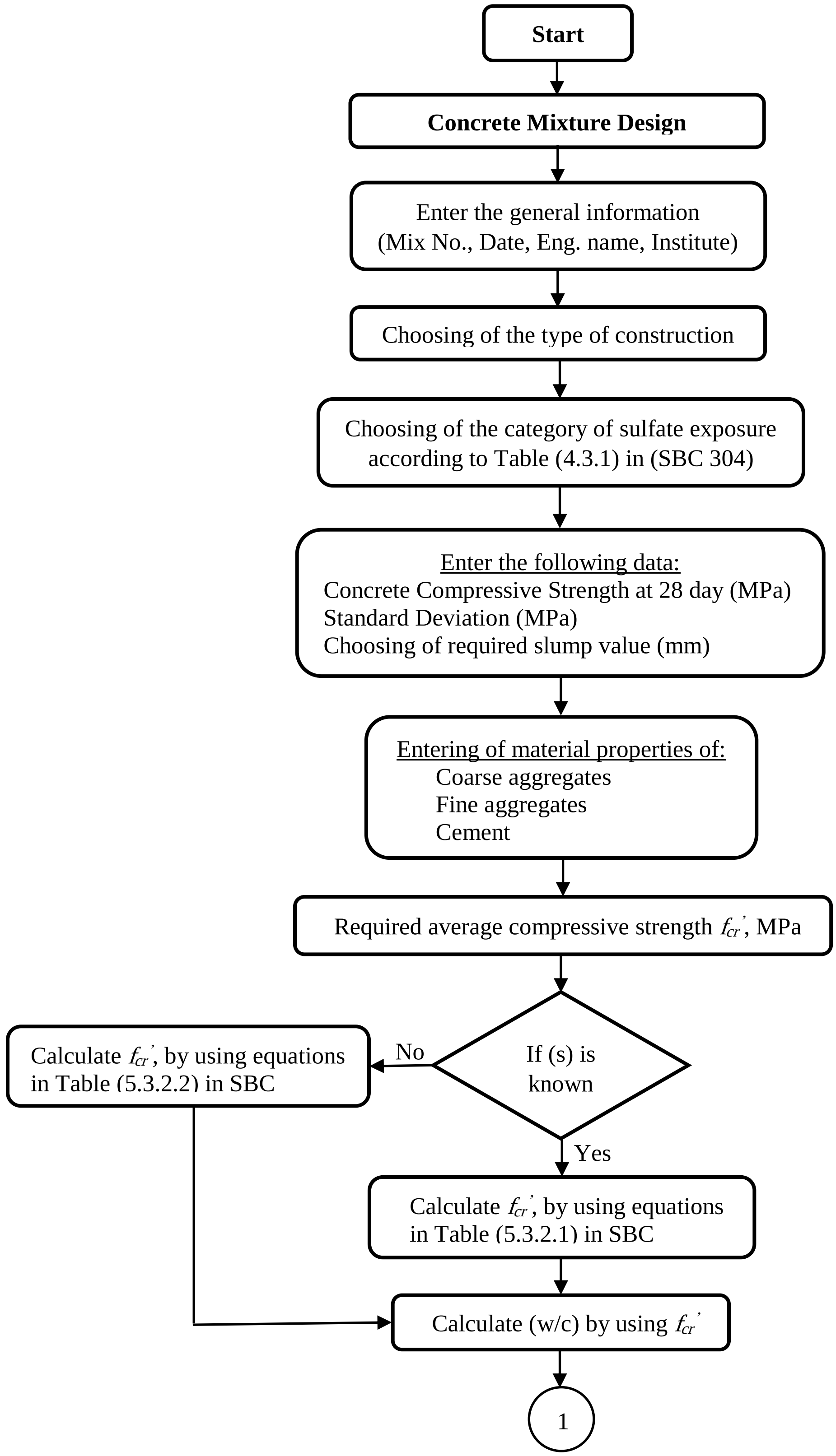

Start
Concrete Mixture Design
Enter the general information
(Mix No., Date, Eng. name, Institute)
Choosing of the type of construction
Choosing of the category of sulfate exposure
according to Table (4.3.1) in (SBC 304)
Enter the following data:
Concrete Compressive Strength at 28 day (MPa)
Standard Deviation (MPa)
Choosing of required slump value (mm)
Entering of material properties of:
Coarse aggregates
Fine aggregates
Cement
Required average compressive strength f_{cr}', MPa
If (s) is
known
No
Calculate f_{cr}', by using equations
in Table (5.3.2.2) in SBC
Yes
Calculate f_{cr}', by using equations
in Table (5.3.2.1) in SBC
Calculate (w/c) by using f_{cr}'
1

Fig. (4). Flowchart of the third part (Concrete mixture design)

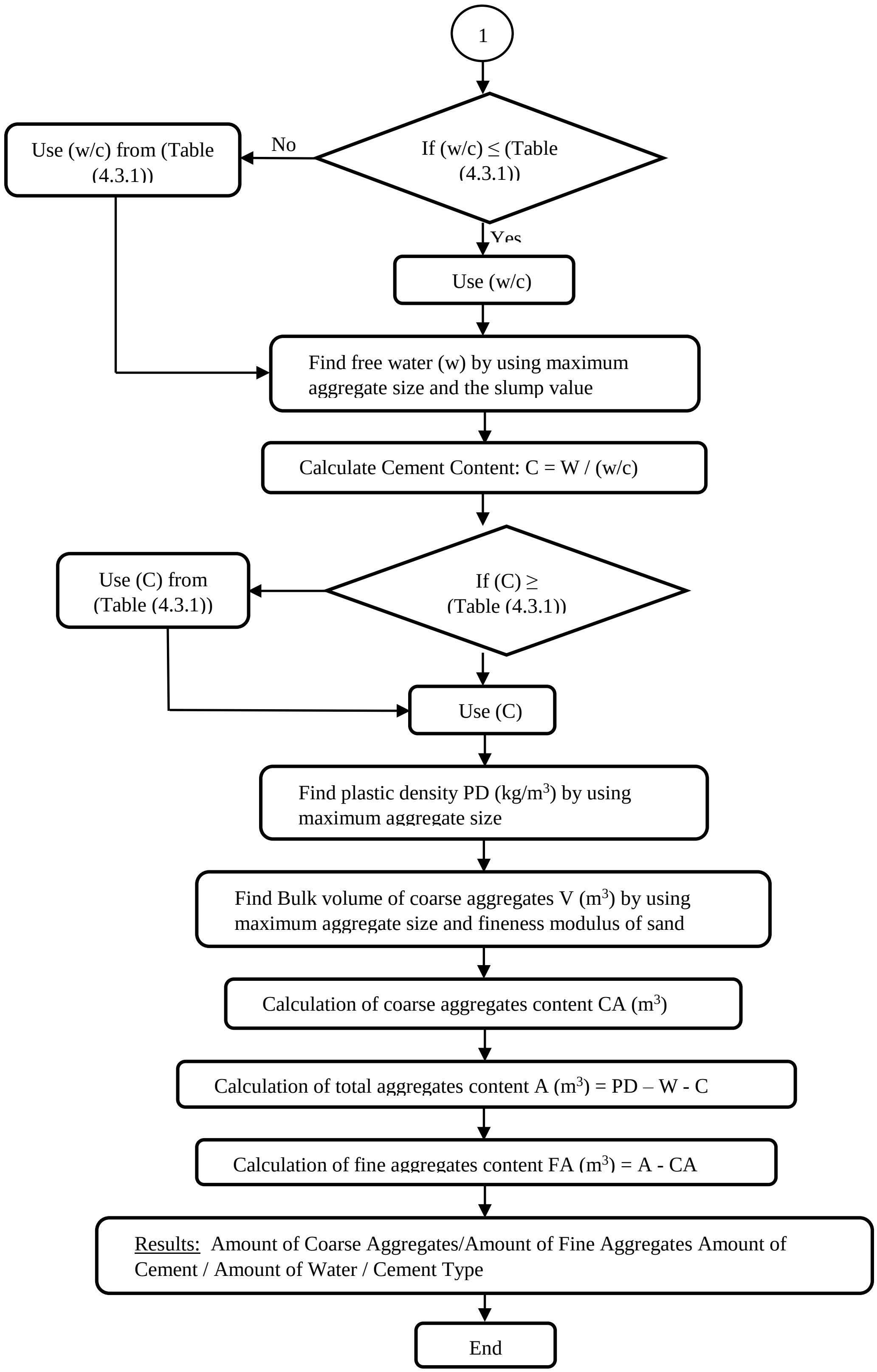

1
If (w/c) ≤ (Table (4.3.1))
No
Use (w/c) from (Table (4.3.1))
Yes
Use (w/c)
Find free water (w) by using maximum aggregate size and the slump value
Calculate Cement Content: C = W / (w/c)
If (C) ≥ (Table (4.3.1))
Use (C) from (Table (4.3.1))
Use (C)
Find plastic density PD (kg/m3) by using maximum aggregate size
Find Bulk volume of coarse aggregates V (m3) by using maximum aggregate size and fineness modulus of sand
Calculation of coarse aggregates content CA (m3)
Calculation of total aggregates content A (m3) = PD – W - C
Calculation of fine aggregates content FA (m3) = A - CA
Results: Amount of Coarse Aggregates/Amount of Fine Aggregates Amount of Cement / Amount of Water / Cement Type
End

Fig. (5). Cont. Flowchart of the third part (Concrete mixture design)

2.3 Data, Variables, and Output in the Interactive Software

The program consists of three main tabs which are frequency of testing, acceptance criteria for concrete, and concrete mixture design. The following sections show the input data and required variables to use the application.

2.3.1 The first tab of the interactive software (Frequency of Testing)

Figure (6) shows the entry data section of the first tab of the interactive software.

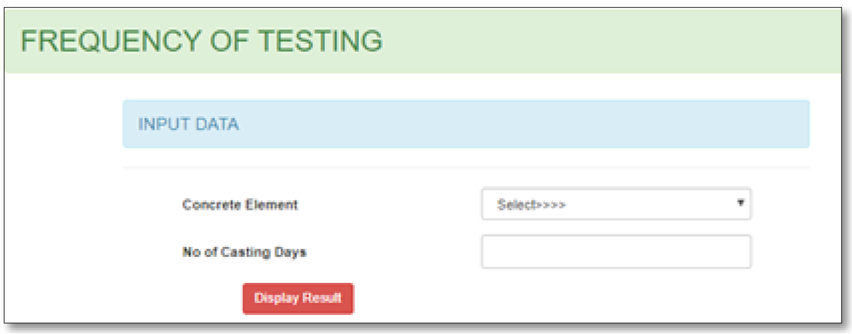


Fig. (6). Entry data section of the first tab (Frequency of Testing)

The user can choose the type of concrete element from drop list as shown in Figure (7).

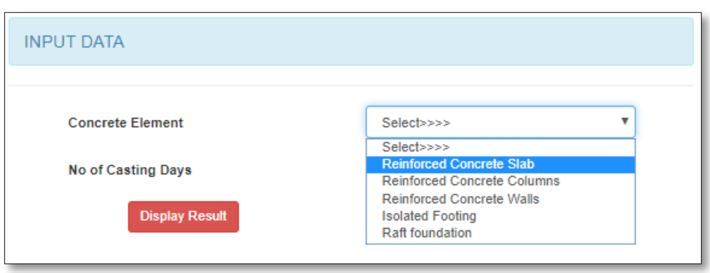


Fig. (7). Selection of the type of concrete element

Figure (8) shows the required data for the first tab. By clicking on (Display Result) button, the number of samples will appear on the screen.

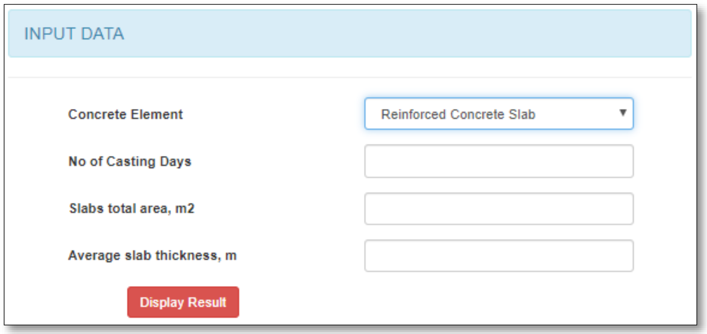


Fig. (8). Required data for the first tab (Frequency of Testing)

2.3.2 The second tab of the interactive software (Acceptance criteria for concrete)

Figure (9) shows the Interface of the second tab (Acceptance criteria for concrete). The user requested to enter the value of the specified concrete compressive strength and the values of three consecutive compression test results. The next step is to click on display result button to see the result. The result will be (Accepted test results according to SBC) or (Not accepted test results according to SBC).

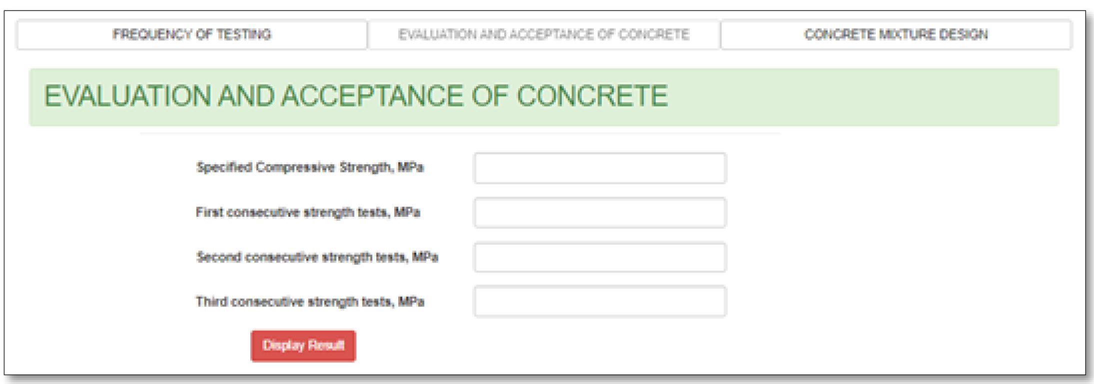


Fig. (9). Interface of the second tab (Acceptance criteria for concrete)

2.3.3 The third tab of the interactive software (Concrete mixture design)

The interface of the third tab (Concrete mixture design) with general information is shown in Figure (10).

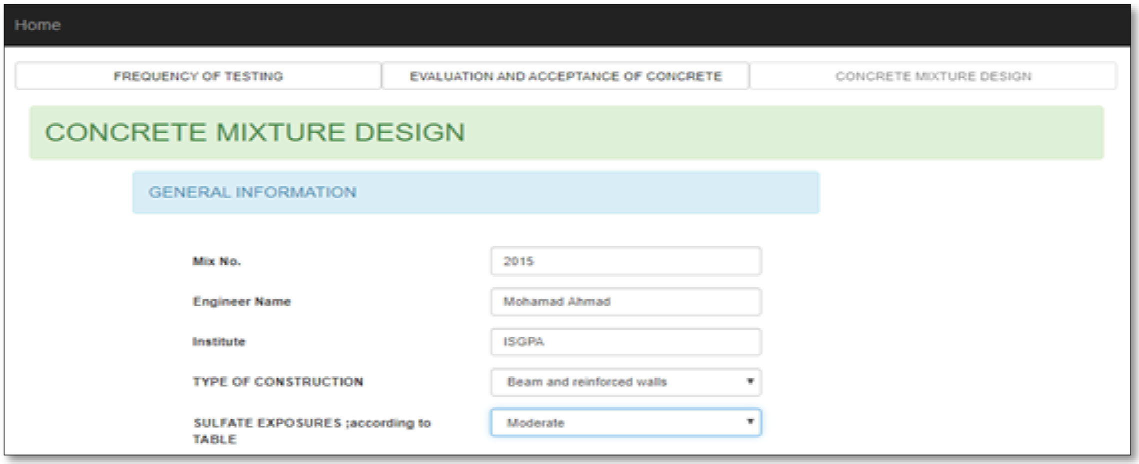


Fig. (10). Interface of the third tab (Concrete mixture design) with General Information

Figure (11) shows the input data and the material properties of concrete ingredients. The user should enter the values of the concrete compressive strength, standard deviation (if available), required slump and available properties of concrete ingredients. By clicking on Display Result button, the software code output (Summary of mix design) of the application will appear as shown in Figure (12). The user can download and print the summary of the mix design by clicking on (Download Data) button. The text file will be downloaded and the entire text can be seen as shown in Figure (13).

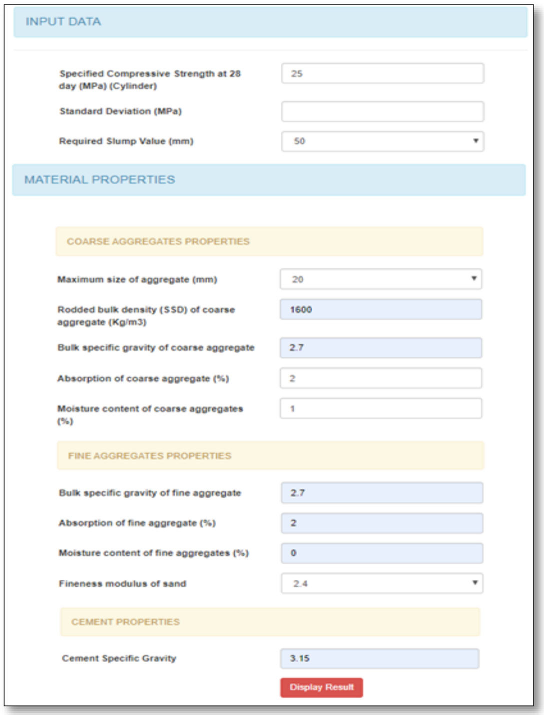


Fig. (11). Input Data and Material Properties of Concrete Ingredients

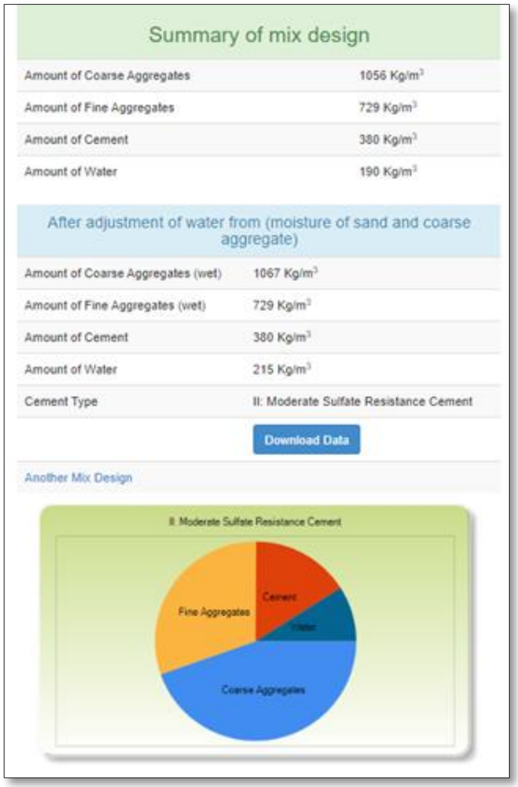
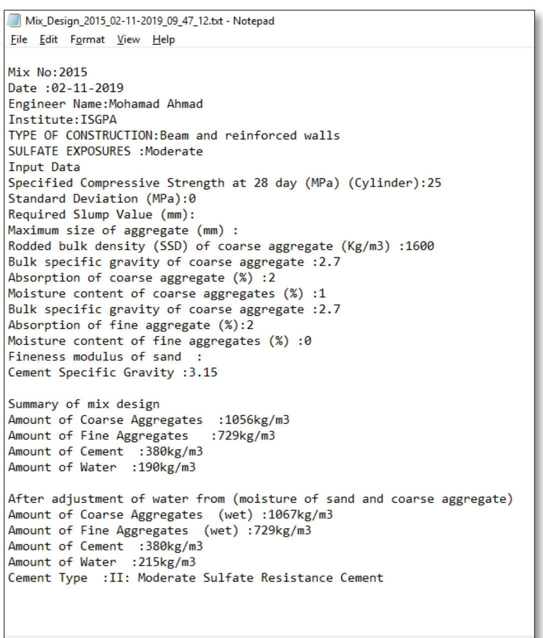


Fig. (12). Software code output data page



Mix_Design_2015_02-11-2019_09_47_12.txt - Notepad
File Edit Format View Help

```
Mix No:2015
Date :02-11-2019
Engineer Name:Mohamad Ahmad
Institute:ISGPA
TYPE OF CONSTRUCTION:Beam and reinforced walls
SULFATE EXPOSURES :Moderate
Input Data
Specified Compressive Strength at 28 day (MPa) (Cylinder):25
Standard Deviation (MPa):0
Required Slump Value (mm):
Maximum size of aggregate (mm) :
Rodded bulk density (SSD) of coarse aggregate (Kg/m3) :1600
Bulk specific gravity of coarse aggregate :2.7
Absorption of coarse aggregate (%) :2
Moisture content of coarse aggregates (%) :1
Bulk specific gravity of coarse aggregate :2.7
Absorption of fine aggregate (%):2
Moisture content of fine aggregates (%) :0
Fineness modulus of sand  :
Cement Specific Gravity :3.15

Summary of mix design
Amount of Coarse Aggregates  :1056kg/m3
Amount of Fine Aggregates   :729kg/m3
Amount of Cement  :380kg/m3
Amount of Water  :190kg/m3

After adjustment of water from (moisture of sand and coarse aggregate)
Amount of Coarse Aggregates  (wet) :1067kg/m3
Amount of Fine Aggregates  (wet) :729kg/m3
Amount of Cement  :380kg/m3
Amount of Water  :215kg/m3
Cement Type  :II: Moderate Sulfate Resistance Cement
```

Fig. (13). Downloaded text file (summary of the mix design)

3. Results and Discussion

The proposed interactive software code was applied. Students at the Civil Engineering Department of College of Engineering used this software for the last year in the courses entitled properties and testing of concrete, structural material, and in the graduation projects. The students compare their results with another software and the results showed good accuracy. It was essential to apply the Saudi Building Code by Saudi engineers. The validation of the proposed software code is done through the following design examples applied by the students of Civil Engineering Department of College of Engineering at Qassim University in their graduation project.

The examples that used for the validation of the interactive web software were 1) Frequency of testing, 2) Acceptance criteria for concrete, and 3) Concrete mixture design. A typical excel design sheet for the examples was used to compare the results with the solution obtained from the proposed software. The results of the solution of all cases are shown in the following examples compared to the obtained results from the proposed software. The matching of the results validated the developed software to be used as a tools for design purposes.

3.1 Verification example on the first part (Frequency of Testing)

Input data for the verification example (1) is shown in Figure (14) and by clicking on (Display Result) button, the result will appear as shown in Figure (15).

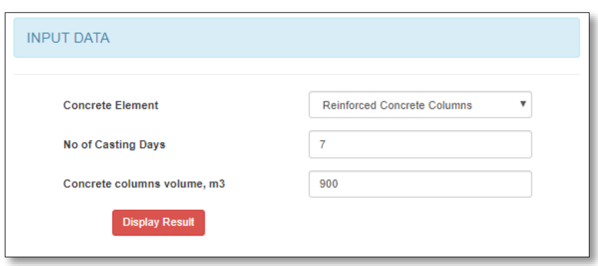


Fig. (14). Input data for example (1)

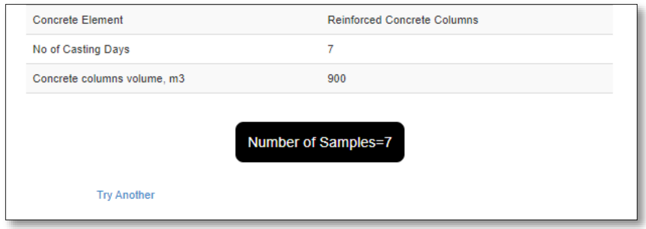


Fig. (15). Results of example (1)

The entry data and obtained results from the excel sheet is shown in Figure (16).

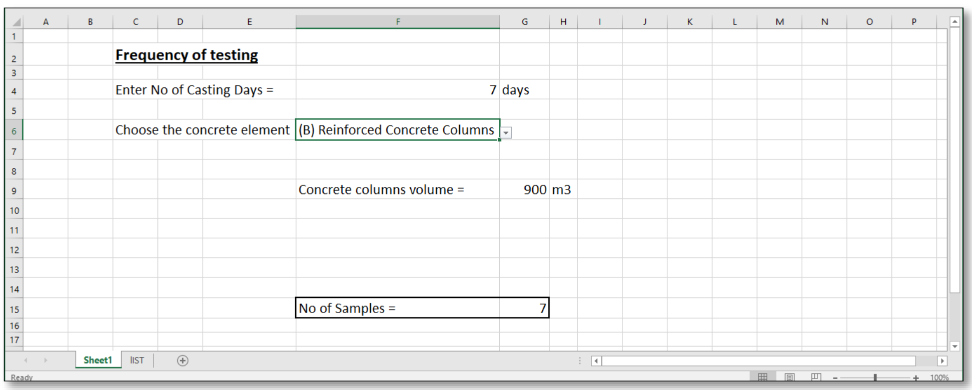


Fig. (16). The result in the excel sheet for example (1)

3.2 Verification example on the second part (Acceptance criteria for concrete)

Input data for the second example is shown in Figure (17) and the result is shown in Figure (18).

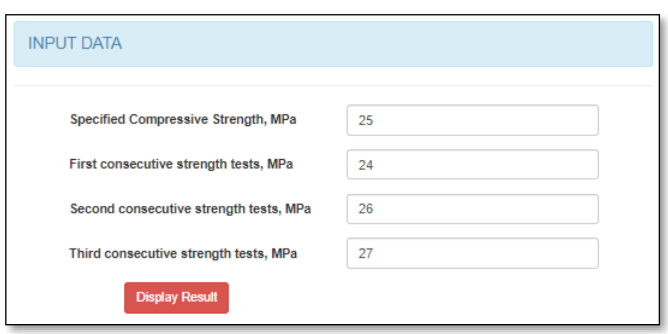


Fig. (17). Input data for example (2)

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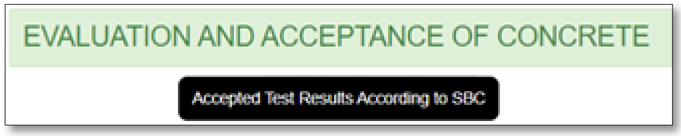

Fig. (18). Result of example (2)

The entry data and obtained results from the excel sheet is shown in Figure (19).

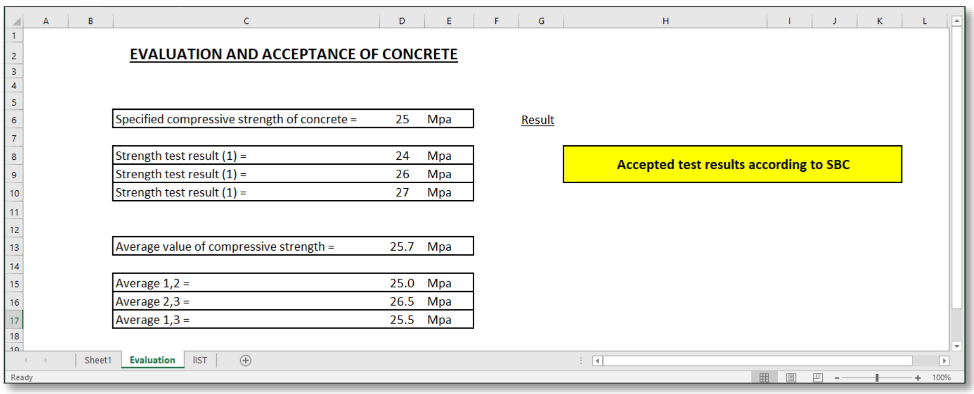

Fig. (19). The result in the excel sheet for example (2)

3.3 Verification example on the third part (Concrete mixture design)

Input data and material properties for concrete ingredients are shown in Figure (20) for example (3).

The output of the interactive software for the third part (concrete mixture design) is shown in Figure (21) as summary of mix design.

The entry data of the excel sheet is shown in Figure (22). The calculation steps are shown in Fig. (23) and the results of mix design is shown in Figure (24).

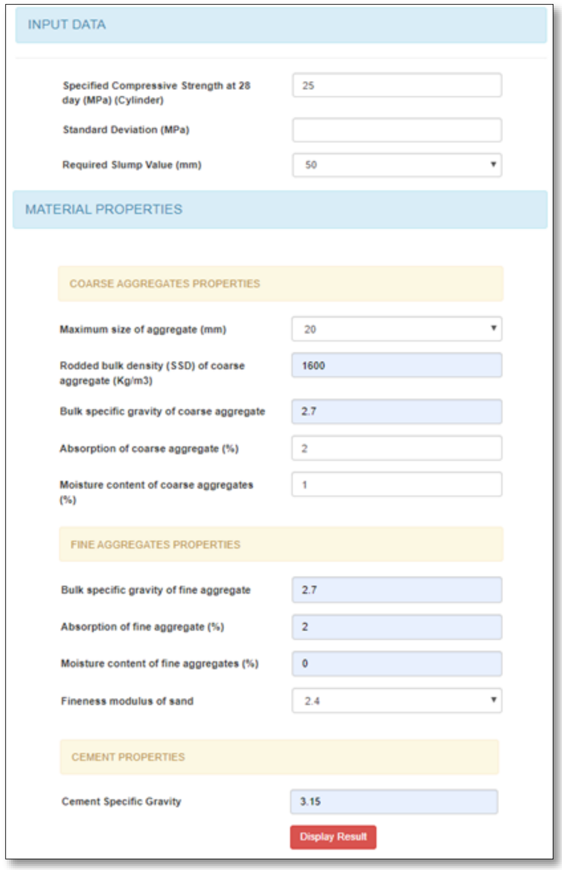

Fig. (20). Input data and material properties of concrete ingredients for example (3)

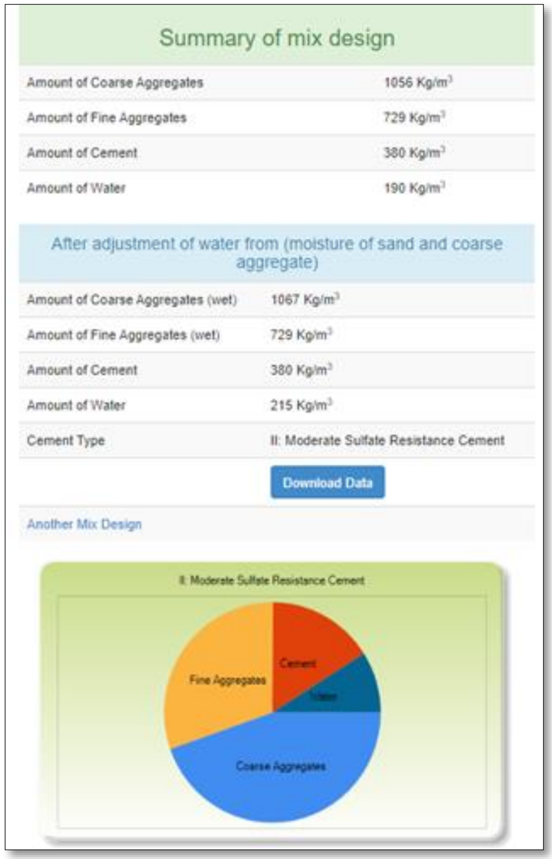

Fig. (21). Output results of the software for example (3) (Concrete mixture design)

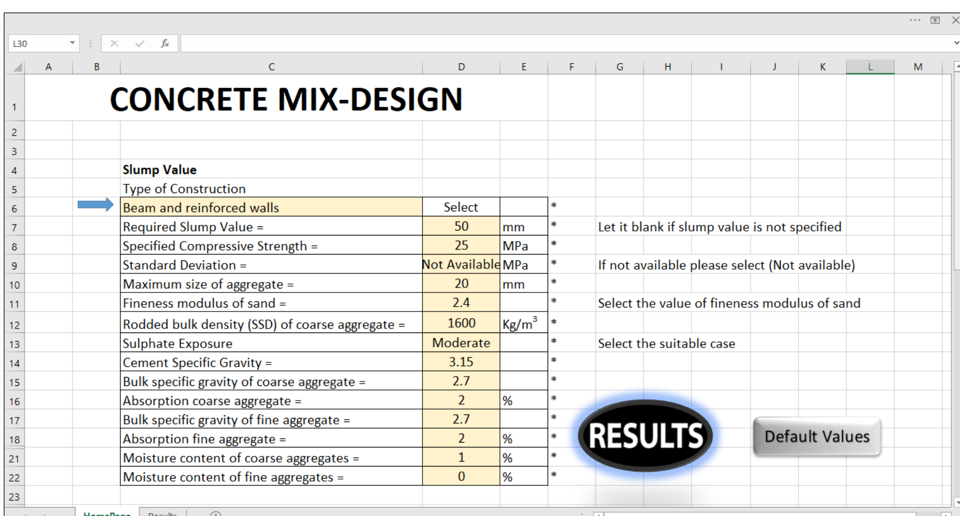

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Fig. (22). The entry data in the excel sheet for example (3)

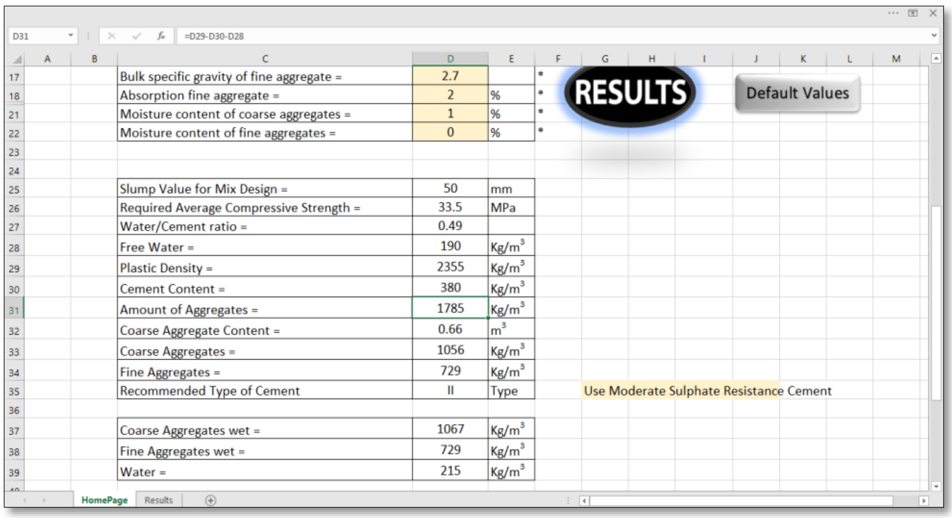

Fig. (23). The calculation of results in the excel sheet for example (3)

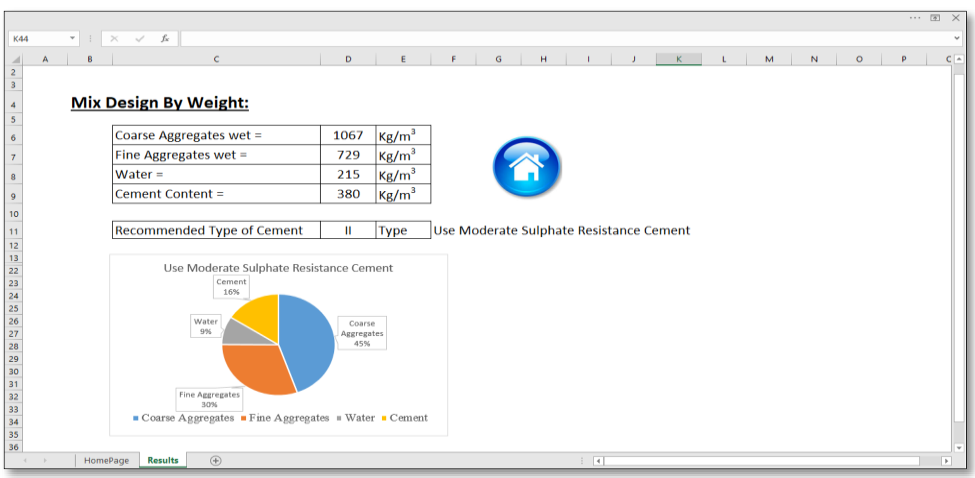

Fig. (24). The final results in the excel sheet for example (3)

4. Conclusions

More efforts are needed to develop such applications for students for advancing e-learning development in Qassim University. To spread the culture of utilization and to apply the provisions of SBC in the field of engineering in KSA, it requires a friendly user interface. The design of a concrete mixture and the analysis of test results of hardened concrete should be checked according to building code requirements. The current paper presented the base framework that would help in advancing the automated SBC in the process of design among civil engineers in KSA and gave awareness to concrete mixture design and analysis of test results among them. Consequently, the engineers in the field of construction will feel unworried when they compare the easiness of using the available commercial software which make them in compliance with the provisions of SBC. The development of such interactive software will provide them with an alternative that take the SBC into consideration. The proposed interactive software will give a better understanding of the code provisions and regulations. The second phase of the proposed software will include the other evaluation criteria for testing in accordance with SBC requirements. It is recommended for future work to focus on experimental work to cover all available construction materials in this software.

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برنامج تعليمي تفاعلي لتصميم الخلطات الخرسانية باستخدام كود البناء السعودي

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ملخص البحث. إن الهدف الرئيسي لكود البناء السعودي هو الحد الأدنى من المتطلبات لتحقيق الأمان من خلال استقرار المنشآت والمرافق وحماية الأرواح والممتلكات من المخاطر المرتبطة بالمنشآت. إن أنظمة ضبط الجودة للخرسانة لها أهمية كبيرة لضمان التطبيق الناجح لكود البناء السعودي للهياكل الخرسانية ، ومن الضروري أخذ متطلباتها وإبراز فوائدها. إن متابعة متطلبات الكود من قبل المهندسين أو طلاب كليات الهندسة تعتبر أمراً صعبا بسبب العدد الهائل من المنحنيات والجداول والمعادلات. يهدف هذا البحث إلى نشر ثقافة التصميم طبقا لمتطلبات الكود من خلال استخدام التعلم الإلكتروني. يجب أن يمر برنامج التصميم بمساعدة الحاسب الآلي بخطوات غير معقدة حتى الوصول إلى قيم التصميم الخاصة بنسب الخلطة الخرسانية. هذا البرنامج هو مرحلة أولى تبدأ بتصميم الخلطات الخرسانية ، وتقييم نتائج اختبارات الخرسانة المتصلدة ومراقبة الجودة في تنفيذ المشاريع الجديدة. يوضح هذا البحث دور جامعة القصيم في خدمة المجتمع وتنميته. صدر كود البناء السعودي لأول مرة عام 2007م. يتكون كود البناء السعودي من ثلاثة عشر مجلدًا رئيسيًا ، من بينها (SBC 301) وهو متطلبات التحميل والقوى. إن تصميم الخلطات الخرسانية يعتبر متطلب في كود البناء السعودي. لذا كان من الضروري تطوير برنامج تفاعلي بواجهة مستخدم رسومية سهلة ليكون حلاً رائعًا لمشكلة التصميم. يمر هذا البرنامج بخطوات غير معقدة حتى الوصول إلى قيم نسب الخلطة الخرسانية وتقييم نتائج الاختبارات.