AN EXPERT SYSTEM FOR MIX DESIGN OF BRICK AGGREGATE CONCRETE

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ABSTRACT
An expert system prototype for mix design of brick aggregate concrete called ESBAC is described in this paper. It was developed for concrete having compressive strength up to 28 MPa (4000 psi). ESBAC is capable of selecting the proportions of cement, mixing water and aggregates. The main issues addressed were the knowledge acquisition process, building of the prototype and verification of its performance. The knowledge was taken from technical literature and experts’ opinion. The knowledge was represented using frames and production rules. Two case studies were carried out to evaluate the performance of the system. In these case studies, the overall performance of the ESBAC was found to be satisfactory.

Keywords: Brick aggregate concrete, Expert system, Knowledge acquisition, Knowledge representation, Mix design.

1. INTRODUCTION
Concrete is the most widely used man-made construction material in the world and is only second to water as the most utilized substance on the planet (Gambhir, 2006). A major portion of this concrete volume is occupied by coarse aggregates. The selection of coarse aggregates should be conducted carefully because they significantly influence the properties and durability of concrete (Safiuddin et al., 2009). The demand for coarse aggregates is enormous in the construction industry. The increased extraction of coarse aggregates from the natural resources is required to meet this high demand. The increasing use of natural coarse aggregate creates an ecological imbalance. Thus, the use of alternative coarse aggregates is vital in construction industry.

In region such as Bangladesh and West Bangle (India), where natural rock deposits are scarce, burnt-clay bricks are used as an alternative source of aggregate. Here, construction of rigid pavement, small to medium span bridges and culverts and buildings up to six stories high using brick aggregate concrete are quite common (Mansur et al., 1999). Brick chips are easily available in the region and are much cheaper than the crushed stone aggregate. In spite of its extensive use and the apparent satisfactory performance of the structure built by concrete using brick aggregate, no systematic investigation on mix design of brick aggregate concrete has been conducted and properly documented (Akhtaruzzaman and Hasnat, 1983).

Mix design of concrete is a process of selecting suitable ingredients and determining their relative proportions to produce concrete of certain minimum properties such as strength and durability (Neville, 1996). In Bangladesh, generally mix proportioning of concrete is based on the ACI Manual of Concrete Practice (ACI 211.1, 2004) and British Standards (BS 1305, 1974). ACI manual and British standards provide information about concrete mix design using natural aggregate (stone chips) and do not deal with broken bricks as coarse aggregate. Concrete mix proportioning with brick aggregate is complicated because of its higher absorption capacity and lower unit weight than natural aggregate. The correct ways to perform this can be achieved with experts’ advice and experience (Bai, 1994). Experts are not sometimes available and they are not always free to consult all possible issues and to review available data (Foo and Akhras, 1993). Many factors such as compressive strength, workability, water-cement ratio, aggregate-cement ratio, size of aggregate, grading of aggregate, durability etc. are the influencing factors of concrete mix proportioning (Raju, 1993). Their mutual association is sometimes so complicated that it is not possible to formulate models to express their mutual relationship (Oh et al., 1999). The information from concrete quality test, experts’ advice and experience are necessary to perform the trial mixes of concrete. It is supposed that the problem of mix proportioning can be alleviated if the engineer’s knowledge can be augmented with some ‘expert systems’ for verifying his judgment (Zain et al., 2005). As the problem is basically judgmental and heuristic-based, an expert system is more appropriate rather than a conventional approach.

This paper describes an expert system prototype called ESBAC for selecting mix proportions of brick aggregate concrete. It also provides an easy and readily available method of consultation for inexperienced staff involved in concrete production.

2. EXPERT SYSTEM AND CONCRETE MIX DESIGN
Expert system is considered as a computer program which is capable in solving the problem like a human expert (Durkin, 1994). It produces advanced knowledge using the experimental or available information and heuristic knowledge thus solves problems as the human expert (Hicky and Aldridge, 1990).

Several expert systems for concrete mix design have been developed and implemented at the prototype stage.
HPCMIX (Zain et al., 2005), COMIX (Smith, 1987), Concrete Mix Designer (Malasri and Maldonado, 1988), ESCON (Celik et al., 1989) and EXMIX (Akhras and Foo, 1994) are expert systems that give recommendation on the selection of concrete constituents using natural aggregate. Neshat and Adeli (2011) and Neshat et al. (2011) also designed fuzzy expert system for the determination of concrete mix design. Abdullahi et al. (2009) developed a program for mix design of light weight concrete which can diagnose and adjust the proportions. Most of these expert systems are based on the ACI Manual of Concrete Practice and some are based on experts’ opinion only. These systems deal with natural stones and do not deal with broken bricks as coarse aggregate. Therefore, the available systems are not suitable for mix design of brick aggregate concrete.

3. DEVELOPMENT OF THE ESABAC

3.1 Knowledge Acquisition
Knowledge for mix design of brick aggregate concrete was acquired from manuals, research articles from journals and conference proceedings, some textbooks written by experts, and some experts involved in concrete production (Neville, 1996; ACI 211.1, 2004; BS 1305, 1974; Mansur et al., 1999; Akhtaruzzaman and Hasnat, 1983; Bai, 1994; Zain et al., 2005; Akhras and Foo, 1994; ACI 211.2, 2004; Islam et al., 2002; Islam et al., 2005; Khaloo, 1994; Zakaria and Cabrera, 1996; Clifton and Kaetzl, 1988; Shetty, 1996; Gambhir, 2006; HBRI, 1993). In addition, interviews were conducted with four civil engineers who have been involved in making brick aggregate concrete for a long time. To survey experts, a set of questionnaire were sent to various professional institutions involved in the production of brick aggregate concrete. Thus knowledge was acquired by text analysis, interviewing experts and survey of experts. It may be mentioned here that the ACI method of mix design (ACI 211.1, 2004) was mainly followed in the development of expert system due to its popularity among the experts in Bangladesh.

3.2. Knowledge Representation
There are a number of different knowledge representation techniques for structuring knowledge in an expert system (Chan, 1996; Salam, 2007). The most widely used techniques are frame-based and rule-based. There is another technique named hybrid system which includes both rule and frame systems. In this research, hybrid knowledge representation technique and Kappa-PC expert system shell was used to develop the proposed expert system (IntelliCrop, 1997). Kappa-PC contains several features that are suitable for hybrid knowledge representation. The acquired knowledge was first represented using flow charts. A flow chart developed to determine concrete ingredients for first trial batch is shown in Figure 1.

Figure 1 Flow chart of first trial batch for mix design of brick aggregate concrete
The knowledge was then represented by frame in Kappa-PC shell. Object hierarchy is an essential tool for representing information in a frame system and facilitating the rule creation process. Figure 2 shows the object hierarchy of ‘MixDesign’ object in a Kappa-PC object browser window. In the ‘Object hierarchy’ frame, ‘MixDesign’ is an object which was divided into classes named Ingredients, ‘FreshConcrete’ and ‘HardConcrete’. The Ingredients class was divided into three subclasses called ‘Aggregate’, ‘Cement’, and ‘Water’. Aggregate class was further divided into two instances named ‘CoarseAggregate’ and ‘FineAggregate’.

The developed flow charts were then converted to expert system rules. An example of a simple rule to determine water content is shown below:

If: slump of fresh concrete is 25 to 50 mm and maximum size of coarse aggregate is 19 mm, Then: Mixing water content should be 150 kg.

In Kappa-PC, this rule was written as:

IF (FreshConcrete:Slump = “25 to 50”) And

(CoarseAggregate:MaxSizeCAmm != 19); THEN (Water:WaterContentkg = 150).

4. DESCRIPTION AND OPERATION OF THE ESBAC

Figure 3 shows the main interface window of the ESBAC. A user interface generally created using label, buttons, text, images and bitmaps (Mustapha et al., 2010). In order to start mix design, the user needs to click on ‘Mix Design’ key of the main window. This opens a new window named ‘Mix Design’ module which consists of several buttons as shown in Figure 4. The functions of the buttons are consistent with their names. The ‘User Guide’ button gives information about the functions of the buttons in a transcript image as shown in Figure 4.

For example, the ‘Flow Diagram’ button, if pressed, shows mix design flow diagram as a bitmap image as shown in Figure 5.

In order to design a concrete mix in SI unit, the user needs to click on the ‘First Trial Batch (SI Unit)’ button of Figure 4. This opens the ‘First Trial Batch (SI Unit)’ interface window as shown in Figure 6. This window displays several buttons namely ‘Mix Design Window’, ‘Data Input for 1 m³’, ‘Display Results’, ‘Explanation of Input Data’, ‘Back’, ‘Main Screen’, and ‘Exit’. This window (Figure 6) also displays a transcript image. The transcript image shows the data required for the first trial batch. In order to start data input, the user needs to click on the ‘Data Input for 1 m³’ button (Figure 6). Then it will open the ‘User Request’ form as shown in Figure 7. The desired input parameters with their limiting values are shown in the ‘User Request’ form. After giving the value of a particular parameter, it is necessary to click on ‘OK’ button. If the user is not sure about the value of the particular parameter, he can chose ‘Comment’ button of Figure 7 for usual values of the parameters as shown in Figure 8. This comment facility gives the user confidence in avoiding input error.

On the other hand, the students who are new in concrete technology and not familiar with the parameters can use ‘Explanation of Input Data’ button of Figure 6. This will give detailed information about the parameter as shown in Figure 9. After finishing the data input session, the user needs to press ‘Display Result’ button of Figure 6 to obtain the mix design result. The user may choose to get output either in weight basis (Figure 10) or in volume basis (Figure 11). In the display window (Figure 10 / Figure 11), the summary of input data also appears. From the display window, the user may go to ‘Mix Design’ window or may exit the display window by pressing the appropriate buttons.

![Figure 2 Object hierarchy of ‘MixDesign’ object (knowledge representation by frame)](image-url)
ESBAC is an expert system for mix design of brick aggregate concrete. It is capable of selecting proportions of cement, mixing water and aggregates.

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For mix design press MIX DESIGN button and to exit from this programme press EXIT button.

Figure 3 Main interface window of ESBAC

Figure 4 Interface window of Mix Design showing user guide
Figure 5 Interface window of Mix Design showing mix design flow diagram

Figure 6 Interface window of First Trial Batch (SI Unit) (after clicking on ‘First Trial Batch (SI Unit)’ button)
Figure 7 A typical User Request form during data input (after pressing Data Input for 1 m³ button of Figure 6)

Figure 8 A typical explanation window during data input (after pressing ‘Comment’ button of Figure 7)

Figure 9 A typical explanation window during data input (after pressing ‘Explanation of Input Data’ button of Figure 6)
Figure 10 Window showing composition and key data of first trial batch (weight basis) (after pressing ‘Display Result (Weight Basis)’ button of Figure 6)

Figure 11 Window showing composition and key data of first trial batch (volume basis) (after pressing ‘Display Result (Volume Basis)’ button of Figure 6)
5. VALIDATION OF THE ESBAC
To evaluate the performance of the ESBAC, validation was carried out on two examples of mix design of brick aggregate concrete. The examples were solved by the expert system and by experts and then results were compared.

5.1. Experts Involved in Validation
To validate the developed expert system, four civil engineers (Table 1) who have been involved in design and production of concrete using brick aggregate were selected. The results of the mix design obtained from ESBAC were compared with those of experts.

5.2. Case Study 1
It is supposed that a 24 MPa (3500 psi) concrete had to be made using following data: Specific gravity of cement = 3.15; maximum size of coarse aggregate (broken brick) = 19 mm, specific gravity (SSD) = 2.00, absorption = 16%, field moisture = 0%, unit weight = 1015 kg/m$^3$; fine aggregate (sand) of fineness modulus = 2.40, specific gravity = 2.67, absorption = 3.1% and field moisture = 0%.

<table>
<thead>
<tr>
<th>Item</th>
<th>ESBAC</th>
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<th>Expert-2</th>
<th>Expert-3</th>
<th>Expert-4</th>
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The trial mix design was compared with the developed system and the experts’ as shown in Table 2. It can be observed from the table that water-cement ratio obtained using the system is the same as those of experts’ opinion. Cement content obtained by the system is close enough to those of Expert-1 and Expert-3 but slightly varies with those of Expert-2 and Expert-4. The amount of cement content was not the same due to variation in using water content for the same water-cement ratio. The amount of coarse aggregate and fine aggregate content is different for the difference of water and cement contents. The individual coarse aggregate and fine aggregate contents varied due to the variation of expert’s opinion.

According to Expert-1, the ratio of weight of fine aggregate to coarse aggregate may be taken as 35:65 for brick aggregate concrete. Expert-2 makes concrete by taking fine aggregate and coarse aggregate proportion as 35:65. Expert-3 has given his opinion to use fine aggregate to coarse aggregate ratio as 35:65. Expert-4 has given his opinion to use fine aggregate to coarse aggregate ratio as 33:67. In this expert system the proportion of fine aggregate and coarse aggregate has been selected as 35:65. In this case, however, experts...
agreed that there is no significant difference in strength for the above proportions. Expert-1 noticed that the differences between his mix proportion and expert system were not critical and Expert-2, Expert-3 and Expert-4 also mentioned that the concrete proportion selected by the system was considerable for the first trial mix. According to Bai (1994), for a particular mix design there are always a number of answers, which also can satisfy the requirements. Therefore, it is evident that the developed system is capable enough for the proportioning of first trial batch for brick aggregate concrete with acceptable accuracy.

5.3. Case Study 2
A 21 MPa (3000 psi) concrete had to be made with the following data: Specific gravity of cement = 3.15; maximum size of coarse aggregate (brick) = 19 mm, specific gravity (SSD) = 2.00, absorption = 16%, field moisture = 0%, unit weight = 1015 kg/m$^3$; fine aggregate (sand) of fineness modulus = 2.40, specific gravity = 2.67, absorption = 3.1% and field moisture = 0%.

The comparison of the mix design selected by the developed system and the experts are shown in Table 3. It can be observed from the table that water cement-ratio was same for the system as well as experts’ calculations. Water content is close enough for the system and those of Expert-1, Expert-3 and Expert-4 but varies with that of Expert-2. But, cement content is close enough for all cases. The amount of coarse aggregate and fine aggregate content is different for the difference of water and cement content. In this case, however, experts agreed that there is no significant difference in strength for the above proportions. They also mentioned that the mix proportion selected by the ESBAC was accurate enough for the first trial mix.

5.4 User-friendliness and the Overall Evaluation of the System
The user interface of the ESBAC was designed for user friendliness. The button named ‘User Guide’ in the ‘Mix Design’ module presents necessary and useful information of the whole consultation processes (see Figure 4). In addition, the ‘Explanation button’ is available in ‘data input’ module (see Figure 6) which will help the end users about design information. Furthermore, each window of consultation has some buttons to guide the users for the next steps. A ‘Comment’ button is incorporated in each ‘User Request’ form of data input (see Figure 7). This will answer the question and thus helps the user more efficiently in the mix design procedure.

The consultation process is flexible enough in this system. The user can reset data, can go back, and can review input values until his satisfaction. The system is very useful with explanatory amenities throughout the mix design process. In addition, ESBAC gives information of data range at every data input stages, which make it better than the conventional systems of concrete mix proportioning. Thus the performance of the system is reasonably satisfactory.

In order for this expert system not to be outmoded, it should be maintained to keep current (Kaetzel et al., 1993). The ESBAC and other expert systems cannot claim unique in their knowledge bases. It is required to improve by refining, expanding, and strengthening its knowledge using new findings and experience from domain experts. Since ESBAC is a research prototype, it must be polished and tested further to be used commercially. ESBAC will serve as a support system for concrete mix design like other expert systems and is not able to replace completely the decision of human experts.

6. CONCLUSIONS
ESBAC was developed to assist the user for mix proportions of brick aggregate concrete. It will also provide an easy and readily available method of consultation for staff involved in concrete production. The Kappa-PC expert system shell was used to develop the expert system.

The developed expert system was tested on two example cases. The mix proportioning of the two example cases was performed using the developed expert system and by experts. It was verified by comparing output of the system with those of experts. It was found that the system is suitable for first trial batching with reasonable accuracy. Whenever possible, thumb rules and past experience should be used for mix design of brick aggregate concrete. If such information is inadequate or not available, the developed expert system can be used to help the user in making intelligent decision in the mix design of brick aggregate concrete.

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