MATLAB BASED M-FILE AND GUI FOR DESIGN OF CONCRETE MIXES

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Abstract: This paper presents the MATLAB based m-file as well as GUI Development Environment (GUIDE) to design a concrete mix calculator. Since, we know that a concrete mix design is prepared under the rules laid out by Indian Standard (IS) codes using different mathematical formulae to compute the ratios of cement, water and aggregates in a concrete mix; it becomes a tedious task to perform these calculations manually. Some researchers prefer to use excel sheets to decrease the computational time, but this methoddoesn't offer data abstraction and human error prevention. As a solution to this problem, a MATLAB based concrete mix calculator has been devised which estimates the proportions of cement, fine aggregates, coarse aggregates (all in Kgs/m^3) and water (in Litres) to design a concretemix. The simulated results of proposed calculator have been successfully verified using MATLAB (R2013a) over different types of concrete grades viz. M10, M15, M20 and M25. The designof calculator is in compliance with IS codes 10262:2009, 456:2000 and 383:2016, which lays down basic formulae to compute the concrete mix ratios. This paper presents the detailed explanation of proposed m-file along with the simulated results of GUIDE. Finally, the simulated results are compared with manual computation (accurate up to 3 decimal places). It is concluded that the accuracy of simulated results is higher than manual computation due to absence of quantization errors. Also, the use of simulated environment not only prevents many scopes of human errors, but it also helps in performing complex computations in a very short amount of time, thereby leading a researcher to perform his tasks more productively.

***IndexTerms* – Aggregates, Concrete Mix, GUI, IS-Codes, MATLAB.**

I. INTRODUCTION

Concrete is basically an artificial material which, after formation, attains the characteristics of a rock like mass; thereby making it useful for constructing civil structures and building civilizations worldwide [1].

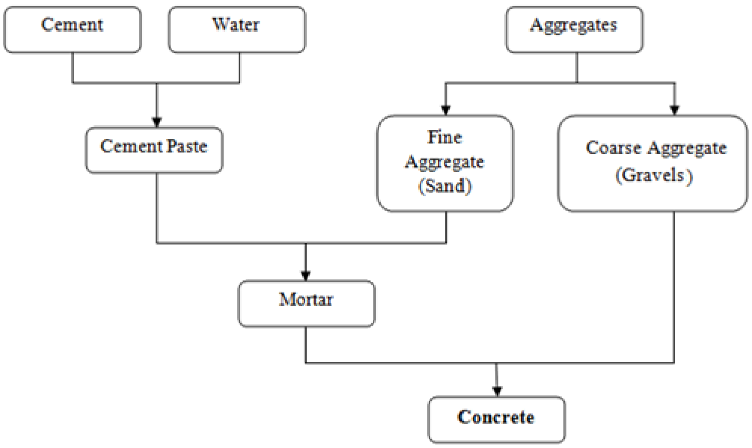

Fig. 1: Formation of Concrete from Cement, Water and Aggregates

Concrete is formed by closely binding the fine aggregate (sand) and coarse aggregate (gravels) together with the help of hydraulic binder i.e. cement paste [2] as shown in figure 1 below. Typically, they are mixed in proportions as given in Table 1 [3].

Table 1: Typical Proportions of Constituents of Concrete

S. No.	Constituents	Proportions
1	Cement	10 – 15%
2	Aggregates	60 – 75%
3	Water	15 – 20%
4	Air	2 – 6%

II. CONCRETE MIX PROPORTIONING

It is the design of a controlled concrete in which desired proportions of concrete constituents i.e. cement, aggregates and water are determined in order to acquire the required durability, strength and economy of concrete. The following data is required for mix proportioning of a particular grade of concrete [4]:

- Grade designation
- Type of cement
- Maximum nominal size of aggregate
- Maximum Water-Cement ratio
- Minimum Cement content
- Workability
- Exposure Conditions as per table 4 and 5 of IS 456
- Maximum temperature of concrete at the time of placing
- Method of transporting and placing
- Type of aggregate
- Maximum Cement Content
- Usage of Admixture

Further, the guidelines for concrete mix design proportioning [CED 2: Cement and Concrete] as given in IS 10262 (2009) are used to design and test the strength of concrete mix design. The detailed explanation of formulas used in concrete mix design is given in section III of this paper along with the m-file of MATLAB.

III. M-FILE FOR CONCRETE MIX DESIGN

This section of paper discusses the literature review and hence, describes the step by step process of designing m-file for concrete mix calculator for M10 to M25 concrete grades as per IS codes. The proposed m-file is divided into different code snippets and the working of each code snippet is described.

3.1 Literature Survey

Few researchers have tried to design a simulator based approach for concrete mix proportioning, such as, the authors in [5] have designed an m-file in MATLAB for designing a high strength concrete whose compressive strength was 60MPa. Similarly, in [6], the authors developed a MATLAB program for concrete whose strength varied from 25 to 45 MPa. Again, the authors in [7] designed and presented a GUI for concrete having strength greater than 60MPa. During the survey, it has been found that the GUI for concrete having strength less than 25MPa has not been devised. The authors in [8] have prepared an m-file but they have not extended it further to developing its GUI. Hence, this paper covers that aspect and proposes the GUI model for concrete strength less than or equal to 25MPa to offer user friendly experience to researcher.

3.2 Clear Memory

The very first of writing an m-file in MATLAB is to clear the previous memory of the workspace and command window, for which the commands ‘clc’ and ‘clear all’ are used at the top of every program code as given below:

```
clc;
clearall;
```

3.3 Concrete Grade Parameters

To start with, we must first enter the type of concrete grade for which the mix is to be prepared, because, as per IS 10262:2009 and IS 456:2000, the parameters like,standard deviation, compressive strength and water cement ratio for each grade is different. To do this, the ‘input’ command asks for real time input from the user as per M10, M15, M20 and M25 concrete grades and accordingly assign the parameter values using ‘if-else’ statement as given below:

```
cemgrade = input('Enter the grade of concrete to be used in mix 10/15/20/25:');
if (cemgrade == 10)
standard_deviation = 3.5;
compressive_strength = 10;
water_cement_ratio = 0.6;
elseif (cemgrade == 15)
standard_deviation = 3.5;
compressive_strength = 15;
water_cement_ratio = 0.6;
elseif (cemgrade == 20)
standard_deviation = 4;
compressive_strength = 20;
water_cement_ratio = 0.5; %assuming severe conditions
elseif (cemgrade == 25)
standard_deviation = 4;
compressive_strength = 25;
water_cement_ratio = 0.4;
else
warning ('Incorrect value of cement grade');
end
```

3.4 Compute Target Strength

The next step is to compute target strength of concrete using the formula given in eq. 1 below as per IS 456:2000:

$$f'c = fc + 1.65s \qquad (1)$$

Where,

f'c (targetstrength) = target average compressive strength at 28 days

fc (compstrength) = characteristic compressive strength at 28 days

s = standard deviation

Using the above formula, the target strength is computed in MATLAB m-file as:

```
target_strength = compressive_strength + (1.65*standard_deviation);
```

3.5 Compute Water Content and Volume of Coarse Aggregates

Further, it is required to determine the volume of coarse aggregates, which is done by determining zone of fine aggregates by comparing the results of sieve analysis test of fine aggregates with the Table 3 of IS 383:2016. Accordingly, the user provides the nominal maximum size of aggregates i.e. 10mm, 20mm or 40mm as an input to the following code section and the 'if-else' statements of the code determine the water content (per m^3) and volume of coarse aggregates as per IS 10262:2009.

```
aggsize = input('Enter the nominal size of the aggregate to be used in mix
10/20/40(in mm):');
if (aggsize == 10)
water_content_per_cubic_meter = 208;
fine_zone = input('Enter the zone of fine aggregates(1/2/3/4):');
if (fine_zone == 1)
volume_of_coarse_aggregate = 0.44;
elseif (fine_zone == 2)
volume_of_coarse_aggregate = 0.46;
elseif (fine_zone == 3)
volume_of_coarse_aggregate = 0.48;
elseif (fine_zone == 4)
volume_of_coarse_aggregate = 0.50;
else
warning ('Incorrect value of zone for fine aggregates');
end
elseif (aggsize == 20)
water_content_per_cubic_meter = 186;
fine_zone = input('Enter the zone of fine aggregates(1/2/3/4):');
if (fine_zone == 1)
volume_of_coarse_aggregate = 0.60;
elseif (fine_zone == 2)
volume_of_coarse_aggregate = 0.62;
elseif (fine_zone == 3)
volume_of_coarse_aggregate = 0.64;
elseif (fine_zone == 4)
volume_of_coarse_aggregate = 0.66;
else
warning ('Incorrect value of zone for fine aggregates');
end
elseif (aggsize == 40)
water_content_per_cubic_meter = 165;
fine_zone = input('Enter the zone of fine aggregates(1/2/3/4):');
if (fine_zone == 1)
volume_of_coarse_aggregate = 0.69;
elseif (fine_zone == 2)
volume_of_coarse_aggregate = 0.71;
elseif (fine_zone == 3)
volume_of_coarse_aggregate = 0.73;
elseif (fine_zone == 4)
volume_of_coarse_aggregate = 0.75;
else
warning ('Incorrect value of zone for fine aggregates');
end
else
warning ('Incorrect value of aggregate size');
end
```

3.6 Compute Revised Water Content (using Slump)

The next input required for design is the slump. Now, the value is also determined by researcher by performing slump test on concrete. This value can vary between 50mm to 100mm. However, there is a 3% increase in water content when slump varies between 50 to 75mm and 6% increase in water content when slump increases between 75 to 100mm. Accordingly, the following snippet of code revises the water content (from cubic meter to litre) as per given slump:

```
slump = input('Enter the value of slump between 50 to 100(in mm):');
if (slump == 50)
water_content_required_in_litre = water_content_per_cubic_meter;
elseif (slump > 50 && slump <= 75)
water_content_required_in_litre = water_content_per_cubic_meter +
0.03*water_content_per_cubic_meter;
elseif (slump > 75 && slump <= 100)
water_content_required_in_litre = water_content_per_cubic_meter +
0.06*water_content_per_cubic_meter;
else
warning ('Incorrect value of slump');
end
```

3.7 Compute Cement Quantity (in Kg/m^3)

The amount of cement required depends upon water cement ratio determined above in step 3.2 and the final water content computed in step 3.5 using eq. 2.

$$\text{Cement required} = \frac{\textit{Water Content Required}}{\textit{Water Cement Ratio}} \qquad (2)$$

The implementation of above equation in MATLAB is done as:

```
cement_content_required_in_Kg_m3 =
water_content_required_in_litre/water_cement_ratio;
```

3.8 Compute Aggregates' Quantity (in Kg)

The next important step is to enter the specific gravity of cement and aggregates, which are also computed by researcher initially, so that the values of specific gravity of cement vary between 3.0 to 3.15 and that of aggregates between 2.5 to 3. The specific gravity of water is considered as 1 and the equations used to determine the quantities are given in eq. 3 through 7 below:

$$\text{Volume of cement} = \frac{\textit{Cement Required in Kg}}{\textit{Specific gravity of cement X } 1000} \qquad (3)$$

$$\text{Volume of water} = \frac{\textit{Water Required in litre}}{\textit{Specific gravity of water X } 1000} \qquad (4)$$

Volume of aggregates (A) = 1 – Volume of cement – Volume of water (5)

Volume of fine aggregates (FA) = 1 – Volume of coarse aggregates (CA) (6)

Where, Volume of coarse aggregates (CA) are already computed in step 3.4 above

Coarse aggregates required in Kg = A * CA * specific gravity of coarse aggregates X 1000 (7)

Fine aggregates required in Kg = A * FA * specific gravity of fine aggregates X 1000 (8)

The MATLAB code for above equations is written as given below:

```
specific_gravity_of_cement = input('Enter the value of specific gravity of cement
(between 3 to 3.15):');
specific_gravity_of_fine_aggregate = input('Enter the value of specific gravity of
sand or fine aggregates (between 2.5 to 3):');
specific_gravity_of_coarse_aggregate = input('Enter the value of specific gravity of
gravels or coarse aggregates (between 2.5 to 3):');
Volume_of_cement =
(cement_content_required_in_Kg_m3/specific_gravity_of_cement)/1000;
Volume_of_water = water_content_required_in_litre/1000;
Volume_of_aggregates = 1 - (Volume_of_cement + Volume_of_water);
volume_of_fine_aggregate = 1 - volume_of_coarse_aggregate;
coarse_aggregates_required_in_Kg = Volume_of_aggregates * volume_of_coarse_aggregate
* specific_gravity_of_coarse_aggregate * 1000;
fine_aggregates_required_in_Kg = Volume_of_aggregates * volume_of_fine_aggregate *
specific_gravity_of_fine_aggregate * 1000;
```

3.9 Computation of Concrete Mix Ratios

The final step is to determine ratios of concrete mix ingredients w.r.t cement i.e.if amount of cement = 1, then ratio of water depends upon water cement ratio of concrete grade (as computed in step 3.2 above), whereas, the ratio of aggregates is computed as per the eq. 8 and 9 below:

$$\text{Ratio of coarse aggregates} = \frac{\textit{Coarse aggregates required in Kg}}{\textit{Cement required in Kg}} \qquad (8)$$

$$\text{Ratio of fine aggregates} = \frac{\textit{fine aggregates required in Kg}}{\textit{Cement required in Kg}} \qquad (9)$$

The MATLAB code for above equations is written as given below:

```
Ratio_of_cement = 1
Ratio_of_water = water_cement_ratio
Ratio_of_coarse_aggregates =
coarse_aggregates_required_in_Kg/cement_content_required_in_Kg_m3
Ratio_of_fine_aggregates =
fine_aggregates_required_in_Kg/cement_content_required_in_Kg_m3
```

IV. IMPLEMENTATION USING MATLAB GUI

This section of the paper presents the design of MATLAB GUI that has been designed with the help of same m-file described in section III above. The front end panel design of GUI is demonstrated in Fig. 2 below.

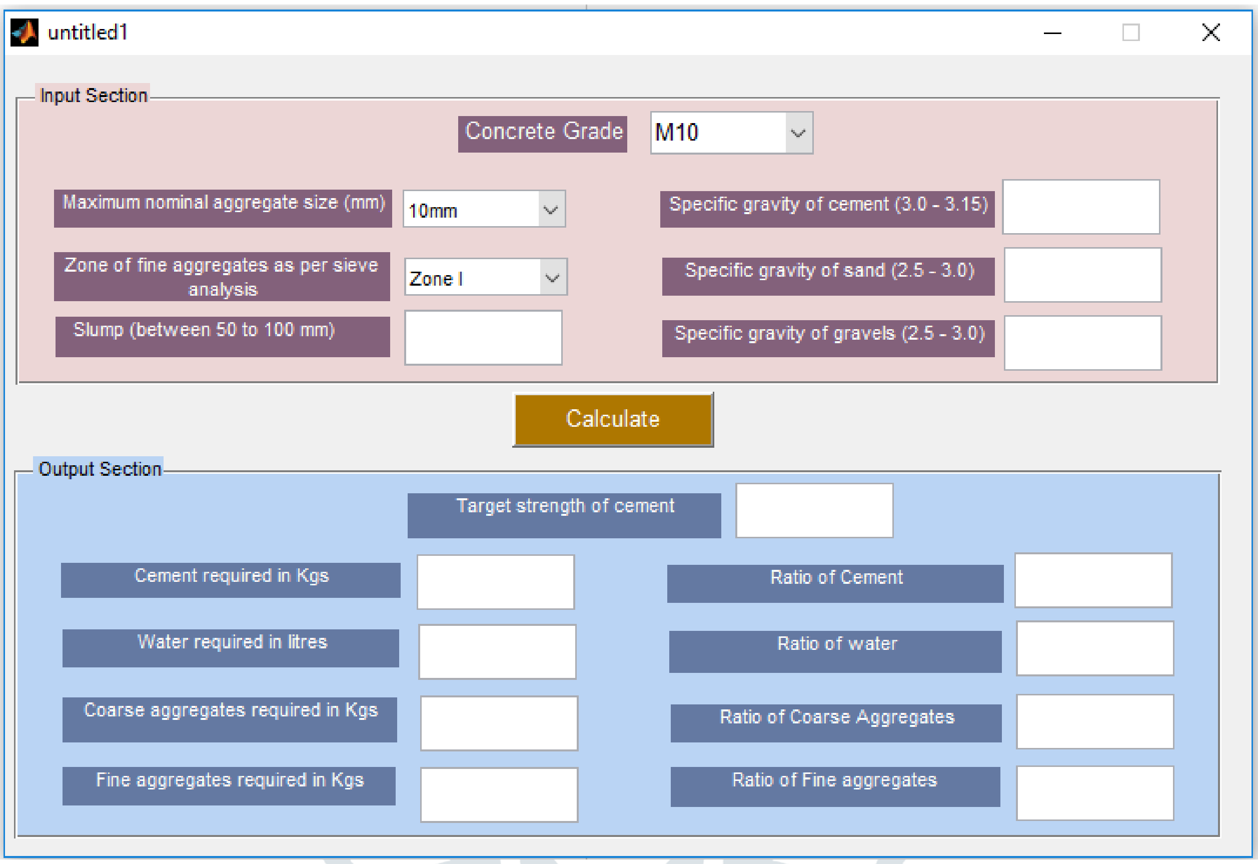

Fig. 2: Front end design of GUI for concrete mix calculator

The front end of GUI has two panels: input section and output section. The input section involves all the parameters that are to be provided by user initially such as concrete grade, maximum nominal size of concrete, fine aggregate zone, slump and specific gravities. The push button named 'calculate' fetches all the above inputs and uses the same formulas as mentioned in m-file under section III to compute the desired outputs. The output section shows the result in two manners: one in exact quantities (in Kgs or litre) and second in the form ratios w.r.t cement.

Figure 3 to 6 below demonstrates the use of this GUI for designing concrete mix using concrete grade M10, M15, M20, and M25 respectively and it also shows the input parameters entered to compute the desired quantities of cement, water, fine aggregates and coarse aggregates in output.

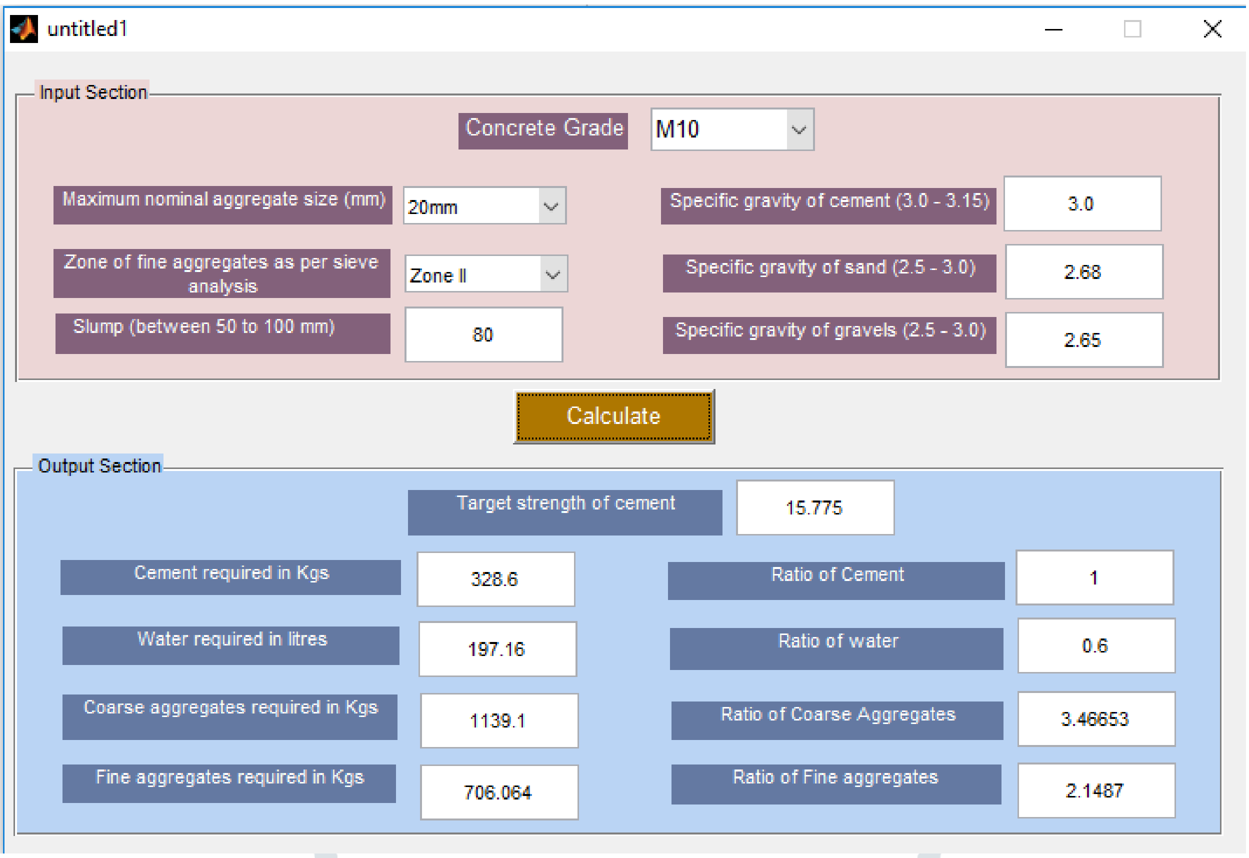

Fig. 3: GUI demonstration for designing concrete mix using M10

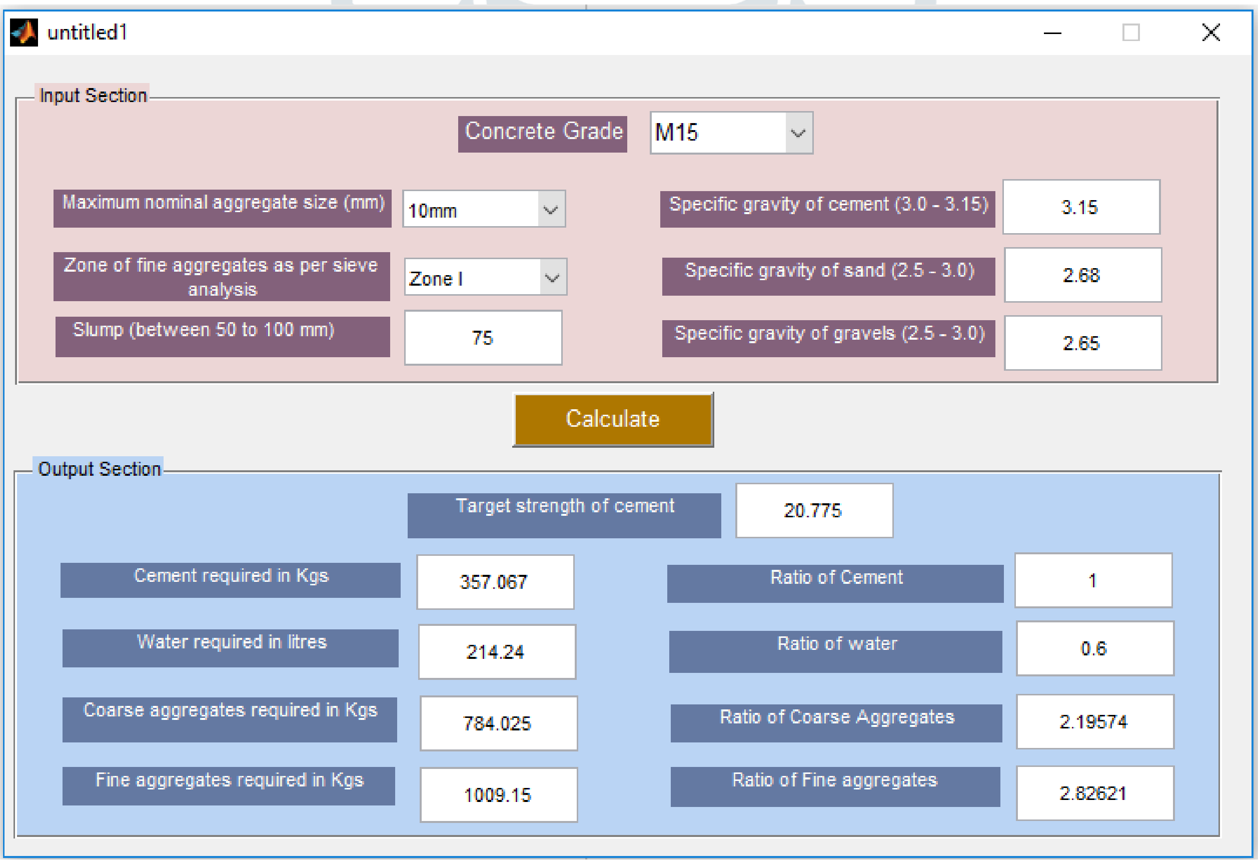

Fig. 4: GUI demonstration for designing concrete mix using M15

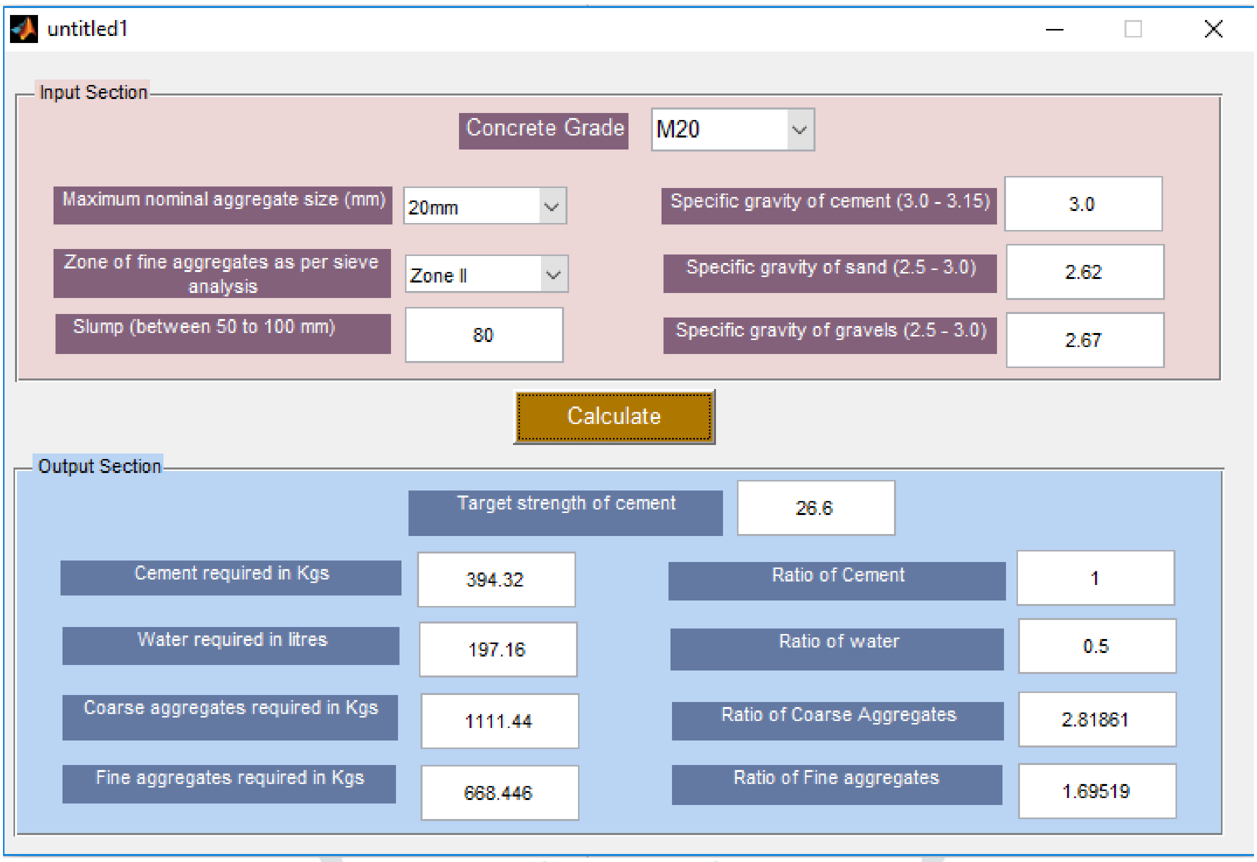

Fig. 5: GUI demonstration for designing concrete mix using M20

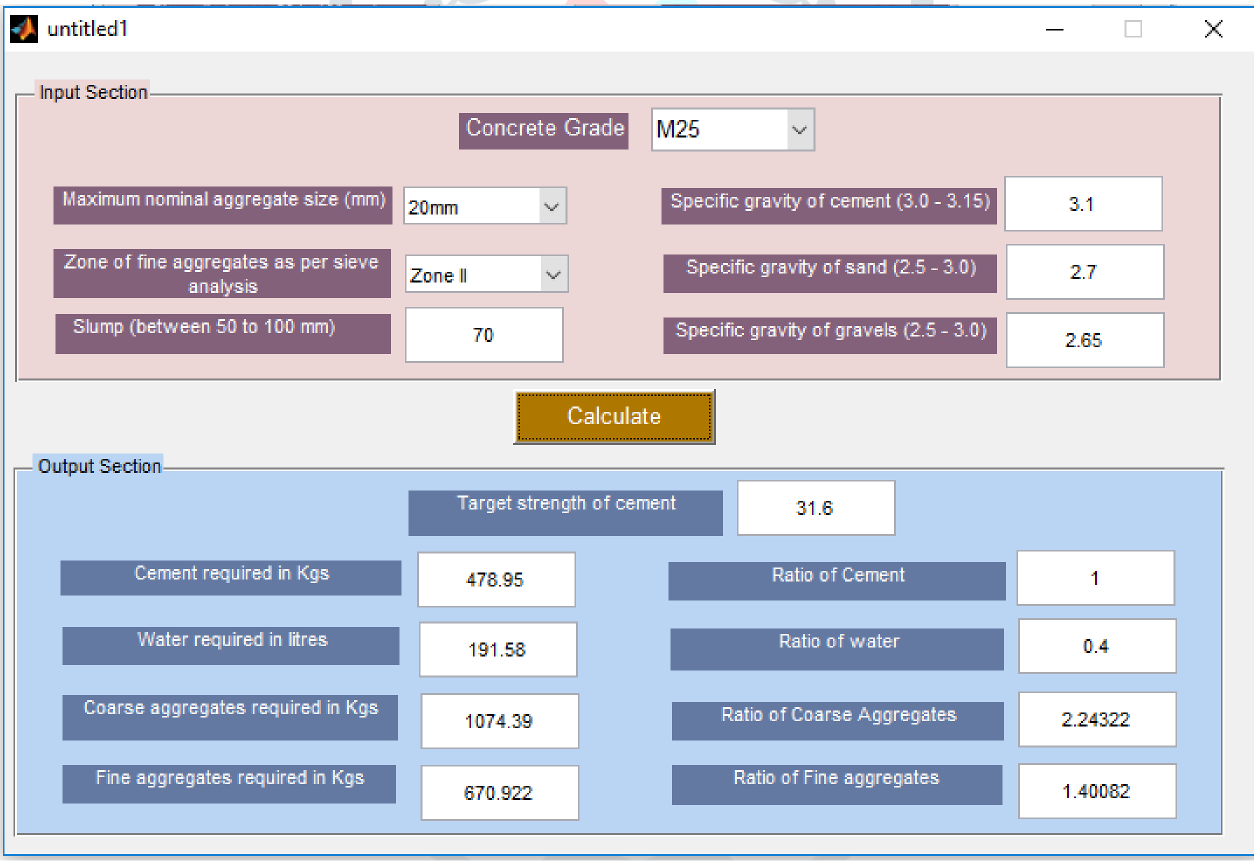

Fig. 6: GUI demonstration for designing concrete mix using M25

V. RESULTS

This section describes the comparison between simulated results of MATLAB and manual computation. For effective comparison, a sample concrete design for M20 concrete with a slump of 80mm and specific gravity values as 3.0, 2.67, 2.62 for cement, coarse and fine aggregates. Also, the maximum nominal size of aggregates is assumed as 20mm.

Target Strength for mix proportioning:
$f'_{ck} = f_{ck} + 1.65s$
Where,
s = standard deviation = 4 N/mm^2,
Therefore, f'_{ck}=target average compressive strength at 28 days = 20 + 1.65 X 4 = 26.6 N/mm^2

Selection of water content:
Estimated water content for 80 mm slump = $186 + \frac{6}{100} X 186$ = 197 litre

Calculation of cement content:
Water cement ratio = 0.5
Cement Content = $\frac{197}{0.5}$ = 394 Kg/m^3
As it is greater than 250 Kg/m^3, hence, suitable for further investigation

Volume of coarse and fine aggregate content:
As per the Table 3 of IS 10262:2009,
Volume of coarse aggregate = 0.62
Volume of fine aggregate = 0.38

Mix Calculations:

1. Volume of concrete (a) = 1 m^3
2. Volume of cement (b) = $\frac{Mass\ of\ cement}{Specific\ gravity\ of\ cement} X \frac{1}{1000}$
   $= \frac{394}{3.0} X \frac{1}{1000}$
   = 0.131 m^3
3. Volume of water (c) = $\frac{Mass\ of\ water}{Specific\ gravity\ of\ water} X \frac{1}{1000}$
   $= \frac{197}{1.0} X \frac{1}{1000}$
   = 0.197 m^3
4. Volume of all in aggregate (d)= [a – (b + c)]
   = [1 – (0.131+0.197)] m^3
   = 0.672 m^3
5. Mass of coarse aggregate = d x Volume of coarse aggregate x specific gravity of coarseaggregate x 1000
   = 0.672 X 0.62 X 2.67 X 1000 = 1112.43 Kg
6. Mass of fine aggregate = d x Volume of fine aggregate x specific gravity of fineaggregate x 1000
   = 0.672 X 0.38 X 2.62 X 1000
   = 669.04 Kg

All the manual computations above are done by taking answers accurate up to 3 decimal places. The results obtained for the same input parameters in case of M20 concrete grade have also been calculated using MATLAB in figure 5 above. Table 2 below represents the tabulated comparison between both of these results.

Table 2: Final Concrete Mix Proportions

Type of Content	Using Manual Computations		Using MATLAB		Difference (D) = X1 – X2
	Net Volume (X1)	Ratio	Net Volume (X2)	Ratio	
Cement	394 Kg/m^3	1	394.32Kg/m^3	1	-0.32 Kg/m^3
Fine Aggregate	669.04 Kg/m^3	1.7	668.446Kg/m^3	1.69519	0.594 Kg/m^3
Coarse Aggregate	1112.43 Kg/m^3	2.8	1111.44Kg/m^3	2.81861	0.99 Kg/m^3
Water	197 Litre	0.5	197.16 Litre	0.5	-0.16 Litre

Here, the positive value of D represents that the quantity of ingredient proposed by MATLAB simulator is higher than manual computation and vice-versa. It is clear from above computation that the quantities of fine and coarse aggregates proposed by MATLAB simulations are respectively 0.594 Kg/m^3 and 0.99 Kg/m^3 lesser than the manual computations. This difference (D) in value is due to the quantization error present in the mathematical analysis done in case of manual computations because usually every value is rounded off up to 3 decimal places. The same doesn't exist in case of MATLAB simulations. Hence, these estimations are more accurate.

VI. CONCLUSION

This paper explained the step by step flow of m-file which is designed in MATLAB to design the concrete mix for different concrete grades in conformance with IS codes. The conversion of m-file to GUI is also demonstrated along with the presentation of simulated results. Finally, the simulated results are compared with the manually computed results. While comparison, it has been observed that the accuracy of quantities generated via MATLAB simulated environment is higher than that of manual computation because MATLAB doesn't omit the negligibly small values that are up to 4th decimal place or above. Due to this, the quantization error i.e. the error involved in computation due to rounding off the values reduces and thus, the requirement of coarse and fine aggregates required to mix the same concrete reduces by 0.5 to 1 Kg in comparison to manually computed results. This proves the achievement of finest level of accuracy via MATLAB. In addition, the time taken to design concrete mix via MATLAB GUI also reduces to a great extent, since a user only has to click few buttons to determine concrete mix ratios, while it requires several steps of calculations manually. Finally, it is also observed that unlike excel sheets, MATLAB GUI offers data abstraction i.e. a user only sees its front end and the background program, which involves formulas, remains entirely hidden from the user. Hence, there is no chance of human errors where the errors are involved due to incorrect application of formula, incorrect use of calculator, or any unintentional typographical errors which changes formula/parameters etc.

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