

M-FILE FOR MIX DESIGN OF STRUCTURAL LIGHTWEIGHT CONCRETE USING DEVELOPED MODELS

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Abstract

An m-file for mix design of structural lightweight concrete is presented. Mix design of structural lightweight concrete is conducted using guide in the standards. This may be tasking involving reading and understanding of the relevant standards. This renders the process inefficient and liable to errors in computations. A computer approach to mix design will alleviate this problem. An m-file was developed in MATLAB environment for the concrete mix design. The m-file has been tested and has proved to be efficient in computing the mix composition for the first trial batch of lightweight concrete mixes. It can also perform concrete mixture proportioning adjustment.

Keywords: Model, Mix design, Lightweight, Concrete, M-file.

1. Introduction

The properties of concrete depend on the mix proportions and the placing and curing methods. Adequate placing of the concrete and suitable curing methods is sought only after obtaining proper mixture proportion of the concrete ingredients. The proportioning of the concrete mix affects its properties in both the plastic and solid state [1]. Mix design of concrete involves the selection of mix ingredients and their proportions. There are two methods for mix design of structural lightweight concrete. These are weight method, where the aggregate are combination of lightweight coarse aggregate and normal weight sand and volume method, where the aggregate are either all composed of lightweight aggregate or a combination of lightweight aggregate and normal weight sand [2]. Conventionally, the ingredient of lightweight concrete is proportioned using experience.

Where this is not available, information obtained from the manufacturer of lightweight aggregate or standard guide for mix design can be employed. None of the approaches have yielded concrete mix ingredient that meet the target requirement using the first trial batch. This leads to several trial and errors in search of the required mix composition. Adjustment of mix composition is therefore required to obtain the desired mix ingredient.

For mix design of structural lightweight concrete, standard practice for selecting proportions for structural lightweight concrete ACI 211.2-98 [3] is commonly referred to. This code contains tables and graphs to serve as a guide in the process of selection of mix ingredient of concrete. Utilisation of this code in mix design requires review of the tabular data and graphs. A good understanding of the data is valuable in the mix design process. However, since the data are numerous, it is likely that errors may arise in selecting values from tables and graphs especially when the mix design is done by novices. Also, interpolations may be required in some cases and mix compositions may require revision as deemed necessary. The manual approach of mix design may not longer be the best option in this computer age and; computer program can alleviate the uncertainty in the mix design process and provide an accelerated solution to concrete mix design.

Researchers have developed computer programs for mix design of concrete [4-7]. Ganju [4] employed spreadsheet to develop a method of designing trial mixes by direct computation of ingredients using formulae only. Day [5] developed a CONAD software system that is capable of examining an existing mix to determine its characteristics, proportioning ingredients to give desired fresh concrete properties, instantaneously revising the proportions of an existing mix for changed circumstances or new materials, using current production mix data to give accurate mix adjustment and accurate predictions for future mixes using the same materials, and storing all currently obtained data and extracting full values from it. De Larrard and Sedran [6] developed two programs for design of high performance and self-compacting concrete mixes for IBM-PC compatible computers in MS-Windows environment. Peyfuss [7] used spreadsheet to simplify concrete mix design using a method similar to the design method in ACI 211.1. These programs have proved to be adequate as tool for mix design of concrete. However, they are only applicable to mix design of normal, high performance and self-compacting concretes. They are not capable of conducting mix design of structural lightweight concrete. To this end, the development of an m-file for mix design of structural lightweight concrete is appropriate and justifiable.

2. Methodology

The data contain in ACI 211.2-98 were used in this work. The tabular data and graphs were converted from imperial to metric units. Predictive models have been developed to obtain the mixing water, air content, water-cement ratio, volume of oven-dry loose coarse aggregate per unit volume of concrete, weight of fresh lightweight concrete, and cement content [8]. The tabular data for the choice of slump is available in Table 3.2.2.1 of ACI 211.2-98 [3]. It was not possible to model this data since there are only two slump values for each type of construction.

An outline of the steps required in conducting the mix design is shown in a flowchart in Fig. 1. The m-file was developed in MATLAB environment. For

each step, conditional statements, and arithmetic and logical expressions were used in coding the required task to be performed. The product from the research work is an m-file in MATLAB environment known as LWC software.

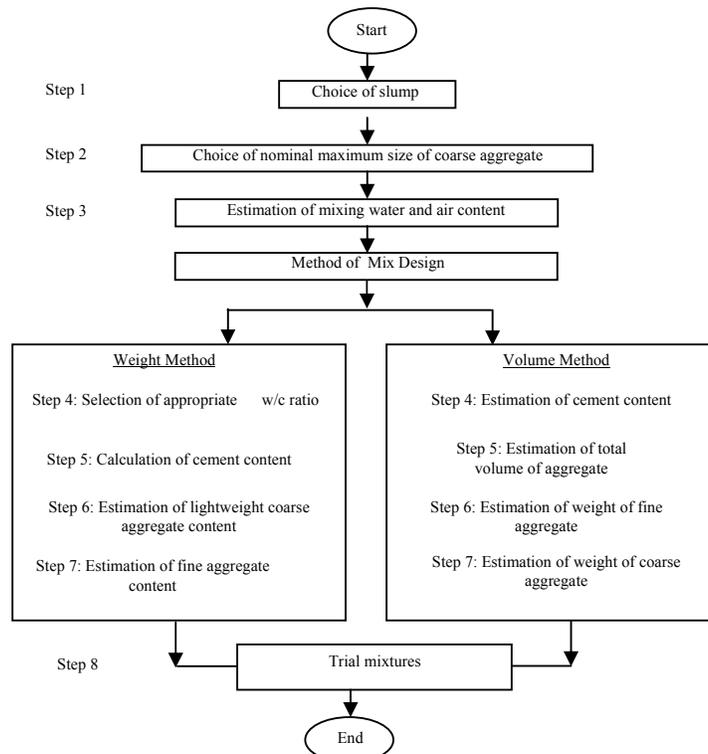


Fig. 1. Flowchart for Mix Design of Structural Lightweight Concrete.

2.1. Development of the m-file

The m-file development process involves three steps; coding, debugging and testing. About seven processes are involved in the mix design as outlined in the flowchart (Fig. 1). The first three processes are common to both weight and volume method of mix design. The last four steps are peculiar to the method of mix design. MATLAB codes are written for each of the subtask outlined in the flowchart.

2.1.1. Coding of the m-file

Here the task is broken down into seven sections to tally with the steps shown in the flowchart (Fig. 1). For each step MATLAB code is written in the m-file. The m-file program is shown in the appendix. It commences with a brief introduction by stating the name of the m-file and title of the program. A brief description of the written MATLAB code is as follows:

Step 1: Choice of Slump:

The data in Table 3.2.2.1 in [3] is used since it is not possible to provide equations for this table. The data it contains can not develop a continuous function. However, the data in Table 3.2.2.1 which is also represented as Table 1 in this work is simple enough to enable users to decide on the required slump for various types of construction. The program commences by initialising a variable `applicable_construction_types` and then a `disp` function is used to display its content to the user in the command window so that the applicable construction type can be chosen. Another variable `construction_type` is initialised together with an input function. The input function prompts the user to key in the desired value of construction type from the display list. This is then followed by an `if-elseif` statement that indicates the maximum and minimum slump depending on the construction type chosen. Two variables, `max_slump` and `min_slump` contain the values of the minimum and maximum slumps which are written out as output statement in a specified format using the `fprintf` function. Another variable `applicable_slump_values`, is initialised and contains typical slump values. The content of this variable is displayed in the command window with the help of the `disp` function. A variable `slump` is then initialised as an input statement and prompts the user to enter the desired slump value. Finally a print function `fprintf` displays the chosen value of slump and its unit using a given format.

Table 1. Recommended Slumps for Various Types of Construction.

Types of construction	Slump (mm)	
	Maximum	Minimum
Beams and reinforced walls	100	25
Building columns	100	25
Floor slabs	75	25

Step 2: Choice of Nominal Maximum Size of Coarse Aggregate

A variable is created, `applicable_nominal_maximum_sizes` that contains typical nominal maximum sizes of aggregates. A `disp` function is then used to display the nominal maximum sizes of aggregates to the user. This is then followed by an interactive input statement that allows the user to enter the nominal maximum size of aggregates. An `fprintf` function displays the chosen value of slump and its unit in a specified format.

Step 3: Estimation of Mixing Water and Air Content

Two input statements interactively allow users to enter the aggregate size and slump values using the variables `aggregate_size` and `slump` respectively. A variable `applicable_entrainments` is then created to give the concrete type (air-entrained concrete or non-air-entrained concrete) and a `disp` function is used to display the information to the user in the command window. An interactive input statement with the variable `entrainment` is then used to choose the type of concrete on the basis of air-entrainment. At this stage there are

three input parameters- aggregate size, slump, and type of concrete. These are used to obtain the water content of the mix with the help of `if-elseif` statement. The `if` part contains given range of slump and type of concrete. Once the `if` or `elseif` part is true the statement that follows is executed to obtain the water content. These statements are developed equations for mixing water. Equations 1-3 and 7-9 in [8] are used. The variable in this equation is the aggregate size. An output statement `fprintf` function writes out water content and its unit in a required format.

`If-elseif` statement is also used for the choice of air content. A variable `entrainment` is used in the `if` part of the `elseif` statement to be used to identify whether the concrete is air entrained or non-air entrained. A variable `applicable_exposure_conditions` contains the exposure conditions which are displayed to the user using the `disp` function. An interactive input statement with the variable `exposure_condition` is used to key in the exposure condition of the concrete. This is then followed by another `if elseif` statement embedded in the first `if elseif` statement. The latter `if elseif` statement contains the variable `exposure_condition` in the `if` or `elseif` part that is used to identify the exposure condition (mild, moderate, or extreme condition). If the `if` or `elseif` part is true, the statement that follows is executed. These statements are equations to calculate the air content as a function of the aggregate size. These equations are equations 4-6 in [8]. This is then followed by an `fprintf` function that writes the value of air content in command window. If the `if` part of the former `if elseif` statement is false it means that the concrete is non-air entrained so that the `elseif` part is executed. This then fires the statement that follows. This statement is an equation that calculates the entrapped air as a function of the aggregate size and it is equation 10 in [8]. This task ends with `fprintf` function that displays the entrapped air.

The remaining steps 4 to 7 are peculiar to the method of mix design employed; either the weight or volume method. The `if-elseif` statement was used to navigate between these methods of mix design.

Weight Method

Step 4: Selection of Appropriate Water-Cement Ratio

A variable `applicable_mix_design_methods` is created to give information about the methods of mix design applicable (weight or volume method). A `disp` function is used to display this information to the user in the command window. An interactive input statement with the variable `mix_design_method` is then used to enter the method of mix design.

If the method of mix design is weight method, another interactive input command is fired. This input command contains the variable `compressive_strength_28_days`, and prompts the user to enter the compressive strength at 28 days. The `if-elseif` statement that contains the variable `entrainment` in its `if` and `elseif` part is used to obtain the water-cement ratio. If the concrete is air entrained equation (12) in [8] is used for the calculation of water-cement ratio as a function of compressive strength at 28 days, otherwise

equation (11) in [8] is used for the calculation of water-cement ratio. An `fprintf` function displays the value of computed water-cement ratio.

Step 5: Calculation of Cement Content

The mathematical description of the cement content is stored in the variable `mathematical_definition_cement_content` and can be displayed to the user with the help of the `disp` function. The equation for computation of the cement content is then fired and the computed value is displayed using the `fprintf` function.

Step 6: Estimation of Lightweight Coarse Aggregate Content

A variable `maximum_size_aggregate`, is used to form an interactive input statement to key in the maximum size of aggregate. The variable `applicable_fineness_moduli_sand`, is used to store the information on fineness modulus of sand which can be displayed using the `disp` function. An interactive input statement with the variable `fineness_modulus_sand`, is then used to key in the fineness modulus of sand. Using the fineness modulus of sand and aggregate sizes, the oven-dry loose volume of coarse aggregate is computed. This is done using the `if-elseif` statement. Equations 13-16 in [8] were used for this computation. The `fprintf` function displays the value of loose volume of coarse aggregate.

The variable `applicable_ovendry_loose_weight`, contains a brief description of oven-dry loose weight of lightweight aggregate which can be displayed on the command window with the help of `disp` function. This is then followed by an input statement that prompts the user to enter the oven-dry loose weight of coarse aggregate. This triggers the computation of the weight of coarse aggregate using the equation that follows and the computed value is displayed including its unit using the `fprintf` function. An input statement with the variable `absorption_coarse_aggregate`, prompts the user to enter the absorption of coarse aggregate, the saturated and surface dry (SSD) weight of coarse aggregate can then be computed using the equation that follows. The output is printed out with the help of `fprintf` function.

Step 7: Estimation of Fine Aggregate Content

The overall weight of concrete is calculated first. The variable `applicable_specific_gravity_factors`, contains information on specific gravity factor of coarse aggregate. This are displayed to the user using the `disp` function. An interactive input statement with the variable `specific_gravity_factor`, permits the user to key in the value of specific gravity factor. Also, the variable `applicable_percentages_entrained_air`, contains information on percentage of entrained air and are shown to the user with the help of `disp` function. An input statement then prompts the user to enter the percentage of entrained air. The `if-elseif` statement are used for the computation of weight of lightweight concrete as a function of specific gravity factor using equations 20-22 in [8]. The weight of lightweight concrete is shown to the user using the `fprintf` function.

The variable `applicable_SSD_weight_fine_aggregate`, contains the mathematical description of the SSD weight of fine aggregate and are displayed in the command window with the help of `disp` function. The SSD weight of fine aggregate can be computed using the equations that follows and the value are displayed using the `fprintf` function. This ends the mix design using weight method. The summary of the mix ingredient are displayed in the command window using series of `fprintf` function for the ingredients computed. Mix revision can be done by changing any of the ingredients as deem necessary and computing again to get the new mix composition.

Volume Method

Step 4: Estimation of Cement Content

If volume method of mix design is employed, the cement content is computed immediately after the computation of water and air content. The variable `applicable_concrete_type` gives information on the type of concrete (all-lightweight concrete or sand-lightweight concrete). A `disp` function displays this information to the user in the command window. An interactive input statement with the variable `concrete_type` can be used to key in the type of concrete into the program. The `if-elseif` statement is used to compute the minimum and maximum cement contents which are displayed with the help of `fprintf` function. Equations 34-37 in [8] are used for this computation. An input statement with the variable `cement_content`, permits the user to enter the cement content desired and finally the cement content chosen can be displayed to the user.

Step 5: Estimation of Total Volume of Aggregate

Input statements prompts the user to enter the volumes of lightweight coarse aggregate, lightweight fine aggregate, and normal weight fine aggregate.

Step 6: Estimation of Loose Weight of Fine Aggregate

The variable `applicable_damp_loose_unit_weight_agg`, contains the description of the damp loose unit weight of aggregate and can be displayed in the command window using `disp` function. Interactive input statements prompt the user to enter the damp loose unit weight of lightweight and normal fine aggregates. The equations that follow calculate the weights of lightweight and normal fine aggregate and store the value in the variables `weight_lightweight_fine_agg` and `weight_normal_weight_fine_agg` respectively.

Step 7: Estimation of Loose Weight of Coarse Aggregate

An interactive input statement prompts the user to enter the damp loose unit weight of lightweight coarse aggregate. An equation then computes weight of lightweight coarse aggregate and stores the value in the variable `weight_lightweight_coarse_agg`.

2.1.2. Debugging of the m-file

The MATLAB program written contains error (syntax, logical, and run-time errors). This made it impossible to run the program accurately for the first time in most cases. Whenever there is an error, MATLAB sent a signal indicating the row and column that contained the error. This error is known as bug. The error was removed by effecting the necessary correction. The process of removing this error is known as debugging.

2.1.3. Testing of the m-file

The m-file was tested to ascertain its capability using mix design problems from reputable textural sources. The examples considered are presented as cases 1 and 2 and the results of computations are compared as shown in Table 2. The MATLAB session for testing the program is also indicated.

Case 1: Volume method

Determine the weights for an initial trial batch of concrete with a compressive strength of 28 MPa and slump of 100 mm. The goal is to produce concrete with a unit weight of no more than 1680 kg/m³ on an air-dry basis. A cement content of 350 kg/m³ is estimated. The lightweight coarse and fine aggregate and normal-weight fine aggregates have damp, loose unit weights of 753, 821, and 1634 kg/m³ respectively. Based on experience with these, the total volume of damp, loose aggregate per meters cube of concrete will be taken as 1.15 m³, consisting of 0.62 m³ of lightweight coarse aggregate, 0.18 m³ of lightweight fine aggregate, and 0.35 m³ of normal-weight fine aggregate [9].

Case 2: Weight method

Design a concrete mixture by the weight method using lightweight coarse aggregate and normal-weight fine aggregate (sand-lightweight concrete) for structural lightweight concrete slab with a design 28-day compressive strength of 35 MPa. Use the following data in the mix design:

Coarse aggregate: 19 mm – N0.4 size; specific gravity factor = 1.5; absorption = 11.0 %.

Fine aggregate: absorption = 1.0 %; fineness modulus = 2.80.

Oven dry loose weight of coarse aggregate = 769 kg/m³.

The author considered an air content of 6% [10].

(a) Case 1: Matlab Session for Volume Method

```
>> lwc_mix
```

This is a "LWC Mix" software that performs mix design of structural lightweight concrete. The file name for the m-file is lwc_mix.m.

Choose construction type from the list: Enter 1 for beams and reinforced walls, enter 2 for building columns, enter 3 for floor slabs

Enter construction type: 1

max_slump = 100 mm.

min_slump = 25 mm.

select slump from the list: 25, 50, 75, 100, 125, 150 (unit in mm).

Enter slump: 100

slump = 100 mm.
 select nominal maximum size from the list: 10, 12, 14, 19 (unit in mm).
 Enter nominal maximum size of lightweight coarse aggregate: 19
 nominal_maximum_size = 19 mm.
 Enter aggregate size: 19
 Enter slump: 100
 Select concrete type based on air entrainment: Enter 1 for air-entrained concrete,
 and 2 for non-air-entrained concrete.
 Enter type of entrainment: 1
 water_content: 181 kg/m³.
 Select exposure condition from the list: Enter 1 for mild condition, enter 2 for
 moderate condition, and 3 for extreme condition.
 Enter exposure condition: 1
 air_content: 3.98 percent.
 There are two method of mix design. Enter 1 for weight method, enter 2 for
 volume method.
 Enter method of mix design: 2
 There are two concrete types for choice of cement content: Enter 1 for all-
 lightweight concrete, enter 2 for sand-lightweight concrete.
 Enter concrete type: 2
 Enter the target compressive strength.
 Enter compressive strength: 28
 min_cement_content: 251.549079 kg/m³.
 max_cement_content: 371.144435 kg/m³
 Enter cement content: 350
 cement_content: 350 kg/m³.
 Enter lightweight coarse aggregate volume (m³): 0.62
 Enter lightweight fine aggregate volume (m³): 0.18
 Enter normal weight fine aggregate volume (m³): 0.35
 The value of damp loose unit weight of aggregate is obtained from experiment or
 the manufacturer of lightweight aggregate (Unit in kg/m³)
 Enter damp loose unit weight of lightweight coarse aggregate (kg/m³): 753
 Enter damp loose unit weight of lightweight fine aggregate (kg/m³): 821
 Enter SSD unit weight of normal weight fine aggregate (kg/m³): 1634

MIX COMPOSITION

water_content: 181 kg/m³.
 water_cement_ratio: 0.52
 cement_content: 350.00 kg/m³.
 weight_lightweight_coarse_agg: 466.86 kg/m³.
 weight_lightweight_fine_agg: 147.78 kg/m³.
 weight_normal_weight_fine_agg: 571.90 kg/m³.

(b) Case 2: Matlab Session for Weight Method

>> lwc_mix

This is a "LWC Mix" software that performs mix design of structural lightweight
 concrete. The file name for the m-file is lwc_mix.m.
 Choose construction type from the list: Enter 1 for beams and reinforced walls,
 enter 2 for building columns, enter 3 for floor slabs

Enter construction type: 3
max_slump = 75 mm.
min_slump = 25 mm.
select slump from the list: 25, 50, 75, 100, 125, 150 (unit in mm).
Enter slump: 75
slump = 75 mm.
select nominal maximum size from the list: 10, 12, 14, 19 (unit in mm).
Enter nominal maximum size of lightweight coarse aggregate: 19
nominal_maximum_size = 19 mm.
Enter aggregate size: 19
Enter slump: 75
select concrete type based on air entrainment: Enter 1 for air-entrained concrete,
and 2 for non-air-entrained concrete.
Enter type of entrainment: 1
water_content: 181 kg/m³.
select exposure condition from the list: Enter 1 for mild condition, enter 2 for
moderate condition, and 3 for extreme condition.
Enter exposure condition: 1
air_content: 3.98 percent.
There are two method of mix design. Enter 1 for weight method, enter 2 for
volume method.
Enter method of mix design: 1
Enter compressive strength at 28 days: 35
water_cement_ratio: 0.40
Enter maximum size of aggregate: 19
select fineness modulus from the list: 2.40, 2.60, 2.80, 3.00.
Enter fineness modulus of sand: 2.8
coarse_aggregate_ovendry_loose_volume: 0.70 m³.
cement content is the ratio of water_content to water_cement_ratio.
cement_content: 453.84 kg/m³.
The value of ovendry loose weight is obtained from experiment or the
manufacturer of lightweight aggregate.
Enter ovendry loose weight of coarse aggregate: 769
weight_coarse_aggregate: 538.30 kg/m³.
Enter absorption of coarse aggregate (in percent): 11
SSD_weight_coarse_aggregate: 597.51 kg/m³.
select value of specific gravity factor from the list: 1.00, 1.20, 1.40, 1.60, 1.80,
2.00.
Enter specific gravity factor: 1.5
select percentage of entrained air from the list: 4, 6, 8.
Enter percentage of entrained air: 6
lightweight_concrete_weight: 1770 kg/m³.
weight of lightweight concrete less the weights of water, cement and coarse
aggregate gives the SSD weight of fine aggregate.
SSD_weight_fine_aggregate: 537.83 kg/m³.

MIX COMPOSITION
water_content: 181 kg/m³.
water_cement_ratio: 0.40
cement_content: 453.84 kg/m³.

SSD_weight_coarse_aggregate: 597.51 kg/m³.
 SSD_weight_fine_aggregate: 537.83 kg/m³.

Table 2. Comparison of Output of Mix Design.

Volume method		
Mix Composition	M-file	Case 1
Water content (kg/m ³)	181	180
Water cement ratio	0.52	0.52
Cement content (kg/m ³)	350	350
Weight lightweight coarse aggregate (kg/m ³)	466.86	467
Weight lightweight fine aggregate (kg/m ³)	147.78	148
Weight normal weight fine aggregate (kg/m ³)	571.90	572
Weight method		
Mix Composition	M-file	Case 2
Water content (kg/m ³)	181	180.96
Water cement ratio	0.4	0.4
Cement content (kg/m ³)	453.44	452.69
SSD weight coarse aggregate (kg/m ³)	597.51	597.45
SSD weight fine aggregate (kg/m ³)	537.83	495.41

3. Discussions

The values calculated using the m-file are very close to the values obtained by the authors as indicated in Table 2. This indicates that the mix design using the m-file agrees with those of the authors in cases 1 and 2. Unavoidable mistakes associated with the manual approach to mix design are prevented since the mix designer only need to key in the required input parameters. The LWC software does the mix design itself. This ensures consistency, efficiency and reliability since the software is not affected by any external influences. Using the LWC software, the rigour of picking data and the need to interpolate between values are avoided. Rather, models have been inserted in the software and various `if` and `if-elseif` statements were used to select the model appropriate to the cases at hand. Human expertise is not always consistent. Human experts get tired or bored, the level of their performance may change if they are under pressure, and they may not produce the best results if the mix design problem is very complicated or if it has to be solved quickly. Where the mix design is conducted by novices the entire process is also slow and may be liable to errors. The need for faster mix design approach has been reiterated by some researchers [4-5]. The LWC software developed in this work would be useful to construction industry as a design tool and schools and research institutions as an educational aid.

4. Conclusions

An m-file known as LWC software has been developed in MATLAB environment using several conditional statements. Several models developed in the previous studies were inserted in the appropriate section in the m-file which may be fired in a logical order. The LWC software has been tested using sample

problems from textural source, and has shown reasonable ability to conduct mix design of structural lightweight concrete. In this work LWC software has been able to conduct mix design for both sand-lightweight and all-lightweight concrete. The output of the computations by LWC software include the water content, water cement ratio, cement content, weight of lightweight coarse aggregate, weight of lightweight fine aggregate, and weight of normal weight fine aggregate. The computations from the software were found to be in agreement with those of the authors considered in this work.

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