A methodology for the effective use of materials in concrete paving block

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Abstract. For a long time, concrete paving blocks have been broadly utilized in different countries as a specialized problem-solving technique to provide pavement in areas where, traditional forms of construction were less robust due to several drawbacks. Low maintenance, ease of placing and evacuation and quick use after installation make it best fit for various utilizations where the conventional pavement technologies are not practical or desirable. So there emerges a dynamic enthusiasm for the concepts of the mix design process for the development of concrete paving blocks arises. This paper aims to develop an optimized mix design for concrete paver blocks for medium traffic as per relevant codes, considering quality and economy. To maximise the particle packing density of concrete, the packing density approach was used here. The method of packing density receipt maximises the concrete material packing density by selecting the perfect measure of different aggregates to fill the voids, allowing a denser and firmer structure. The higher degree of particle packing contributes to minimum voids, maximum density, and thus fewer cement and water demands, leading ideal medium traffic design.

1. Introduction
Worldwide, concrete paving block have been extensively used in special problem areas, where traditional forms of pavement are less durable due to several technical and environmental restraints [1]. They were individual blocks of various sizes and patterns that laid between edge restraints on a thin bed of sand. In India, concrete paving blocks have been used for 30 years, particular in footpaths, parking lots, gas stations, city roads, military roads, industrial hardstands, etc.[2]. This study aims to establish an optimised mix design for medium traffic concrete paver blocks by using the method of packing density that optimises the concrete particle packing density, leading to minimum cement and water requirements, prompting ideal design.

2. Background

2.1. Basic concept of paving block
Concrete paving block was flexible, aesthetically appealing, reliable, and cost-effective and demands little or no maintenance if manufactured and laid efficiently [3]. They were manufactured by pouring into a standard-shape mould of various layers of mix of concrete and some sort of colouring agent and allowing it to be set. This makes them compatible. No real adhesive or retaining technique, excluding edging, was used other than the weight of the block itself. What's more, unlike homogenous concrete surfaces and hardened concrete, these interlocking paving units allow temperature fluctuations without...
developing surface cracks. Each unit had joints that allow a small amount of movement without its functionality or cracking being impaired. In addition, the performance specifications of concrete paving blocks made it reasonable to accommodate significant loads and resist shear and braking forces for the heaviest duty applications [4].

2.2. Specific prerequisites for mix design
Mix design was respected as the method of choosing the scope of various concrete component materials to create an item of sufficient condition. IS 10262-2009 providing the methodology for proportioning concrete mixes as required by the use of concrete making materials [5]. The basic features required for the mixture proportioning of pavement blocks [6] as given below:

2.2.1. Grade and thickness of concrete. The strength of the block was not considered as the primary factor as a whole but a minimum of 40 MPa required resisting the wear and tear and damages. The grade of concrete along with thickness varies depending on traffic conditions upon which the paving blocks used. The grades can be selected as per IS 15658:2006[7].

2.2.2. Characteristics of aggregates. The collection of fine and coarse aggregates would conform with IS 383:1970[8] prerequisites. Aggregates should be sound and free from impurities of any kind. The scale can vary between 6 mm and 12 mm for coarse aggregates [9]. The volume of coarse aggregate in the mix is typically 40% and the fine aggregate is 60% [9].

2.2.3. Cement type and water cement ratio. The cement selected for this mix design was ordinary Portland cement of grade 53, in order to achieve higher initial strength. The ratio of water cement must be between 0.34 and 0.38 as per IRC SP 63:2004[9].

2.2.4. Water quality. The specifications stated in IS 456:2000, IS 15658:2006 shall be verified in respect of the water to be used in the development of paving blocks. [7], [10].

2.3 Packing Density Method
Packing density, a modern type of mix design process used to design different types of concrete. In order to increase the particle packing density of concrete and to achieve a compact and robust particle structure, particles should be selected in order to fill the voids between large particles with smaller particles. The greater degree of particle packing contributes to minimal voids, thus the criteria for cement and water outcomes will be lower [11].

In a volume fraction of the total aggregate, the packing density of the individual aggregate is determined from its maximum bulk density of the mixture and specific gravity by the following relation.

\[
Packing\ density = \frac{Bulk\ density \times Weight\ fraction}{Specific\ gravity} \quad (1)
\]

Calculation of voids content in percentage volume of aggregate or mixture of three aggregate is calculated from the following relationships based on its bulk density.

\[
Void\ content\ in\ per\ cent\ volume = \frac{Specific\ gravity - Bulk\ density}{Specific\ gravity} \times 100 \quad (2)
\]

or in terms of packing density

\[
Void\ content\ in\ per\ cent\ volume = (1- total\ packing\ density) \times 100 \quad (3)
\]

Using this void content percentage of cement paste required for design of concrete mix can be carried out i.e., percentage of void content would be the required percentage of cement paste for the design of concrete mix [11].

3. Methodology
The primary objective of this research study is to create an optimised process of mix design for the production of concrete paver blocks. Until designing the mix design, the initial task of the work is to
refine the materials. The materials selected for optimization are cement of OPC 53 grade, coarse aggregate of size 12.5mm, 10mm and 6.25mm, fine aggregate as M sand and water selected is of drinking quality. The optimized mix design is obtained by packing density method. In this the bulk density of raw materials is calculated for different proportions and the proportion with maximum bulk density is selected for mix design. The main objective of packing density method is that it helps to calculate the minimum binder content which optimizes the mix design. The bulk density of aggregates is therefore tested individually and at different proportions.

Table 1. Specific Gravity Values of aggregates

| Specific gravity | Values |
|------------------|--------|
| Coarse aggregate | 2.67   |
| Fine aggregate   | 2.76   |

After testing the specific gravity of aggregates (Table 1) the bulk density was calculated both individually and different proportions.

3.1 Optimization Using Packing Density

As per IS 2386 part 3 the bulk density test was conducted, and the values obtained are given in Table 2.

Table 2. Bulk Density

| Aggregate | Bulk density of Loosely packed (kg/m³) | Bulk density of Compacted (kg/m³) |
|-----------|----------------------------------------|----------------------------------|
| 12.5 mm   | 1494                                   | 1677                             |
| 10 mm     | 1542                                   | 1671                             |
| 6.25 mm   | 1569                                   | 1677                             |
| M sand    | 1410                                   | 1764                             |

Next the sizes of coarse aggregates selected (12.5mm, 10mm and 6.25mm) were mixed in various proportions and their bulk density was calculated as per procedures in packing density method and presented in Table 3.

A sample calculation for Table 3 is given below.

For 50:30:20,

Empty weight of cylinder = 12.5kg

Cylinder + Aggregate weight of loosely packed = 35.30kg

Cylinder + Aggregate weight of compacted = 37.700kg

Volume of cylinder = \( \pi \times 0.125 \times 0.125 \times 0.3 \approx 0.0147 \) m³

Bulk density for loosely packed aggregate

\[
\text{Bulk density for loosely packed aggregate} = \frac{\text{Cylinder + Aggregate weight} - \text{Empty weight of cylinder}}{\text{Volume of cylinder}}
\]

\[
= \frac{35.3 - 12.5}{0.0147} = 1551.02 \text{ kg/m}^3
\]

Bulk density for compacted aggregate

\[
= \frac{37.2 - 12.5}{0.0147} = 1680.272 \text{ kg/m}^3
\]

Bulk Density coefficient

\[
= \frac{\text{Loosely packed density}}{\text{Compacted bulk density}} = 0.923
\]
Analysing the Table 3, the proportion with 70:15:15 gives the maximum bulk density coefficient value. So, we choose the proportion 70:15:15 for the mix design since the proportion with maximum bulk density gives the maximum strength.

**Table 3. Bulk Density for different proportion of aggregate**

| Proportion of Aggregate in % | 12.5mm Weight (kg) | 10mm Weight (kg) | 6.25mm Weight (kg) | Bulk Density (kg/m³) | Bulk Density Coefficient |
|-----------------------------|--------------------|-----------------|-------------------|---------------------|------------------------|
| 50 30 20                    | 35.3               | 35.3            | 35.6              | 1551.02             | 0.923                  |
| 50 20 30                    | 35.3               | 35.3            | 35.6              | 1551.02             | 0.921                  |
| 50 10 40                    | 35.7               | 35.7            | 35.8              | 1578.23             | 0.928                  |
| 60 5 35                     | 35.6               | 35.6            | 35.8              | 1571.428            | 0.920                  |
| 60 10 30                    | 35.6               | 35.6            | 35.8              | 1571.428            | 0.905                  |
| 60 15 25                    | 35.8               | 35.8            | 35.9              | 1591.836            | 0.917                  |
| 70 5 25                     | 36.4               | 36.4            | 36.4              | 1625.850            | 0.914                  |
| 70 10 20                    | 35.9               | 35.9            | 36.1              | 1591.836            | 0.917                  |
| 70 15 15                    | 36.2               | 36.2            | 36.2              | 1612.245            | 0.937                  |
| 80 10 10                    | 34.5               | 34.5            | 34.5              | 1496.598            | 0.884                  |
| 80 5 15                     | 34.5               | 34.5            | 34.5              | 1496.598            | 0.880                  |

3.2 Proposed Mix Design

In accordance with the packing density technique followed by IS 10262: 2000; the mix design can be prepared. 12.5 mm is the maximum size of the coarse aggregate used. Thus, the chosen coarse aggregate sizes were 12.5 mm, 10 mm and 6.25 mm. M sand, which conforms to Zone 1, was the fine aggregate used and the selected water cement ratio was 0.38. Since the chosen terrain was medium traffic category, the M40 grade was chosen.

3.2.1. Packing Density

i) For 12.5mm Coarse Aggregate

\[
\text{Bulk Density} = \frac{41800 - 12500}{3.14 \times 12.5 \times 12.5 \times 30} = 1.99 \text{ g/cm}^3
\]

\[
\text{Packing Density} = \frac{1.99 \times 0.42}{2.67} = 0.313 \text{ g/cm}^3
\]

ii) For 10mm Coarse Aggregate

\[
\text{Packing Density} = \frac{1.99 \times 0.09}{2.67} = 0.0671 \text{ g/cm}^3
\]

iii) For 6.25mm Coarse Aggregate

\[
\text{Packing Density} = \frac{1.99 \times 0.09}{2.67} = 0.0671 \text{ g/cm}^3
\]

iv) For Fine Aggregate

\[
\text{Packing Density} = \frac{1.99 \times 0.4}{2.76} = 0.288 \text{ g/cm}^3
\]

Total Packing Density = Packing Density of CA + Packing Density of FA

\[
\text{i.e., Total Packing Density} = 0.7352 \text{ g/cm}^3
\]

\[
\text{Void Content} = 1 - 0.7352 = 0.2648
\]

Adding 10% extra
Paste Content = 0.2648+(0.1 x 0.2648) = 0.2913
Volume of Aggregate = 1-0.2913 = 0.7087 cc
Volume of total solid in aggregate
\[\text{Volume of total solid in aggregate} = \frac{\text{Weight of 12.5mm aggregate} \times \text{Specific Gravity}}{\text{Specific Gravity}} + \frac{\text{Weight of 10mm aggregate} \times \text{Specific Gravity}}{\text{Specific Gravity}} + \frac{\text{Weight of 6.25mm aggregate} \times \text{Specific Gravity}}{\text{Specific Gravity}} + \frac{\text{Weight of fine aggregate} \times \text{Specific Gravity}}{\text{Specific Gravity}}\]
\[= \frac{0.42}{2.67} + \frac{0.09}{2.67} + \frac{0.09}{2.76} + \frac{0.4}{2.76} = 0.3696 cc\]
Weight of aggregate
\[\text{Weight of aggregate} = \frac{\text{Volume of aggregate}}{\text{Total solid volume}}\times \text{weight of aggregate} \times 1000\]

3.2.2. For M40 grade concrete
w/c ratio = 0.38[16]
w = 0.38c
Total paste = \(c + o = \frac{c}{0.2913} + \frac{0.38 \times c}{1} = 0.69746c\)
Cement content = \(0.2913 \times 1000 = 417\) kg/m³
Water content = \(0.38 \times 417 = 158.5\) kg/m³

3.2.3. Final mix proportions
Cement: 417 kg/m³
Water: 158.5 kg/m³
Fine aggregate: 767.013 kg/m³
Coarse aggregate
For 12.5 mm: 805.364 kg/m³
For 10 mm: 172.578 kg/m³
For 6.25 mm: 172.578 kg/m³
Water cement ratio: 0.38
Using the above data, concrete mix shall be prepared, and cubes can be casted after ensuring the concrete with zero slump and tested for 7 and 28 days.

4. Conclusion
To optimize materials in the mix design of the concrete paver block, we are able to adopt the methodology explained within the above study. The packing density approach optimizes concrete particle packing density and produces a dense and firmer structure, thus reducing the binder material in turn. The calculations for a typical mix design for M40 grade for medium traffic is outlined in this paper. The above approach can also be used to achieve a mix design for material replacement.

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