A.1. Basic considerations

A.1.1 The proportioning of concrete mixes consists of determination of quantities of different concrete-making materials necessary to produce concrete having the desired workability and 28-days compressive strength of concrete for a particular grade of concrete and durability requirements. Emphasis is laid on making the most economical use of available materials so as to produce concrete of required attributes at the minimum cost.

A.1.2 Concrete has to be satisfactory both in fresh and hardened states. The proportioning of concrete mixes is accomplished by the use of certain established relationships from experimental data which provides reasonably accurate guidance for selecting the best combination of ingredients so as to achieve the desired properties of the fresh and hardened concrete. Out of all the physical characteristics of concrete compressive strength is often taken as an index. Therefore, the mix design is generally carried out for a particular compressive strength of concrete coupled with adequate workability so that the fresh concrete can be properly placed and compacted. In addition the mix proportions are also checked against the requirement of adequate durability for the type of exposure condition anticipated in service. The following basic assumptions are made in design of concrete mixes of medium strength:
   a) For given aggregate characteristics, the workability of concrete is dependent on its water content.
   b) The compressive strength of concrete is related to its water-cement ratio.

A.1.3 For high strength concrete mixes, considerable interaction occurs between these two criteria and validity of such assumptions may become limited. Moreover, there are various other factors which affect the properties of concrete e.g. the quality and quantity of cement, water, aggregates and admixtures (if used); procedures of batching, mixing, placing, compaction and curing etc. Therefore, the specific relationships that are used in proportioning concrete mixes, should be considered only as a basis for trial mixes. Concrete mix design on the basis of recommended guidelines is really a process of making an initial guess at the optimum combination of ingredients and final mix proportions are arrived at, only on the basis of further trial mixes.

A.2. Factor in the choice of mix design

The design of concrete mix is based on the following factors:
   a) Grade of concrete
   b) Type of cement and its strength
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c) Desired workability of concrete
d) Maximum nominal size of aggregate
e) Minimum cement content and Maximum water-cement ratio to satisfy durability requirements.

Out of these, the grade of concrete provides the characteristics strength requirement of concrete. Depending upon the level of quality control expected to be exercised at the site, the concrete mix has to be designed for a target mean strength which is somewhat higher than the characteristics strength.

The workability of concrete for satisfactory placing and compaction is related to the size and shape of the section to be concreted, the quality and spacing of reinforcements, and the methods to be employed for transportation, placing and compaction of concrete.

Provision of minimum cement content and maximum water cement ratio ensure adequate durability of the structure to withstand environmental loads.

A.3. Concrete mix design procedure as per Indian Standard recommended guidelines (IS:10262-1982)

A.3.1 The Indian Standard recommended guidelines give a procedure for proportioning concrete for general type of construction using concrete-making materials normally available. The mix design is carried out for a desired workability and 28 days compressive strength of concrete, using continuously graded coarse aggregates. The mix design procedure is for normal concrete mixes(non-air-entrained), both for medium and high-strength concrete. In this method, the water content and proportion of sand(as % of total aggregate by absolute volume) are determined for fixed values of w/c ratio, workability and grading of sand. The water content and % of sand are then adjusted for any difference in workability, w/c ratio and grading of sand. The batch weight of materials per m$^3$ of concrete is finally calculated by the absolute volume method.

In case of RMC, generally admixtures are used which may reduce the strength of concrete to 90%. Thus, while designing the mix, the characteristic strength should be enhanced to that extent.

A.3.2 The following basic data are required:
  a) Grade of concrete along with characteristic strength (fck)
  b) Degree of workability desired (Slump or compacting factor value)
  c) Degree of quality control expected to be exercised at the construction site,
  d) Exposure condition at the construction site
  e) Type and maximum size of aggregate to be used.
  f) Standard deviation (S) of compressive strength of concrete samples.
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A.3.3 The following test data on materials are required:
   i) Specific gravity of cement
   ii) Test data on cement-testing (28 days strength of cement-mortar), if available,
   iii) Specific gravity and water absorption (%) for coarse and fine aggregates,
   iv) Grading of coarse and fine aggregates,
   v) Accelerated strength of "reference" mix concrete (if 28 days cement-strength data is not available)

A.3.4 Procedure of concrete mix design
   (i) The 28 days target mean strength \( f_{ck} \) is first calculated from the following formula:

   \[
   f_{ck} = f_{ck} + 1.65 \cdot S
   \]

   The value of Standard deviation S (if not available from the construction site) can be assumed as given in Table: 2, depending on the degree of quality control expected to be exercised as given in Table: 4.

   For concrete containing admixtures (retarders) characteristic strength \( f_{ck} \) should be enhanced to take into account loss of strength due to retarder. Enhanced value of characteristic strength should be used in the above formula.

   (ii) For the target mean strength, w/c ratio is selected from Fig. 1, if 28 days cement-strength is known. If it is not available, accelerated strength test should be conducted to obtain the accelerated strength of ‘reference’ concrete mix. In that case, the w/c ratio for the target mean strength is selected from fig.2. Brief details regarding method of estimation of water cement ratio based on accelerated strength test are described in para A.4.

   (iii) The W/c ratio selected should be checked against the limiting W/c ratio for the durability requirement (Table: 3) and the lower of the two values is to be adopted.

   (iv) The water content and % of sand in total aggregate by absolute volume are next selected from Tables: 5 and 6 (For ‘medium’ and ‘high-strength’ concretes respectively), for fixed workability of 0.80 C F and W/c ratios of 0.60 and 0.35 respectively for crushed (angular) coarse aggregate and for sand conforming to grading zone II.

   (v) For other conditions of workability, W/c ratio, grading of sand, and for rounded coarse aggregate, certain adjustments on the quantity of mixing water and % of sand given in Tables 5 and 6 are to be made according to Table 7.
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**Fig. 1** Relation Between Free Water-Cement Ratio and Concrete Strength for Different Cement Strengths

28-Day Strength of Cement, Tested According to IS: 4031-1968

- **A** = 31.9-36.8 N/mm² (325-375 kg/cm²)
- **B** = 36.9-41.7 N/mm² (375-425 kg/cm²)
- **C** = 41.7-46.6 N/mm² (425-475 kg/cm²)
- **D** = 46.6-51.5 N/mm² (475-525 kg/cm²)
- **E** = 51.5-56.4 N/mm² (525-575 kg/cm²)
- **F** = 56.4-61.3 N/mm² (575-625 kg/cm²)
GUIDELINES ON USE OF READY MIXED CONCRETE

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**Fig. 2 Relation Between Free Water-Cement Ratio and Compressive Strength of Concrete for Different Cement Strengths Determined on Reference Concrete Mixes (Accelerated Test-Boiling Water Method)**

---

*Accelerated Strength (Tested According to IS: 9013-1978) of Reference Mix*

- **A**: 12.3-15.2 N/mm² (125-155 kg/cm²)
- **B**: 15.2-18.1 N/mm² (155-185 kg/cm²)
- **C**: 18.1-21.1 N/mm² (185-215 kg/cm²)
- **D**: 21.1-24.0 N/mm² (215-245 kg/cm²)
- **E**: 24.0-27.0 N/mm² (245-275 kg/cm²)
- **F**: 27.0-29.9 N/mm² (275-305 kg/cm²)
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(vi) The cement content is calculated from the W/C ratio adopted and for the final water content after adjustment. The cement content so calculated is next checked against the minimum cement content for the durability requirement (Table-3), and the greater of the two values is to be adopted.

(vii) With the quantities of water and cement and the ratio of fine to total aggregate already determined, the sand and coarse aggregate contents are calculated by absolute volumes method, using the following equations:

\[
V = \left[ \frac{W + \frac{C}{S_c}}{1 - p} \right] \times \frac{1}{1000}
\]

where,

- \( V \) = Absolute volume of fresh concrete, which is equal to gross volume \((m^3)\) minus the volume of entrapped air (being 1% for 40 mm MSA, 2% for 20mm MSA and 3% for 10mm MSA)
- \( W \) = Weight of water (Kg) per \( m^3 \) of concrete,
- \( C \) = Weight of cement (Kg) per \( m^3 \) of concrete,
- \( S_c, S_f, S_c \) = Specific gravities of cement, fine aggregate and coarse aggregate respectively
- \( p \) = ratio of fine aggregate to total aggregate by absolute volume and
- \( f_a, C_a \) = Weight (Kg) of fine aggregate and coarse aggregate per \( m^3 \) concrete respectively.

The coarse aggregate of different size fractions (e.g., 4.75-10 mm, 10-20mm and 20-40 mm) should be combined in suitable proportions, so as to result in an overall grading conforming to Table 2 of IS: 383-1970 for the particular nominal maximum size of aggregate.

(viii) The quantities of various ingredients per \( m^3 \) of concrete are next converted to quantities per 0.05 \( m^3 \) for mix design trial.

(ix) The quantities of aggregates calculated above are for saturated surface dry condition of aggregates. If dry aggregates are used, the amount of mixing water should be increased by an amount equal to the moisture likely to be absorbed by the aggregates. If wet aggregates are used, necessary reductions should be made for mixing water by an amount equal to the free (surface) moisture contributed by the coarse and fine aggregates. Accordingly quantity of coarse & fine aggregates should also be adjusted.

(x) The calculated mix proportions shall be checked by trial mixes. If the measured workability satisfies the workability desired, 6 cubes can be cast...
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(3 for accelerated curing and 3 for 28-days compressive strength test). This becomes trial mix no.1. Two more trial mixes (Trial mixes No. 2 and 3) shall be made with the water content same as trial Mix. no. 1 and varying water cement ratio by ± 10% of the preselected value. For these two additional trial mixes no. 2 and 3, the mix proportions are to be recalculated for the changed condition of water-cement ratio with suitable adjustments in accordance with Table -7.

(xi) The three trial mixes cast on the same day will provide sufficient information on the relationship between water-cement ratio and 28-day compressive strength of concrete for the materials used, from which the water-cement ratio for the target average 28 days compressive strength of concrete can be arrived at. The water-cement ratio and hence the final mix proportions can be recommended for field trials.

A.4 Method of Estimation of Water Cement Ratio based on accelerated strength test.

A.4.1 Use of Fig. 1 will necessitate testing of the cement for its 28 day compressive strength and another 28 days are needed to obtain the compressive strength of concrete according to the trial mixes. As an alternative, a rapid method of concrete mix design which will take only 3 days for trials is described in this paragraph. The procedure is based on the use of accelerated curing (boiling water) method for determination of compressive strength of concrete according to IS: 9013-1978.

A.4.2 Procedure

A.4.2.1 Determine the accelerated strength (boiling water method) of a ‘reference’ concrete mix, having water cement ratio as 0.35, compacting factor as 0.80 with the cement proposed to be used, on 150mm cube specimens. The nominal maximum size of aggregate of the ‘reference’ concrete shall be 10mm and fine aggregate used shall conform to Zone II of Table 4 of IS: 383-1970.

Typical concrete mix proportion per m$^3$ of concrete for the reference concrete mix are as follows:

- Cement (Proposed to be used in construction) = 530 kg.
- Water = 200 litre
- Sand (Zone II) = 460 Kg (S S D )
- Coarse aggregate (10mm MSA) = 1178 Kg (S S D )

A.4.2.2 Corresponding to this accelerated strength, determine the water cement ratio for the required target strength of the concrete mix from Fig. 2.

A.4.2.3 Work out the mix proportions according to A.3.4 (iii to ix) and further action may be taken as per A.3.4 (x) so as to make three trial mixes.
A.4.2.4 Determine the accelerated compressive strength of all the three trial mixes (boiling water method) and estimate their 28 days compressive strength with the help of correlations between accelerated and 28 days strength of concrete. From these results, the required water cement ratio and final mix proportion can be recommended for field trials.

### TABLE -1
**Approximate Air Content**

<table>
<thead>
<tr>
<th>Nominal maximum Size of coarse aggregate (mm)</th>
<th>Entrapped air (% of volume of concrete)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>1.0</td>
</tr>
<tr>
<td>20</td>
<td>2.0</td>
</tr>
<tr>
<td>10</td>
<td>3.0</td>
</tr>
</tbody>
</table>

### TABLE-2
**Suggested Values of Standard Deviation**

<table>
<thead>
<tr>
<th>Grade of concrete</th>
<th>Standard deviation for different degree of control (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Very good</td>
</tr>
<tr>
<td>M10</td>
<td>2.0</td>
</tr>
<tr>
<td>M15</td>
<td>2.5</td>
</tr>
<tr>
<td>M20</td>
<td>3.6</td>
</tr>
<tr>
<td>M25</td>
<td>4.3</td>
</tr>
<tr>
<td>M30</td>
<td>5.0</td>
</tr>
<tr>
<td>M35</td>
<td>5.3</td>
</tr>
<tr>
<td>M40</td>
<td>5.6</td>
</tr>
<tr>
<td>M45</td>
<td>6.0</td>
</tr>
<tr>
<td>M50</td>
<td>6.4</td>
</tr>
<tr>
<td>M55</td>
<td>6.7</td>
</tr>
<tr>
<td>M60</td>
<td>6.8</td>
</tr>
</tbody>
</table>
### Table 3
**MINIMUM CEMENT CONTENT & MAX. WATER CEMENT RATIO REQUIRED IN CEMENT CONCRETE TO ENSURE DURABILITY UNDER SPECIFIED CONDITIONS OF EXPOSURES**

*(Extract of para 5.4.3 & 5.4.5 of IRS Concrete Bridge Code)*

<table>
<thead>
<tr>
<th>Exposure</th>
<th>R.C. Concrete</th>
<th>Prestressed Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum cement content</td>
<td>Maximum water cement ratio</td>
</tr>
<tr>
<td>Mild</td>
<td>350</td>
<td>0.45</td>
</tr>
<tr>
<td>Moderate</td>
<td>400</td>
<td>0.40</td>
</tr>
<tr>
<td>Severe</td>
<td>400</td>
<td>0.40</td>
</tr>
<tr>
<td>Very Severe</td>
<td>430</td>
<td>0.38</td>
</tr>
<tr>
<td>Extreme</td>
<td>430</td>
<td>0.35</td>
</tr>
</tbody>
</table>

### Table 4
**DEGREE OF QUALITY CONTROL EXPECTED UNDER DIFFERENT SITE CONDITIONS**

<table>
<thead>
<tr>
<th>Degree of Control</th>
<th>Conditions of Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Good</td>
<td>Fresh cement from single source and regular tests, weigh batching of all materials, aggregates supplied in single sizes, control of aggregate grading and moisture content, control of water added, frequent supervision, regular workability and strength tests, and field laboratory facilities.</td>
</tr>
<tr>
<td>Good</td>
<td>Carefully stored cement and periodic tests, weigh batching of all materials, controlled water, graded aggregate supplied, occasional grading and moisture tests, periodic check of workability and strength, intermittent supervision, and experienced workers.</td>
</tr>
<tr>
<td>Fair</td>
<td>Proper storage of cement, volume batching of all aggregates, allowing for bulking of sand, weigh-batching of cement, water content controlled and occasional supervision and tests.</td>
</tr>
</tbody>
</table>
### Table - 5
**APPROXIMATE SAND AND WATER CONTENTS PER CUBIC METER OF CONCRETE**
(Applicable for concrete upto grade M 35)
Zone II Sand,  W/C Ratio = 0.60,  Workability = 0. 80 C.F

<table>
<thead>
<tr>
<th>Maximum size of aggregate (mm)</th>
<th>Water content including surface water, per cubic meter of concrete (Kg)</th>
<th>Sand as percent of total aggregate by absolute volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>208</td>
<td>40</td>
</tr>
<tr>
<td>20</td>
<td>186</td>
<td>35</td>
</tr>
<tr>
<td>40</td>
<td>165</td>
<td>30</td>
</tr>
</tbody>
</table>

### Table - 6
**APPROXIMATE SAND AND WATER CONTENTS PER CUBIC METER OF CONCRETE**
(Applicable for concrete above grade M 35)
Zone II Sand,  W/C Ratio = 0.35,  Workability = 0. 80 C.F

<table>
<thead>
<tr>
<th>Maximum size of aggregate (mm)</th>
<th>Water content including surface water, per cubic meter of concrete (Kg)</th>
<th>Sand as percent of total aggregate by absolute volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>200</td>
<td>28</td>
</tr>
<tr>
<td>20</td>
<td>180</td>
<td>25</td>
</tr>
</tbody>
</table>

### Table - 7
**ADJUSTMENT OF VALUES IN WATER CONTENT AND SAND PERCENTAGE FOR OTHER CONDITIONS**

<table>
<thead>
<tr>
<th>Change in conditions stipulated for tables</th>
<th>Adjustment required in Water content % sand in total aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>For sand conforming to grading Zone I, Zone-III or Zone IV of Table-4, IS: 383-1970</td>
<td>0  + 1.5 for Zone I - 1.5 for Zone III - 3.0 for Zone IV</td>
</tr>
<tr>
<td>Increase or decrease in the value of compacting factor by 0.1</td>
<td>± 3%  0</td>
</tr>
<tr>
<td>Each 0.05 increase or decrease in water-</td>
<td>0  ± 1%</td>
</tr>
</tbody>
</table>
A.5. Typical Example:

I. Design Stipulations

1.1 Characteristics strength of concrete specified: 25 N/mm²
1.2 Maximum size of aggregate to be used: 20 mm
1.3 Desired workability of concrete: 25-50 mm slump (0.88 - 0.92 C F).
1.4 Exposure condition specified: Mild
1.5 Degree of quality control expected to be exercised at site: Good.

II. Test Data on Materials

2.1 Specific gravity of cement (OPC) = 3.15
2.2 Specific gravity of coarse aggregate = 2.60
2.3 Specific gravity of fine aggregate = 2.59
2.4 Water absorption of Coarse aggregate = 0.5%
2.5 Water absorption of fine aggregate = 1.0%
2.6 Free (Surface) moisture for coarse and fine aggregates = Nil & 2% respectively.
2.7 Absorbed moisture for coarse and fine aggregates = Nil & 1% respectively.
2.8 Grading of Fine Aggregate

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percentage passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.75 mm</td>
<td>100</td>
</tr>
<tr>
<td>2.36 mm</td>
<td>97.5</td>
</tr>
<tr>
<td>1.18 mm</td>
<td>86.3</td>
</tr>
<tr>
<td>000 microns</td>
<td>52.2</td>
</tr>
</tbody>
</table>
GUIDELINES ON USE OF READY MIXED CONCRETE

150 microns      10.6

The fine aggregate conformed to grading zone II as per Table 4 IS : 383-1970

2.9 Grading of Coarse Aggregate

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>Coarse Aggregate Fractions</th>
<th>(percentage passing)</th>
<th>Combined Grading of Coarse Aggregate Fractions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>II</td>
<td>(70% of Fraction I+30% of fraction II)</td>
</tr>
<tr>
<td>20.00</td>
<td>96.6</td>
<td>100.0</td>
<td>97.6</td>
</tr>
<tr>
<td>10.00</td>
<td>6.7</td>
<td>82.7</td>
<td>29.5</td>
</tr>
<tr>
<td>4.75</td>
<td>0.8</td>
<td>32.6</td>
<td>10.3</td>
</tr>
<tr>
<td>2.36</td>
<td>-</td>
<td>9.4</td>
<td>2.9</td>
</tr>
</tbody>
</table>

The coarse fraction aggregate fraction I and II to be used for concrete mix are 70% & 30% respectively, which satisfy the grading requirement as per IS:383.

III. Reference Mix

10mm MSA, C F = 0.80, W/C Ratio = 0.35

Zone II clean sand

Accelerated strength of reference mix = 28.9 N/mm²

IV. Mix Design

4.1 Standard deviation (from Table 2) = 5.3N/mm²
   (for Good control)

4.2 Target average 28-day compressive strength of concrete
   = 25 + 1.65 X 5.3 = 33.745 N/mm²
GUIDELINES ON USE OF READY MIXED CONCRETE

Note: In case of concrete containing retarder, strength of concrete may get reduced to 90%. Thus, target characteristic strength is required to be enhanced to this extent. In such case, targeted strength shall be 36.522 (25 ÷ 0.9 + 1.65 x 5.3) N/mm².

4.3 Water - cement ratio (from Fig. 2) = 0.52 (using data from 3.0 and 4.2)

4.4 Maximum water - cement ratio specified for durability condition = 0.45 (from Table-3 )

4.5 Water cement ratio to be adopted for concrete = 0.45 (Lower of 4.3 and 4.4)

4.6 Water content from Table -5 = 186 (for a workability of 0.80 C F)

4.7 Sand as percentage of total aggregate by absolute volume from Table- 5 = 35% for W/C ratio of 0.60

4.8 Adjustment of water content (using table-7)
   ( For C F of 0.90 ) = 186 + .03 x 186 = 191.6 kg/m³.

4.9 Adjustment for sand content (using Table -7)
   35% - 3.0% = 32% (for W/C of 0.45)

4.10 Modified water content = 191.6 litre

4.11 Modified sand content = 32%

4.12 Cement content = \( \frac{1916}{0.45} = 425.8 \text{ kg/m}^3 \)

4.13 Minimum Cement content = 350 kg/m³ (from Table-3 specified for durability condition)

4.14 Required Cement content = 425.8 kg/m³ (Higher of 4.12 and 4.13)

4.15 Entrapped air, as percentage of volume of concrete = 2 %

4.16 Sand content

\[
V = \left[ W + \frac{C}{S_c} + \frac{1}{(p)} \cdot \frac{f_a}{S f_a} \right] \times \frac{1}{1000}
\]

\[
(1-0.02) = \left[ 191.6 + \frac{425.8}{3.15} + \frac{1}{0.32} \cdot \frac{25.9}{2.59} \right] \times \frac{1}{1000}
\]

\[
\Rightarrow f_a = 541.4 \text{ kg/m}^3
\]
4.17 Coarse Aggregate Content

\[ V = \left[ W + \frac{C}{S_c} + \frac{1}{(1-p)} \frac{C_a}{S C_a} \right] \times \frac{1}{1000} \]

\[ (1-0.02) = \left[ 191.6 + \frac{425.8}{3.15} + \frac{1}{0.68} \frac{C_a}{2.60} \right] \times \frac{1}{1000} \]

\[ \Rightarrow C_a = 1154.9 \text{ kg/m}^3 \]

4.18 (10-20 mm) size coarse aggregate (70%) = 0.7 x 1154.9 = 808.43 kg.

4.19 Below 10mm size coarse aggregate (30%) = 0.3 x 1154.9 = 346.47 kg.

4.20 Extra water required for absorption of coarse aggregate = (@ 0.5%) x 1154.9 = 5.77 litre

4.21 Extra water available as surface moisture in fine aggregate = (@ 2.0%) x 541.4 = 10.83 litre

4.22 Actual quantity of water to be added = 191.6 + 5.77 - 10.83 = 186.5 litre.

4.23 Actual quantity of sand. = 541.4 x 1.02 = 552.23

4.24 Actual quantity of coarse aggregate

10-20 mm : 808.43 / 1.005 = 804.4 kg
below 10 mm : 346.47 / 1.005 = 344.8 kg

4.25: Quantities of Ingredient for trial mix shall be as under

<table>
<thead>
<tr>
<th>Quantities</th>
<th>Cement</th>
<th>Water</th>
<th>Sand</th>
<th>Coarse Aggregate (10-20mm)</th>
<th>Coarse Aggregate below 10mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>per cum</td>
<td>425.8</td>
<td>186.5</td>
<td>552.23</td>
<td>804.4</td>
<td>344.8</td>
</tr>
<tr>
<td>per 0.05 m³</td>
<td>21.29</td>
<td>9.325</td>
<td>27.61</td>
<td>40.22</td>
<td>17.24</td>
</tr>
</tbody>
</table>