WATER TRANSPORT STUDIES IN STONE MASONRY WITH SOIL CEMENT MORTAR

L. ARUN¹, G. SARANGAPANI² & H.S. PRASANNA³

¹Research Scholar, Department of Civil Engineering, The National Institute of Engineering, Mysore, India
²,³Professor, Department of Civil Engineering, The National Institute of Engineering, Mysore, India

ABSTRACT

The work concerns with studies related to the flow of moisture from water-rich fresh soil cement mortars to stones. The study carried involves the rate of absorption of moisture in the stones, the moisture transport from mortar to stone, and the influence of the contact duration on the moisture present in mortar. Characteristics of stones and soil cement mortar are also reported. Four types of stones and two proportions of soil cement mortars have been studied. It has been observed that to achieve required conditions for hydration of mortar and development of bond for partially saturated stones with 11 to 13% moisture content is required to be used for stone masonry construction.

KEYWORDS: Granite and Gneiss Stones, Soil, Rate of Water absorption, Porosity & Pore size

INTRODUCTION

Building stones are available in large quantity in various parts of the world. Stones are rocks of igneous, sedimentary or metamorphic origin that occur naturally. Most of the stones are consolidated to the desired degree so that they can be cut or produced in different shapes and in the form of blocks or slabs for walling, paving or roofing materials. Conventionally Stone masonry are used in buildings, dams, bridges and forts etc. Stone masonry are constructed using cement mortar (1 Cement: 6 Sand). Soil can be used as an alternative to the sand in preparing mortars as there is scarcity of sand nowadays. In order to understand the suitability of using soil in mortar a thorough understanding of the moisture transportation behaviour of soil cement mortar in stone masonry is essential.

A good number of parameters influence the characteristics of stone masonry. The composition of mortar, the cement soil ratio, water cement ratio, the porosity and pore size distribution of the stone and the moisture in stone at the time of construction are some of the most important of these stone tend to absorb water due to capillary suction and causes the transportation of water from mortar to stone. The rate of suction can vary with type of stone and duration of suction. This stone property has several impacts for the characteristics of masonry. The stone mortar bond and compressive strength of masonry are affected by due to suction of water, water cement ratio can become deficient resulting in poor hydration conditions.

The present study is focused on moisture transport in stone masonry in soil cement mortar. The following aspects have been examined:

- Porosity in stones
• The rate of absorption of moisture in stones,
• The transport of moisture from mortar to stone in masonry.

EARLIER STUDIES

There are several studies available on the water absorption properties of natural building stones.

B. Vásárhelyi and P. Ván (2006) investigated the weakening effect of water on rocks has been studied in detail for various rocks, in particular sandstone. As a result of these studies, it was determined that as the degree of water saturation increases, rock strength decreases and sediment rocks are more susceptible to water than magmatic and metamorphic rocks. Later on,

Ali Sariisik et al., (2010) mentioned the effect of the penetration of ground water into sedimentary rocks such as marble and travertine. The capillary suction of ground water resulted in a low compressive strength of the rock. This result is attributed to the presence of sulphate ions in groundwater.

P. Vazquez et al., (2013) reported a detailed petrographic study of six porous stones. Stones with low porosity were of the highest quality. Differences in composition and pore distribution also influence the quality of the stones.

Martin Ondrášik, Miloslav Kopecký (2014) indicated that pore sizes and porosity control the absorption of water into stones. The deterioration of the rock is therefore related to the structure of the rock pore. At the same time,

Y. Ozcelik, A. Ozguven (2014) investigated on the absorption of water in natural building stones. It is concluded that the porosity of water absorbing stones is an acceleration factor for the drying process. Also, the apparent density, open and total porosity properties are highly related to the water absorption ratio.

Murat Unal (2019) was derived the relationship between the water absorption properties and the porosity properties of the sedimentary, magmatic and metamorphic rocks. Based on three different parameters coefficient of determination is derived i.e., $r^2 = 0.92$ to $0.99$. The strongest correlation was obtained between the water absorption in rocks and porosity values.

D. V. Babets et al., (2020) mentioned the effect of water saturation on sedimentary rocks. It has been established that the relative variation in uniaxial compressive strength increases with an increase in the water content of sedimentary rock samples. The most severe decrease in sandstone, mudstone and siltstone samples occurs with an increase in water content from 1 to 2 percent.

Characteristics of Stones

The geological characteristics of engineering properties were determined through megascopic studies. Table 1 gives the geological characteristics of the four different types of stone samples considered for the study.
Table 1: Geological Characteristics of Stones

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Source</th>
<th>Stone Designation</th>
<th>Rock Type</th>
<th>Geological Classification</th>
<th>Color</th>
<th>Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Chamundi Hill, Mysore</td>
<td>GR1</td>
<td>Grey Granite</td>
<td>Plutonic Igneous rock</td>
<td>Grey</td>
<td>Equigranular Fine grained</td>
</tr>
<tr>
<td>2</td>
<td>Chamundi Hill, Mysore</td>
<td>GR2</td>
<td>Pink Granite</td>
<td>Plutonic Igneous rock</td>
<td>Pink</td>
<td>Equigranular Coarse grained</td>
</tr>
<tr>
<td>3</td>
<td>Nagamangala</td>
<td>GN1</td>
<td>Gneiss</td>
<td>Metamorphic</td>
<td>Grey</td>
<td>Gneissose (Banded)</td>
</tr>
<tr>
<td>4</td>
<td>T.M.Hosur</td>
<td>GN2</td>
<td>Gneiss</td>
<td>Metamorphic</td>
<td>Pink</td>
<td>Gneissose (Banded)</td>
</tr>
</tbody>
</table>

The following engineering properties were determined for all the four types of stones:

- Compressive strength and flexural strength
- Water absorption
- Initial rate of absorption (IRA)
- Porosity and pore size (GR1, GR2, GN1 and GN2)

**Compressive Strength, Water Absorption, IRA and Flexural Strength**

Details of compressive strength, water absorption, and flexural strength and IRA values are given in Table 2 for the four types of stones. IS: 1124 - 1974 code recommendations were followed for arriving at the compressive strength and water absorption. The IRA was determined in accordance to the procedure prescribed in ASTM-C67. The flexural strength of stones was arrived by applying a central concentrated load on a stone over a span of 20 mm. The values obtained are the mean of six samples in each case. From the results given in Table 2. It is observed that granite stones have higher compressive strength than gneiss. This is due to the lesser mica content in granite as compare to that of mica content of gneiss. The igneous rock-like granite generally have lesser mica content than metamorphic rocks (gneiss). Mica is a clay mineral with chlorite montmorillonite and illite.

Table 2: Properties of Stones

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Type of Stone</th>
<th>GR1</th>
<th>GR2</th>
<th>GN1</th>
<th>GN2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Compressive Strength (N/mm²)</td>
<td>179.0</td>
<td>119.5</td>
<td>38.17</td>
<td>30.13</td>
</tr>
<tr>
<td>2</td>
<td>Water absorption in (%)</td>
<td>0.14</td>
<td>0.26</td>
<td>0.32</td>
<td>0.34</td>
</tr>
<tr>
<td>3</td>
<td>IRA in Kg/m²/min.</td>
<td>0.12</td>
<td>0.19</td>
<td>0.31</td>
<td>0.42</td>
</tr>
<tr>
<td>4</td>
<td>Flexural Strength (N/mm²)</td>
<td>14.30</td>
<td>11.04</td>
<td>9.34</td>
<td>8.40</td>
</tr>
</tbody>
</table>

*GR1-Grey Granite, GR2-Pink Granite, GN1- Grey Gneiss, GN2-Pink Gneiss

**Porosity and Pore Size of Stones**

Stones were examined for their pore size and porosity. Scanning electron microscopy (SEM) and image analysis were used for determining the pore size and porosity. Samples collected from four different stones in each type were examined for pore size and porosity determination.
Figures 1 and 2 shows the size and shape of typical pores present in the stones. Table 3 gives details of pore sizes and porosity for the different types of stones. The pores are of irregular shape hence the mean diameter of the pores is given in the Table. Pore sizes of four samples taken from different stones is given for each type of stone. The following points are clear from the data given in the above Table.

- The diameter of the pores varies between 1.59 microns to 4.50 microns and porosity values vary between 0.70% to 1.25%
- There is not much variation in the diameter of the pores for the type of stones.
- Mean diameter of the pores of granite stone (GR1 & GR2) are little more than that of gneiss stone (GN1 & GN2). Bigger diameter pores have lower values of IRA.
- The porosity values for medium fine grained and coarse-grained texture in granite stone varies from 0.70% to 0.85%. which is relatively lower, when compared to gneiss stone which as a porosity value ranging from 0.98% to 1.25%. As such the water absorption values are higher for gneiss. This is mainly due to the textural arrangement in rocks associated with mineral composition.

![Figure 1: Typical Pores of GR1 and GR2](image1)

![Figure 2: Typical Pores of GN1 and GN2](image2)
Table 3: Details of Pores

<table>
<thead>
<tr>
<th>Types of Stone</th>
<th>Mean diameter of Pores (Microns)</th>
<th>Porosity in (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GR1</td>
<td>4.50</td>
<td>0.70</td>
</tr>
<tr>
<td>GR2</td>
<td>3.50</td>
<td>0.83</td>
</tr>
<tr>
<td>GN1</td>
<td>1.60</td>
<td>0.98</td>
</tr>
<tr>
<td>GN2</td>
<td>1.80</td>
<td>1.25</td>
</tr>
</tbody>
</table>

*GR1-Grey Granite, GR2-Pink Granite, GN1- Grey Gneiss, GN2-Pink Gneiss

Characteristics of Mortars

The cement soil mortars of proportion 1:3 and 1:6 is used for the study. Table 4 gives details of proportions and compressive strength of mortar. The results provided in this table represent the mean of six specimens. The compressive strength of the mortar was determined using 70mm size cube specimens as per [IS:10080-1982, IS:2250-1981]. The mortar specimens were cured by immersing them in water. The soil Sample used for cement-soil mortar has a composition of 48%, 12% and 33% sand, silt and clay size fractions, respectively. This is a local red loamy kaolinite soil containing predominantly a non-expansive type of clay mineral. Figure 3 shows the stress strain curves for the mortars. Table 4 gives the details of proportions, water/cement ratio and compressive strength for all three mortars. From the Table 4 we can observe that the compressive strength of soil cement mortar decreases with increase in water cement ratio. The compressive strength of 1:3 cement-soil mortars is 28.5% higher than that of 1:6 cement-soil mortars. The cement mortar 1:3 cement m-sand, has the highest strength of 41.66 MPa.

Table 4: Properties of Mortar

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Types of Mortar</th>
<th>CM</th>
<th>CSM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mortar Proportion (by Weight) *C : Ks : Sa</td>
<td>1:0.3</td>
<td>1:3:0</td>
</tr>
<tr>
<td>2</td>
<td>Water cement ratio</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>3</td>
<td>Compressive strength (MPa)</td>
<td>41.66</td>
<td>24.0</td>
</tr>
<tr>
<td>4</td>
<td>Secant modulus (@25%of ultimate stress) of Elasticity (MPa)</td>
<td>19360</td>
<td>7317</td>
</tr>
<tr>
<td>5</td>
<td>Poisson’s ratio</td>
<td>0.19</td>
<td>0.20</td>
</tr>
<tr>
<td>6</td>
<td>Peak strain</td>
<td>0.0018</td>
<td>0.0035</td>
</tr>
</tbody>
</table>

* C- Cement, Ks- K Soil, Sa- M sand

Figure 3: Stress-Strain curve for 1:3 Cement Mortar with M-sand, 1:3 and 1:6 Cement Soil Mortar
EXPERIMENTAL PROGRAMME

Several tests were designed to understand the movement of moisture between mortar and stone. The following tests were undertaken.

Rate of Water Absorption Test for Stone

The test involves completely immersing the oven-dried stones in water for different periods of time. The moisture content of the stones is measured at the end of each period of immersion. Then a plot of soaking duration against the moisture content of the stones is obtained.

Water transport in Stone and Stone Masonry

Masonry units possess porous characteristic and have the tendency to absorb water from the mortar due to capillary suction. The absorption rate of water is dependent on time. Initially, the absorption of water is seen at a higher rate and this declines gradually. It is this property of the masonry units that adversely affects the behaviour of masonry. In the process, the mortar experiences water deficiency since the water present in the mortar is transported to the masonry units. There occurs incomplete hydration and thus results in reduction in strength of masonry. An elaborate study on water transport was carried by G. Sarangapani (1998) for brick units. The study concerns use of cement mortars, soil cement mortars and cement lime mortars. It is observed that the water in the masonry units has to be appropriately taken care to avoid possible water deficiency. This could be achieved by employing partially saturated blocks. Partial saturation could be achieved by soaking the masonry units in water before construction.

In the present study, the water transport studies are carried for stones with cement mortars and soil cement mortars.

RESULTS AND DISCUSSIONS

Rate of Moisture Absorption in Stones

Figure 3 shows the absorption of water content in GR1, GR2, GN1 and GN2 which are soaked in water for 5min, 10min, 20min, 25min, 30min 1hour and 24 hours durations of time. The curves shown in the Figures represent the mean of six specimens. All the stones tested show a more rapid absorption of water in initial stages and they absorb around 0.025% to 0.15% of their saturation value within 5 minutes. The rate of moisture absorption slows down to a very low value of 0.12% to 0.28% after 25 min. A similar result was achieved by G Sarangapani (1998) for clay bricks and cement mortars. From the test results, it can be understood that higher the compressive strength lesser is the water absorption and rate of moisture absorption values. The moisture content should be around 60% of its saturation value to keep the rate of moisture absorption low. This can be achieved by immersing the masonry units in water from 5 to 20 minutes.
Transport of Moisture from the Mortar to the Stone in Masonry

Figures 4 to 6 show the mortar moisture variation for different cases that has been studied. From the Figures, it is very clear that for all three cases most of the moisture in the mortar will find its way into the stone within one hour. However, the w/c ratio is between 0.66 to 0.75 for 1:3 and 1:6 soil cement mortar and is more than sufficient for cement hydration. From this, it can be understood that when soil is used in sufficient quantities in cement mortar there will be improvement in the water retentivity capacity of mortar. The water transport from the mortar will be very less and sufficient water will be available for the cement hydration. It can also be observed that prewetting of stones will decrease the movement of water from the mortar. When the movement of water is prevented sufficient water will be available for the cement hydration in mortar. A moisture content of around 11 to 13% is desirable in the masonry units to have a satisfactory water cement ratio in the mortar.
CONCLUSIONS

- The strength of stones, in particular the compressive strength is mainly dependent on the properties of stones like granularity / texture and mineral composition.

- Equigranular fine grained granite stone possess high compressive strength when compared to gneiss stone. This is because of the presence of biotite mica content which is high in gneiss.

- In medium grained granite the pores present are not abundant where as in coarse grained granite the pores are
Due to the presence of pores, there is a gradual increase in the percentage of water absorption in GR1, GR2 and GN1, GN2.

The water transport behavior of stone masonry units is similar to that of conventional clay bricks.

A satisfactory water cement ratio between 0.56 to 0.66 in cement soil mortar to achieve proper cement hydration can be maintained by using masonry units with 11 – 13 % moisture content.

To achieve 11 to 13 % moisture content in the masonry units, they shall be soaked in water for 10 to 20 minutes

REFERENCES


