Modeling of Moisture in Masonry Structures: A Case-Study of Structures in Chandkheda, Ahmedabad

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Abstract—Presence of unwanted moisture in buildings leads to decrease in the strength of structural components, poor living conditions and health problems for the residents. In India, majority of residential structures are constructed using masonry and are usually not-engineered. Further, the residents use several moisture preventing mechanisms based on available market products using their own judgment. The present study is a step towards evaluating the efficacy of such treatment strategies used by residents in a scientific manner. A survey has been conducted in the Chandkheda area of Ahmedabad, India, to evaluate the present condition of residential buildings and the state of knowledge of the residents. A computational model has been developed to simulate moisture transport in masonry walls under different ambient conditions to facilitate identification of possible sources of moisture in the structures. Numerical studies have also been performed to assess the efficacy of plaster and damp proof course (DPC) as moisture retarding agents.

Keywords—moisture diffusion, masonry structures, dampness of walls

I.   Introduction

Unwanted moisture in the structural components of a building, often referred to as dampness, causes several adverse effects on the building as well as its occupants. Most household structures in India are built using masonry and the problem of dampness of walls and/or roof leading to spalling of plaster and unhealthy living conditions is widespread. Dampness can cause damage in bricks and/or mortar due to saturation, rusting of steel reinforcement bars and rotting of timber structures. As far as its effects on humans are concerned, dampness has been known to cause health conditions like asthma, allergies of dust and skin, mold, eye infections, drip cough and headache [1, 2].

The objective of the present study is to characterize the extent of dampness present in residential buildings in Chandkheda, Ahmedabad, with the aim of developing a simulation-based framework to enable rapid identification of the source of moisture and to assess the efficacy of measures typically employed to treat moisture-affected structures.

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A two-step procedure has been adopted: first, a survey has been conducted to determine the extent of the problem along with the existing moisture treatment mechanisms used by the residents, and second, a computational model has been developed to perform an in-depth scientific study of moisture propagation in masonry walls under various environmental conditions.

Many researchers have studied the propagation of moisture in civil structures. Lin et al. (2005) [3]modeled moisture migration in fiber reinforced polymer to understand hydro-thermo-mechanical response of building materials. Jain et al. (2014) [4] also developed a moisture diffusion model for fiber reinforced composites at micro-scale. Chen and Mahadevan (2007) [5] studied the mechanism of crack initiation due to heat and moisture in plain concrete. While several researchers have studied moisture diffusion in concrete and fiber composites, little to no work is available on modeling of moisture transport through masonry walls. Tamene et al. (2011)[6] carried out a numerical study on heat and moisture transfer through a wall. However, they considered the wall to be constructed entirely of bricks (with no mortar) or plywood. de Freitas et al. (1996) [7] developed a finite element model based on the theory of Philip and De Vries [8] to study moisture migration in masonry walls. While their model provides a detailed view of the interface behavior, its applicability is limited to very small models (they considered a system of two bricks) and thus, is not entirely suitable for studies related to full-scale models of masonry walls. Several researchers have performed experimental moisture measurements as well (see, for example [9, 10]).The next section discusses results of the survey of masonry structures conducted in Chandkheda.

II.   Survey of Masonry Structures in Chandkheda

In order to ascertain the extent to which masonry structures in Chandkheda are affected by dampness, a survey has been conducted as part of the present study. In addition to a visual assessment of the buildings, a questionnaire was formulated to collect certain relevant information from the residents, such as age of the building, whether the building has a moisture problem and if it does, how long has the problem persisted. To assess the awareness of the residents, questions such as whether they have identified the source of moisture and whether they have taken any measures to remedy the situation and if they did, how much have they spent in its treatment.

The survey revealed that about40% of the buildings suffered from the moisture problem arising from various sources including pipe leakage, rain water penetration, water

accumulation, water table rise, absence of damp proof course (DPC), and condensation due to lack of ventilation. Remedies used by residents of the buildings involved chemical treatment, brick bat water proofing, use of cotta stone, bitumen role, cement sheets, DPC injection, and re-plastering. Some photographs of the affected areas in certain buildings were taken, two of which are shown in Figure 1.

(a)

(b)

Figure 1: Photographs of moisture-affected masonry walls.

Figure 1(a) depicts a wall affected by ground water while Figure 1(b) shows a wall affected by a combination of rain water penetration and condensation due to lack of ventilation. The type of treatment required for a particular moisture problem hinges on the correct identification of its source, which requires expert judgment and professional experience, and inherently involves some amount of uncertainty. In order to provide a scientific basis to the identification of the source of the moisture problem, a computational model has been developed to simulate moisture transport under different environmental conditions. The ultimate goal of these simulations is to create a repository of context-based scenarios

using which, the source(s) of moisture in real buildings can be predicted. Such a repository will not only reveal the scientific basis of experience-based investigations, but will also allow a layman to confidently identify the cause of moisture problem. The next section presents the development of the computational model.

III. Modeling of Moisture Propagation in Masonry Walls

Consider a continuum body Ω as shown in Figure 2. The moisture diffusion (mass transport) phenomenon can be described by Fick's laws [11] as

$$\frac{\partial \phi}{\partial t} + \nabla \cdot \mathbf{J} = 0 \text{ on } \Omega, \qquad (1)$$

$$\phi = \phi_0 \text{ on } \Gamma_D, \qquad (2)$$

$$\mathbf{J} \cdot \mathbf{n} = q \text{ on } \Gamma_N, \qquad (3)$$

where $\phi = C/C_{max}$, is the dimensionless moisture concentration and $\mathbf{J} = -D\nabla\phi$ is the mass flux (m s^{-1}) with D being the diffusivity (m^{2}s^{-1}) of the medium. Γ_D and Γ_N ($\Gamma_D \cap \Gamma_N = \varnothing$) represent portions of the boundaries where Dirichlet and Neumann conditions are applied, respectively; q is the externally applied moisture flux.
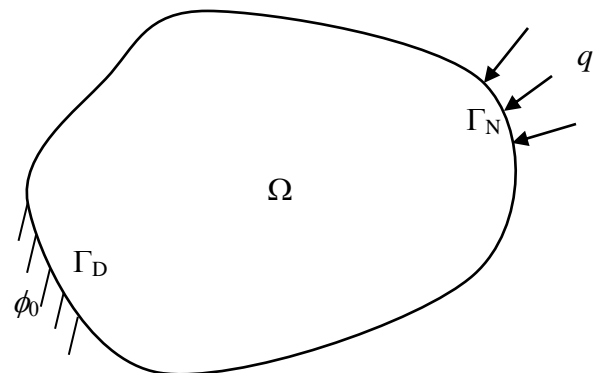

Figure 2: Schematic of physical domain considered for moisture diffusion.

The discretized weak form of (1)-(3) can be obtained using Galerkin's approximation. Owing to the direct analogy between heat and moisture diffusion [12], (1) is solved numerically using the thermal solver of commercial finite element software, ANSYS [13].A hexahedralspatial mesh was utilized along with an explicit time marching scheme. In the present study, effects of temperature and mechanical deformations have not been considered and the diffusivities of the involved materials have been assumed to be constant for the sake of simplicity.It should be noted that these assumptions do not restrict the developed model from capturing the actual physical response of the system provided

the model parameters are calibrated properly using experimental moisture transport measurements.

A. *Model Parameters*

As such, there is only one model parameter, namely the diffusivity of moisture in brick and mortar. The moisture diffusion coefficient of brick has been taken as 10^{-8} m^2s^{-1} and that of mortar has been taken as 5.1×10^{-8} m^2s^{-1}[6].For DPC, the same has been taken to be 6.8×10^{-10} m^2s^{-1}, which is of the same order as that of plain concrete [14], typically utilized as a DPC layer in construction. Other relevant propertiesof bricks, mortar, and DPC, such as strength, density, etc. can be found in the literature[5, 15, 16].Bricks of M class (dimensions 215 mm × 100 mm × 65 mm) and mortar havingcement-to-sand ratio of 1:6 [15] have been considered. The thickness of plaster and DPC, when present, has been considered to be 15mm and 40 mm, respectively.The next section presents the numerical studies performed using the computational model developed in this section.

IV. Numerical Studies

Figure 3 shows the model of the masonry wall that has been used for the numerical studies presented herein. Two scenarios that typically cause the dampness problem are considered: (a) face of wall exposed to rain, and (b) bottom of wall exposed to ground water. In the computational model, these conditions have been modeled by assuming the portion of the wall exposed to moisture to be fully saturated at all times, as shown in Figure 3. For walls exposed to rain, three cases have been considered: with plaster, without plaster and partial plaster, while for walls exposed to ground water, two cases have been considered: with and without DPC. The subsequent subsections discuss the numerical results in detail.

A. *Walls Exposed to Rain*

Walls exposed to rain are simulated using the boundary conditions shown in Figure 3(b). The exposed portion of the wall is assumed to be fully saturated at all times. $\nabla \phi = 0$ at all the other boundaries. The model is run for 5 hours of simulation time and the level of moisture at various depths along the thickness of the wall is tracked. The time history of the dimensionless moisture content of the wall is shown in Figure 4. The most important observation is that the difference between with and without plaster cases is not significant, which questions the efficacy of re-plastering as a moisture treatment strategy. It should be noted that re-plastering is one of the most widely used strategy for moisture treatment. Walls with 10%, 20%, 30%, 40% and 50% partial plaster have also been considered and simulations show similar trends and thus, reinforce the thesis that plaster is not a good moisture retarding agent, contrary to popular belief. Detailed results of the partial plaster simulations are not presented for the sake of brevity.

B. *Walls Affected by Ground-water*

Walls affected by ground water are simulated using the boundary conditions shown in Figure 3(c). The exposed portion of the wall is assumed to be fully saturated at all times.

$\nabla \phi = 0$ at all the other boundaries.The model is run for 5 hours of simulation time and the level of moisture at various depths along the height of the wall is tracked. Figure 5 shows the spatial variation of the dimensionless moisture content and can be visually compared with Figure 1(a), suggesting that the key factor affecting the wall shown in Figure 1(a) is ground water (due to DPC failure).The time history of the dimensionless moisture content of the wall is shown in Figure 6. It clearly shows the importance of a DPC layer in masonry construction. For depths greater than 40 mm (thickness of the DPC layer), almost no moisture is present in case of wall with DPC.
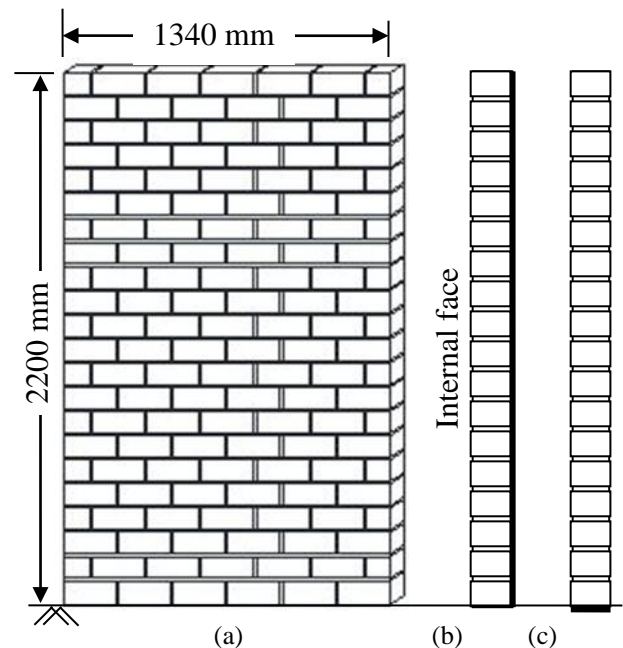

Figure 3: Model of the masonry wall panel used for numerical studies: (a) dimensions of the panel, (b) side-view of the panel with exterior face of the wall exposed to rain, (c) side-view of the panel with bottom of the wall exposed to ground water.

V. Conclusions & Future Scope

A survey was conducted in Chandkheda, Ahmedabad, which showed that about 40% of the households suffered from the dampness problem and re-plastering was one of the most popular moisture treatment strategies. In order to facilitate identification of the source of moisture as well as to assess the efficacy of plaster and DPC as moisture retarding agents, a computational model for moisture diffusion in masonry walls was developed. Results of the numerical studies presented herein showed that the presence of plaster did not affect moisture migration in masonry walls significantly and hence, re-plastering may not be an effective method to treat the dampness problem. Numerical studies also showed the importance of a DPC layer in checking moisture transport in masonry walls. A visual inspection of the spatial variation of the moisture diffusion field showed its applicability in identifying possible causes of the dampness problem of existing structures.

Future studies will be aimed at evaluating other methods of moisture treatment (e.g. chemical treatment) which will require a more intensive computational model (consideration of effects of temperature, mechanical deformations and cracks). Further, a repository of the spatial variation of simulated moisture field will be created for various ambient conditions to facilitate easier identification of the possible causes behind a particular moisture-affected scenario.
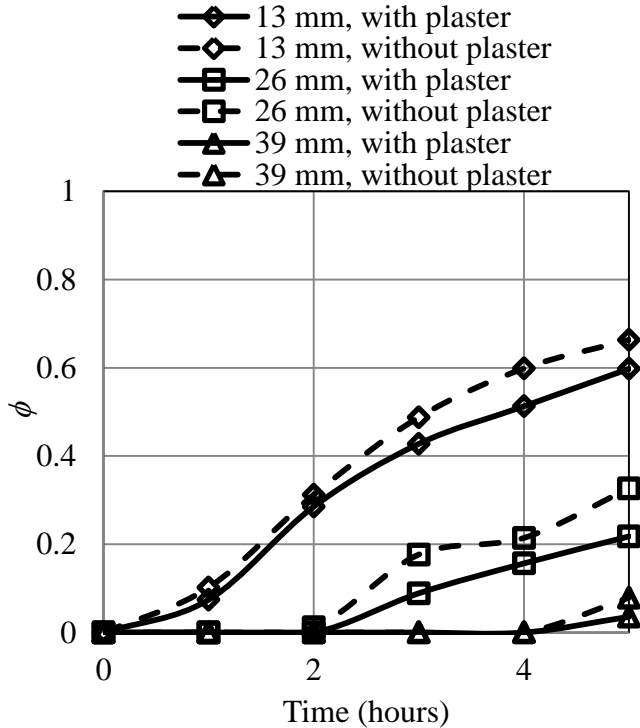

Figure 4: Dimensionless moisture content at various depths along the wall thickness for walls with and without plaster.
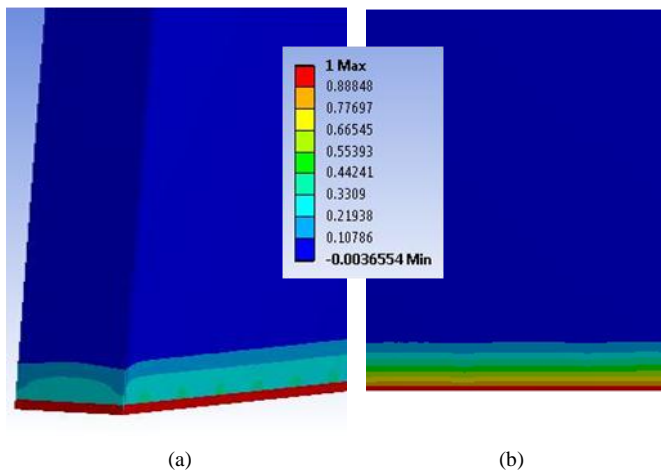

(a)   (b)

Figure 5: Spatial distribution of dimensionless moisture content. (a) oblique view of masonry wall with 40 mm DPC layer, (b) front view of masonry wall without DPC layer.
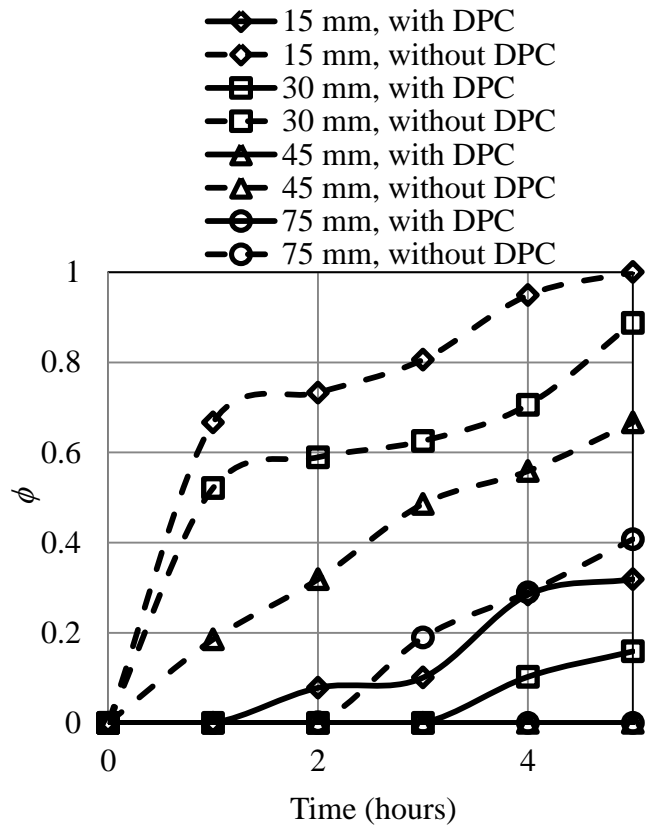

Figure 6: Dimensionless moisture content at various depths along the wall height for walls with and without DPC.

Acknowledgment

References

[1]   Bornehag, C. G., Blomquist, G.,Gyntelberg, F., Jarvholm, & Nielsen, A. (2001). Dampness in Buildings and Health. *Indoor Air*, *11*, 72-86.

[2]   Naydenov, K., Melikov, A., Markov, D., Stankov, P., Bornehag, C. G., & Sundell, J. (2008). A comparison between occupants' and inspectors' reports on home dampness and their association with the health of children: The ALLHOME study. *Building and environment*, *43*, 1840-1849.

[3]   Lin, M. W., Berman, J. B., Khoshbakht, M., Feickert, C. A., & Abatan, A. O. (2006). Modeling of moisture migration in an FRP reinforced masonry structure. *Building and Environment*, *41*, 646-656.

[4]   Jain, D., Mukherjee, A., & Kwatra, N. (2014). Local micromechanics of moisture diffusion in fiber reinforced polymer composites. *International Journal of Heat and Mass Transfer*, *76*, 199-209.

[5]   Chen, D., & Mahadevan, S. (2007). Cracking Analysis of Plain Concrete under Coupled Heat Transfer and Moisture Transport Processes. *Journal of Structural Engineering*, *133*, 400-410.

[6]   Tamene, Y., Abboudi, S., & Bougriou, C. (2011). Study of Heat and Moisture Diffusion Through a Wall Exposed to Solar Heat Flux. *Journal of Engineering Science and Technology*, *6*(4), 429-444.

[7]   deFreitas, V.P., Abrantes, V., & Crausse, P. (1996). Moisture Migration in Building Walls – Analysis of the Interface Phenomena, Building and Environment, *31*(2), 99-108.

[8] Philip, J. & De Vries, D. (1957). Moisture Movement in Porous Materials under Temperature Gradients. *Transactions American Geophysical Union*, *38,* 222-232.

[9] Mollo, L., & Greco, R. (2011). Moisture Measurements in Masonry Materials by Time Domain Reflectometry. *Journal of Materials in Civil Engineering*, *23*(4), 441-444.

[10] Nielson, A. (1972). Gamma-ray-attenuation used for Measuring the Moisture Content and Homogeneity of Porous Concrete, Building Science, *7*, 257-263.

[11] Crank, J., 1975. *The Mathematics of Diffusion*, 2nd ed., Oxford UniversityPress, UK.

[12] Yoon, S., Bongtae, H. & Wang, Z., On moisture modeling using thermal-moisture analogy, *Journal of Electronic Packaging ASME, 129*, 421–426, 2007.

[13] ANSYS®*Academic Research, Release 14.0.*

[14] Zhang, J., Hou, D., Gao, Y., & Wei, S. (2011). Determination of Moisture Diffusion Coefficient of Concrete at Early Age from Interior Humidity Measurements. *Taylor & Francis Group, LLC*, *29*, 689-696.

[15] Kaushik, H. B., Rai, D. C., & Jain, S. K. (2007). Stress-Strain Characteristics of Clay Brick Masonry under Uniaxial Compression. *Journal of Materials in Civil Engineering*, 728-739.

[16] Narayanan, S. P., & Sirajuddin, M. (2013). Properties of Brick Masonry for FE modeling. *American Journal of Engineering Research*, *1*, 6-11.

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"…the difference between with and without plaster cases is not significant, which questions the efficacy of re-plastering as a moisture treatment strategy."

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"Dampness issue must be given importance while designing masonry buildings to prevent adverse effects on the building and its occupants."