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INVESTIGATION OF FACTORS INFLUENCING THERMAL MOVEMENTS IN MASONRY WALLS

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Abstract: Masonry is the most widely used construction material around the world. Masonry is susceptible to dimensional changes due to environmental conditions such as temperature variations and moisture variation. This phenomenon is known as "movements in masonry walls". Thermal movements in masonry walls are mainly governed by the temperature variations in masonry walls which are caused due to the ambient temperature and other physical parameters of the walls. From this research study it is identified that the thickness, colour and the surface texture of the masonry walls are the other physical parameters that would significantly affect the temperature in masonry walls. Therefore an attempt has been taken by carrying out an experimental study to develop a correlation between the ambient temperature and wall temperature considering physical parameters, to predict the maximum and minimum temperatures that a wall would achieve. These values are necessary to predict the extent of thermal movement in masonry walls. Using the developed model, it is possible to predict the maximum strain that a particular masonry wall would experience under given maximum and minimum ambient temperatures. Therefore a precise value for the joint spacing between movement joints in masonry walls can be calculated using the strain.

Keywords: Joint spacing; Masonry; Strain; Thermal movement

1. Introduction

Building materials which are used for masonry walls, susceptible to dimensional changes due to changes in environmental conditions such as temperature and moisture. This phenomenon is known as Movement in masonry walls. Movement may induce due to elastic deformations, creep and other factors which develop stresses in masonry walls. When these movements are not allowed or restricted due to lack of expansion joints, stresses will develop and this will bring extensive damages to the structure. Therefore it is important to identify the factors influencing thermal movements in masonry walls and predict the extent of thermal movement depend on the varying properties of the masonry walls to account for these movements and prevent such damages.

Dimensional changes of building materials due to above factors are highly variable as they are dependent on material properties and are illustrated in Table 1. Since most of the material properties of the building materials change over its service life, it is difficult to define a specific value for building material properties. Therefore mean values for material properties are used when they are used in a design. Hence the actual movement may vary from the expected movement when considering the net effect of a variety of conditions. [9]

Table 1: Types of movements experienced by different types of building materials [9]

Building material	Thermal	Reversible Moisture	Irreversible Moisture	Basic Deformation	Creep
Brick Masonry	✓	-	✓	✓	✓
Concrete Masonry	✓	✓	-	✓	✓
Concrete	✓	✓	-	✓	✓
Steel	✓	-	-	✓	-
Wood	✓	✓	-	✓	✓

Thermal Movements

All building materials expand and contract as they are subjected to heat up due to temperature rise and cool down due to temperature fall respectively. Unrestrained thermal movements are theoretically reversible. Unrestrained thermal movement can be assessed by the following equation. (Eq 1) [3]

$$\Delta l = L_0 \, \alpha \, \Delta t \qquad (1)$$

Whereas,

Δl - Change in length L_0 - Initial length

α - Coefficient of linear thermal expansion

Δt - Change in temperature

According to this equation it is apparent that the coefficient of linear thermal expansion is one of the major factors that govern the thermal movements.

Though it is evident that the coefficient of linear thermal expansion is the main governing factor for thermal movement, when considering the change in temperature component in the equation, the other factors which would influence the temperature variation can be listed as follows. [5]

- Atmospheric temperature.
- Construction element type and its properties.
- Thickness of the wall.
- Surface condition. (whether it is rough or smooth finished)
- Colour of the wall.
- Orientation of the wall.(in which direction the wall is faced)
- Radiation from other walls.

To identify how each parameter influence the temperature variation in masonry wall, it is required to construct similar wall panels but changing one parameter at a time and measure the temperature variation thorough out a pre- determined time period to obtain a correlation

2. Material Description

➢ Bricks

Dimensions of a brick = 205mm * 105mm * 55mm Mean Compressive strength = 2.35 N/mm^2

Water absorption ratio = 22.08%

➢ Cement

OPC (grade 42.5) was used. It is manufactured in compliance with Sri Lankan Standard SLS 107:2008 and British Standard CEM I 42.5N of BS EN 197-1:2000.

➢ Fine aggregate

Local river sand with a 5mm maximum size was used. It conforms to BS 882.

➢ Lime

Chemical composition - $CaCO_3$, CaO (Quartz)

➢ Colour wash

Nerox weather shield paints of colour Dark Green and Brilliant White were used for colour washing.

3. Methodology

Before constructing the wall panels for the experimental study, pilot tests were carried out on previously constructed wall panel (Figure 1(a)) with following properties to determine the dimensions of the wall panels to be constructed for the experiment.

- Masonry wall panel.
- Smooth finished surface with lime plastering
- Dimension = 1270mm * 840mm * 115mm

Temperature was measured using a Data logger(DL 2E Data Logger) and type K thermo couples, along the diagonal of the wall panel for 5 consecutive days. Figure 1(b) illustrates the temperature variation measured on 23/07/2015 which was a sunny day.

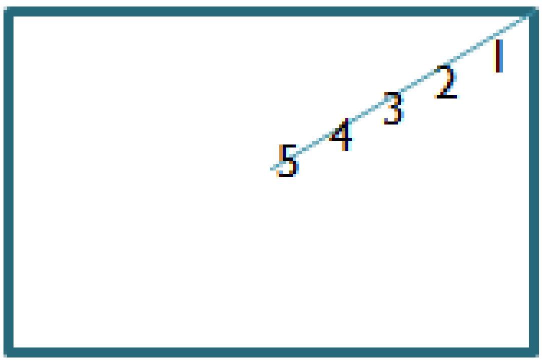

Figure 1(a) : Location of thermo couples fixed on masonry wall

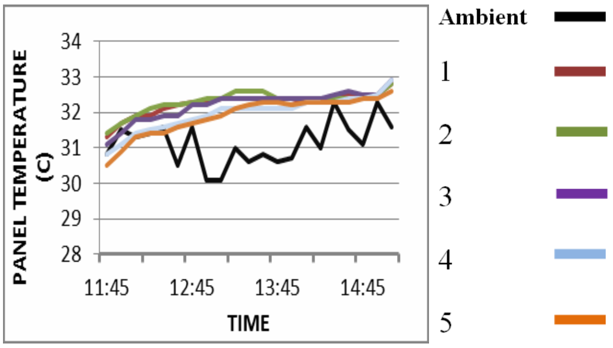

Figure 1(b) : Temperature variation along a diagonal of a masonry wall panel

From Figure 1(b) it is clear that there is no significant difference in temperature variation along the panel diagonal and it was decided to construct wall panels of 4 bricks in length and 9 courses of bricks in height. Details of the masonry walls constructed for the experimental study are listed below.

- Wall panels were constructed in an open area on wooden pallets and assumed to have fixed end conditions at support.
- Half brick thick and one brick thick wall panels
- 4 Bricks per row in length
- 9 courses of bricks in height
- 1:5 mortar combination and 10mm thick bed joints
- 1:6 mortar combination and 10mm thick plaster
- Lime plastering to get the smooth finish
- Color washed with Weather Shield Dark green and Brilliant white (2 coats)

10 wall panels were constructed with different parameters which are illustrated in following Table 2 and the orientation is illustrated in Figure 2.

Table 2: Masonry wall parameters

	Thickness	Surface texture	Wall Color
1	half brick thick (125mm)	smooth	light
2			dark
3		rough	light
4			dark
5	Full brick thick (235mm)	smooth	light
6			dark
7		rough	light
8			dark

Figure 2 : Orientation of Masonry Wall panels in the experiment arena

Fused end of the thermo couple was fixed at the centre of the panel, which was driven halfway through in to the panel and fixed to the panel centre using cement mortar. Other end was connected to the data logger for temperature measurement and it was set to measure temperature at 10 minutes' interval.

Fused end of the thermo couple used to measure the ambient temperature was placed next to the data logger housing and special concern was given to locate it in a place where it is not expose to direct sunlight and radiation from wall panels.

It was assumed that there would be an effect on temperature variation from adjacent panels due to radiation from adjacent panels itself. To overcome this issue, it was decided to isolate adjacent panels when taking measurements by covering other panels with black polythene sheets in order to minimize the effect from radiation from adjacent panels.

4. Test Results and discussion

Temperature variations of panels were monitored regularly and temperature variation of each wall panel throughout a particular day is illustrated in Figure 3.

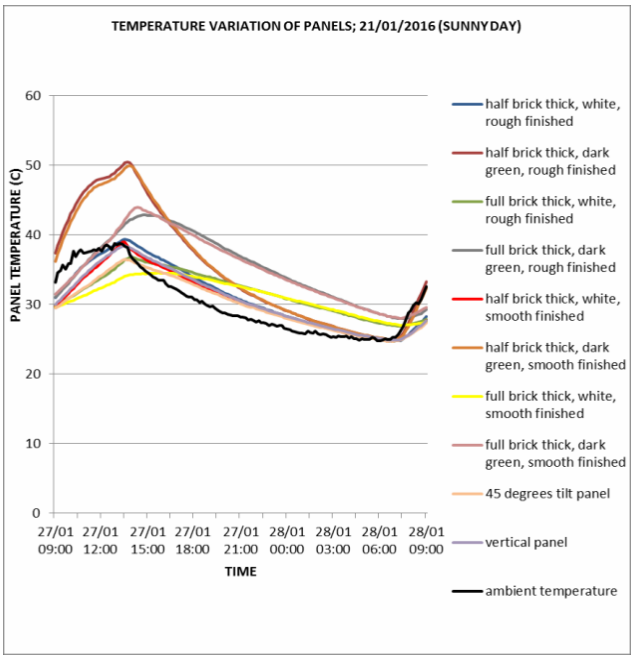

Figure 3: Temperature variation of wall panels on 27/01/2016 (sunny day)

Following findings were ascertained from the test results.

- Maximum temperatures of the dark coloured panels are significantly higher than that of the light coloured panels and they tend to converge to similar temperatures in the morning around 7am.
- Maximum temperatures of the half brick thick panels are higher than that of full brick thick panels and minimum temperatures of the half brick thick panels are lesser than that of full brick thick panel.
- Maximum temperatures of the rough surface finished panels are slightly higher than that of smooth surface finished panels.
- Vertically, 45 degrees' tilt and horizontally oriented panel temperatures exhibit the same temperature variation. Usually the panels oriented perpendicular to the path of the sun must exhibit higher temperatures than that of others. Therefore, this distorted behaviour was expected to take place due to the smaller sizes of wall panels.
- Usually the ambient temperature should be lower than the wall panel temperatures at any given time. But in some instances ambient temperature was found to be higher than the panel temperatures around morning from 5.30am to 10.30am. This distorted behaviour was expected to take place due to the absorption of morning dew into the panels which makes panels much cooler than the atmosphere due to the high moisture content and it would take some time for panels to completely evaporate the moisture absorbed by the wall panel.

For the analysis, only white panels were considered due to the time constraint. Temperature variation in wall panel and Panel temperature vs. Ambient temperature for half brick thick, white, smooth panel for a particular day is illustrate in Figure 4 and Figure 5.

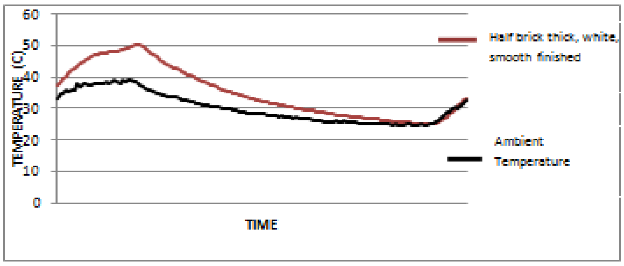

Figure 4 : Temperature variation of half brick thick, white, smooth panel on 19/02/2016 (sunny day)

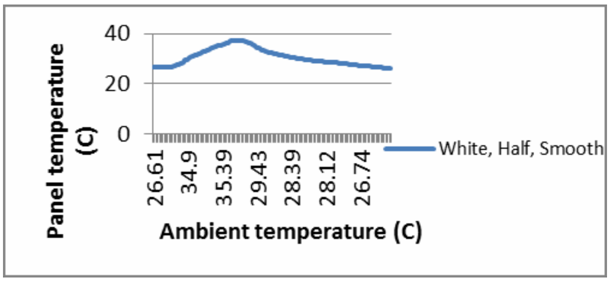

Figure 5: Panel Temperature vs Ambient Temperature

From the above figure it is evident that to develop a correlation between ambient temperature and panel temperature, another variable which is gradually increasing and then reducing throughout the 24 hour time period is required. Therefore, to account for this, a variable called "Time Variable" is introduced, considering the maximum and minimum wall panel temperatures. From the data obtained it has identified that the most of the panels reach their maximum temperatures around 3pm and minimum temperatures around 7am, thus the Time Variable is defined to assign a maximum value for 3pm and minimum value for 7am. (Table 4)

From the temperature data obtained for 10 consecutive days following correlation (Eq 2) was derived for half brick thick, white smooth panel by carrying out an Multi Regression Analysis using Microsoft Excel (Table 3)

Table 3: Multi regression analysis - summary output for half brick thick, white, smooth finished wall panel

Regression Statistics			***Coefficients***
Multiple R	0.9553227	**Intercept**	**12.98906**
R Square	0.9126414	**Ambient**	**0.4749896**
Adj. R Square	0.9125199	**T Variable**	**1.0152781**
Std. Error	0.1079701		
Observations	1441		

$$T_{p1} = 12.989 + 0.475A + 1.015t_v \quad (2)$$

T_{p1} - half brick thick, white, smooth panel temperature

A - ambient temperature

t_v - time variable; values for each hour within a day is given in Table 4

Table 4: Value for t_v

Time of day	Value for t_v	Time of day	Value for t_v
7am	0	7pm	6
8am	1	8pm	5.5
9am	2	9pm	5
10am	3	10pm	4.5
11am	4	11pm	4
12pm	5	12am	3.5
1pm	6	1am	3
2pm	7	2am	2.5
3pm	8	3am	2
4pm	7.5	4am	1.5
5pm	7	5am	1
6pm	6.5	6am	0.5

Using the Eq 2 it is possible to obtain a particular panel temperature for a given time within a particular day and for a given ambient temperature. However objective of this research study is to predict the maximum and minimum temperature of a particular masonry wall and using that difference to predict the total thermal movement that a masonry wall can subjected.

From Figure 3 it is apparent that maximum ambient temperature does not map with the maximum panel temperature. Nor does the minimum ambient temperature. Maximum panel temperature occurs after maximum ambient temperature has occurred and minimum panel temperature also occurs after minimum ambient temperature has occurred.

Therefore it is required to modify the Eq 2 to account for this relationship as well. Considering the same panel used to derive the Eq 2, following modifying parameter can be derived using the temperature data obtained which are illustrate in Table 5.

Table 5: Maximum and minimum temperatures of the half brick thick, white, smooth finished panel

Max. Panel Temperature (°C)				Min. Panel Temperature (°C)			
Max. Ambient Temp.	Corresponding Panel Temp.	Max. Panel Temp	$\Delta^o t$	Min. Ambient Temp.	Corresponding Panel Temp.	Min. Panel Temp.	$\Delta^o t$
37.32	34.09	37.27	3.18	25.82	26.02	25.72	-0.3
38.01	34.48	38.16	3.68	27.2	27.7	27.58	-0.12
38.87	35.95	39.55	3.6	26.64	27.48	27.23	-0.23
37.05	34.26	38.25	3.99	26.19	26.74	26.46	-0.28
39.06	36.25	39.58	3.33	27.67	28.66	28.32	-0.34
37.40	35.98	38.4	2.42	25.77	25.68	25.5	-0.18
37.54	33.49	38.13	4.64	26.64	26.96	26.83	-0.13
37.69	35.17	38.97	3.8	27.2	27.92	27.65	-0.27
38.52	35.22	40.04	4.82	28.02	28.81	28.64	-0.17
37.91	36.59	40.34	3.75				

To be conservative in the correlation it is advisable to select the maximum Δot values as the modifying parameter for the Eq 2. Then the modified correlation can be interpreted as follows.

For maximum panel temperature,

$$T_{p1,max} = 12.989 + 0.475A_{max} + 1.015t_v + 5 \quad (3)$$

$T_{p1,max}$ - maximum temperature of half brick thick, white, smooth panel

A_{max} - maximum ambient temperature

t_v - time variable; values for each hour within a day is given in Table 4

Similarly for the prediction of minimum panel temperature, the maximum temperature drop recorded was selected to obtain the modifying parameter.

$T_{p1,min} = 12.989 + 0.475A_{min} + 1.015t_v - 0.4$ (4)

$T_{p,min}$ - minimum temperature of half brick thick, white, smooth panel

A_{min} - minimum ambient temperature

t_v - time variable; values for each hour within a day is given in Table 4

<u>Summary</u>

Summary of all the correlation obtained for wall panels can be generalized in to following equation (Eq 5).

$T_{p,max/min} = K_1 + K_2 A_{max/min} + K_3 t_v + K_{4\ max/min}$ (5)

$T_{p,max/min}$ - maximum/minimum temperature of the wall panel

$A_{max/min}$ - maximum/minimum ambient temperature

t_v - time variable; values for each hour within a day is given in Table 4

K_4 - Modifying parameter to get max/min temperatures (Table 6)

Table 6: Values for k1, k2, k3, k4 max and k4min

	K_1	K_2	K_3	$K_{4\ max}$	K_{4min}
half, white, smooth	12.99	0.47	1.02	5	-0.4
half, white, rough	5.85	0.74	0.86	6	-0.4
full, white, smooth	19.74	0.29	0.83	5	-0.6
full, white, rough	9.01	0.67	0.74	7	-0.4

5. Conclusion

Using the Eq 5 it is possible to predict the maximum and minimum temperatures that a particular masonry wall would experience. When predicting the maximum temperature it is required to use maximum value for t_v which is 8 and relevant $K_{4,max}$ value and when predicting the minimum temperature it is required to use minimum value for t_v which is 0 and relevant $K_{4,min}$ value. Then it is possible to obtain the Δt value of Eq 1 by getting the difference between the maximum and minimum temperatures. Finally using the Eq 1, thermal movement of a masonry wall with particular parameters can be obtained.

Using the Δt value it is possible to calculate the strain occur due to thermal movements in masonry walls. Maximum Δt will give the maximum strain that would occur in a masonry wall, due to the thermal movements as a result of temperature variation. As it is mentioned before thermal movements and moisture movements are the dominant factors that affect the horizontal movements in masonry walls. Using the total strain developed due to thermal and moisture movements, more accurate joint spacing for movement joints in masonry walls can be obtained.

From the developed model to predict the maximum and minimum panel temperatures, which finally gives the maximum change in temperature of a particular masonry wall panel with different properties under certain circumstances, it is possible to predict the spacing for movement joints in masonry wall panels.

Eq 6 can be used to calculate the spacing for movement joints in masonry walls. [8]

$$S_e \leq \frac{w_j * e_j}{\varepsilon} \quad (6)$$

S_e - spacing between movment joints, in. (mm)

w_j - width of expansion joint, typically the mortar joint width, in. (mm)

e_j - movement accommodation factor of joint sealant (MAF)

ε - Total strain occur due to movements

The movement joint is typically sized to resemble a mortar joint, usually 10mm to13mm. The width of a movement joint may be limited by the sealant capabilities.

Extensibility of sealants in the 25 percent to 50 percent range is typical for brickwork. Compressibility of filler materials may be up to 75 percent.

Total strain developed due to movements are mainly due to thermal movements and moisture movements. Because only the horizontal movements are considered when calculating joint spacing and thermal movements and moisture movements are the main two movements that affect the horizontal movements.

Maximum strain in brick masonry due to moisture movement in Sri Lankan context was found to be 0.04% from the literature. [6]

Maximum strain in brick masonry due to thermal movements can be predicted using the following equation. (Eq 7)

$$L^{I} = L_0\,(1 + \alpha\,\Delta t) \qquad (7)$$

L^{I} - Final length
L_0 - Initial length
α - Coefficient of linear thermal expansion
Δt - Change in temperature

From **Eq 7**, it can be derived that,

$$\frac{L^{I} - L_0}{L_0} = \alpha\,\Delta t \qquad (8)$$

$\frac{L^{I} - L_0}{L_0} = \varepsilon$; Strain due to thermal movement

Therefore the strain due to thermal movement in a masonry wall can be calculated by using the coefficient of linear thermal expansion and the change in temperature of the masonry wall.

Thus using the Eq 6 minimum joint spacing for an expansion joint in a given masonry wall panel with particular parameters, can be obtained.

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