Cracking Behavior of Base Restrained High Strength Plain Concrete Walls Due to Shrinkage

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Abstract: ***The cracking caused by volume change in plain and reinforced concrete walls restrained at their bases is a widespread problem. Moreover, when High Strength Concrete (HSC) may be used in construction of such walls, cracking behavior of such walls due to shrinkage must be studied. In this work, six walls with Length/Height (L/H) ratio of 6, 8 and 12, were cast using high strength concrete and monitored for 90days after appropriate curing. All the walls were of 500mm height and 100mm thickness and without horizontal reinforcement but only 150mm length vertical dowels extended from the base to provide base restraining. In the present work four out of six walls had been cracked, this finding is in conflict with what was believed by many researchers that base restrained high strength concrete walls could not cracked under weathering conditions. ACI 207.2R stated that cracks under shrinkage effect cannot be eliminated, but it was shown in this work that cracking could be prohibited by limiting the L/H ratio to be 6 or less in base restrained high strength plain concrete walls. In the current work it was shown that there were a large difference between the observed values of maximum crack width, minimum and maximum crack spacing in high strength base restrained concrete walls and those values calculated utilizing the equations developed for normal strength base restrained concrete walls.***

Keywords: High strength concrete, Shrinkage, base restrained walls

1. Introduction

High Strength Concrete (HSC) is commonly defines the concrete having a 28days compressive strength more than 60 MPa [1]. HSC has been advantageously used for many structural members like columns and shear walls of multistory buildings. Such concrete is being specified where reduced weight is important or where architectural considerations require slenderer vertical load carrying elements [2].

The cracking caused by volume change in concrete walls restrained at their base is a widespread problem. Concrete shrinks when it is exposed to a drying environment causing loss of pore water. Based on that the following classification on the types of shrinkage can be made; plastic shrinkage, autogenous shrinkage and drying shrinkage. The amount of shrinkage depends on many factors: a-Type of cement, Troxel [3] concluded that shrinkage of low heat cement (type IV) is greater than that of (type I). This is believed to be due to high (C2S) content in (type IV) cement, which exhibits high shrinkage. b-Coarse aggregate as concrete, with higher aggregate content and higher modulus of elasticity exhibits smaller shrinkage. Moreover, aggregate with rougher surfaces is more resistant to the shrinkage process. c- Curing duration, Powers [4] reported that prolonged moist curing delays the initiation of shrinkage but the curing effect on the shrinkage magnitude is small. d- Water content, Carlson [5] reported that a decrease of water content of concrete by 15 percent causes a decrease in shrinkage of about 30 percent. e- Temperature and Relative humidity, a high temperature and a low relative humidity of the ambient environment accelerate the diffusion of the adsorbed water and capillary water so as to increase shrinkage [6]. f- Admixtures, also affect the amount of shrinkage but their effect varies from admixture to another [12].

1.1 Shrinkage Induced Cracking

Concrete is always under some degree of restraint, either internally or externally. Internal restraint is a result of steel reinforcement imbedded in concrete and the rigidity of the aggregate, while external restraining is due to the connection with the foundation or other part of the structure. The exposure to environment conditions like temperature and humidity leads to contraction in concrete, consequently the restraining will resist that contraction. So, tensile stresses will develop within the concrete. These stresses increase with time with a decreasing rate due to decreased shrinkage and due to stresses relaxation in concrete. Relaxation occurs and may prevent the development of cracking when the shrinkage develops slowly. Cracking will occur when the tensile stress that is caused by the restrained shrinkage (reduced by relaxation) exceeds the tensile strength of concrete [7].

1.2 Tensile Strain capacity

Tensile Strain capacity is defined as the maximum strain that concrete can endure in tension before cracking occurs. Tensile strain capacity is affected by some factors like moisture content, mix richness, amount and type of aggregate and age of concrete. The effect of concrete age on tensile strain capacity is a confliction point between researchers as some researchers found that tensile strain capacity increased with the increase in age, but others refer to an opposite trend [7] [8] [15] [16]. The tensile strain capacity is normally assessed by testing the concrete in flexure or indirect tension [8].

1.3 Creep of Concrete

Creep is the gradual increase in deformation (strain) with time for a constant applied stress, taking into account other time deformations not associated with applied stress, like shrinkage, swelling and thermal deformation. Creep could not be desirable in case of pre-stressed elements emparing the transfer of load from concrete to reinforcement, however creep is considered as beneficial for restrained movement because it relieves the stresses induced by restrained strains due to drying shrinkage and thermal movement [9]. Al-Rawi [10] assumed that creep is the difference between tensile strain capacity and elastic tensile strain capacity when he measured creep under shrinkage cracking conditions.

2. Research Significance

The main aim of this study is to study the shrinkage induced cracking behavior of base restrained plain concrete walls cast using high strength concrete and compare the results with previous studies on normal and high strength reinforced concrete walls in order to evaluate the factors on controlling cracking of such walls.

3. Materials and Methods

3.1 Materials

Portland Type V cement manufactured by Lafarge plant in Karbala was utilized in this work. Annajaf natural sand with specific gravity (2.65) was used as fine aggregate. No coarse aggregate was used in order to accelerate shrinkage process. High range water reducing admixture (superplasticizer) type Epsilon HP580 was used. Adding superplasticizer to the mixing water was performed before adding water to the mix. Silica fume made in UAE/Sharja was also added to all mixes throughout this research. Deformed steel bars with 10 mm diameter, complying with the ASTM-A615 specifications of 623 MPa tensile strength were used as dowels.

3.2 Mix Proportions

The proportions of the concrete mix are summarized in Table 1.

Table 1: Mix Proportions

w/c ratio	Mix proportions kg/m^3 Cement : Silica fume : Sand : Gravel : Water	Superplasticizer (Liter/100kg cement)	Slump (mm)
0.23	650 : 65 : 1522 : 0 : 165	0.2	100

3.3 Determination of shrinkage, tensile strain capacity of end restrained beam model

The free shrinkage was determined using the ELE CT-171M extensometer on 2 demec points (spaced 20 cm apart) fixed on the web of concrete mortar beam (casted in the steel mold shown in Figure 1) on the sides of an artificial crack. The free shrinkage was calculated by measuring the widening of the artificial crack for the period between the end of curing till the time when no movement could be recorded. The end restrained mold was used also to determine the elastic tensile strain capacity of concrete.

3.4 Loss of restraint

Loss of restraint is obtained using the ELE CT-171M extensometer on 2 demec point (spaced 20 cm apart) fixed at the middle of the web of the steel mold of the mortar beam (Figure 1). Loss of restraint represents the steel shortening before crack occurrence.

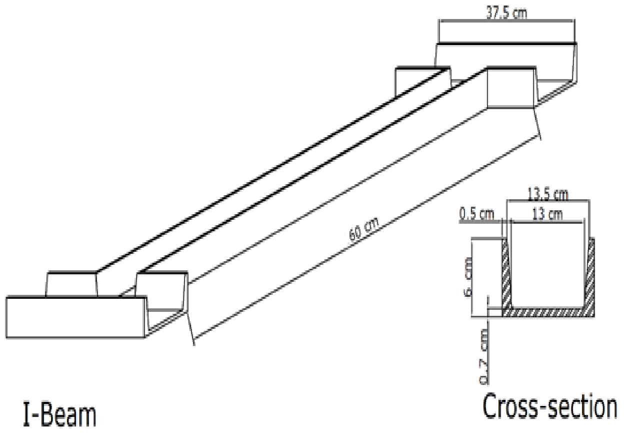

Figure 1: End Restrained I-beam mold

3.5 Compressive, splitting strength and static modulus of elasticity

To test the compressive strength of concrete, cubes with (100x100x100) mm dimensions were used. while (100x200) mm cylinders were used for testing the splitting tensile strength. (150x300) mm cylinders were used to detect the static modulus of elasticity at specified ages. 28days concrete compressive strength was 70.3 MPa as shown in Table 2.

Table 2: Results of compressive strengths test

Age of concrete (days)	Compressive strength (MPa)
3	42.6
7	60
14	66.4
28	70.3
60	79.5
90	83

3.6 Base Restraining

The base for the tested walls was casted 5 months before the time of casting of the walls, in order to ensure that most of the shrinkage strain of the concrete base had been consumed. The base dimensions were (14000x4000x200) mm (length x width x thickness) respectively. The base was reinforced with 10 mm diameter deformed bars (grade 425 MPa) at 200 mm spacing in both directions to perform a rigid base. Dowels were extended from the base to ensure a perfect bond with the walls casted on the base.

3.7 Tested walls

Six plain walls were casted during summer season having the geometry shown in Figure 2. Only vertical dowels of length 150mm extended from the base was used to perform the base restraining effect. Table 3summarizes the walls characteristics.

Table 3: Walls characteristics

Walls notation	Length (mm)	Height (mm)	Thickness (mm)	L/H
W3	3000	500	100	6
W4	4000	500	100	8
W6	6000	500	100	12

Note: Two duplicate walls were casted for each type.

3.8 Mixing and Casting

A mechanical drum mixer of 0.1 m^3 maximum capacity was used after an appropriate cleaning. Fine aggregate was mixed with cement and silica fume with one fourth of mixing water for a period of one minute in the mechanical drum mixer. At the same time, the superplasticizer was added to the remaining water and properly mixed then added to the mix in the mechanical drum after that the mixing continued for 2 minutes. Total mix time was about 4 minutes. Then, the mix was casted into the formwork of the walls (which was made of plywood). Three layers of concrete were casted, each layer was properly compacted using a moveable electrical vibrator.

3.9 Curing and Exposure

According to ASTM C192 specification in order to prevent occurrence of plastic shrinkage at the surface of the walls, polythene sheets were utilized to cover the surface of the walls after 30 minutes after the end of casting. The walls were moistured by water three times daily for the first week, then were exposed to uncontrolled drying conditions for 90-days.

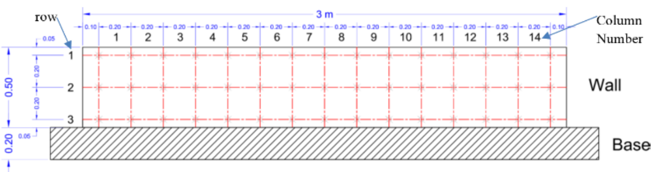

Figure 2(a). W3 geometry

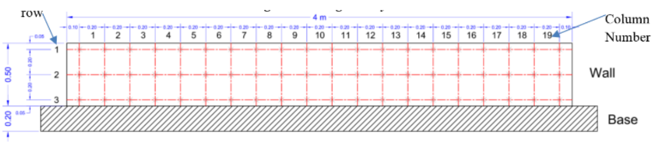

Figure 3(b). W4 geometry

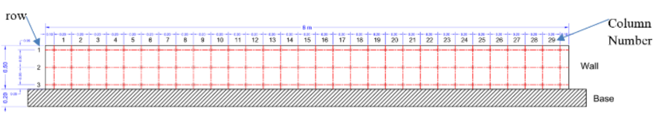

Figure 4(c). W6 geometry

4. Results and Discussion

4.1 Free volume change of high strength concrete

Free volume change was determined by monitoring the free shrinkage strains of unrestrained (500x500x100) mm (length, width and thickness) walls casted with the same materials and time when the restrained walls of the present work were cast. The strains were measured between demec points fixed on concrete surfaces using the extensometer ELE CT-171M. For comparison purposes the dimensions of this wall were similar to the model employed by Al-Tameemi [13] for normal strength concrete. The free shrinkage results are shown in Figure 3.

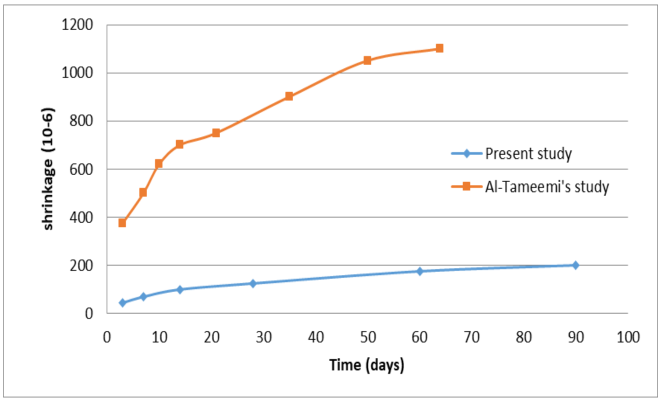

Figure 3: Free shrinkage development with time of the free wall of the present study and Al-Tameemi study

As shown in Figure 3 the free shrinkage values of the present work were much smaller than the free shrinkage values carried out by Al-Tameemi. This could be attributed to the characteristics of the concrete since the internal structure of high strength concrete is very dense which tends to seal the gel pores and consequently inhibit the evaporation of gel water (which is the main cause of shrinkage).

4.2 Shrinkage Strain

Longitudinal movements of the base restrained high strength plain concrete walls were measured for 90days in summer season to investigate the cracking behavior of the walls. Figures (4 to 6) show the development of restrained shrinkage strain with time for the upper rows of the walls of the current study with L/H = 6, 8 and 12. The measurements were taken for 20 cm spacing internal for each row. The results of the present study showed that the shrinkage strains at the upper level were larger than the strains at the other levels. This finding is in line with the fact that the restraint in base restrained walls decreases with the increase in height above the base. The maximum measured strains in the upper row in all tested walls are presented in Table 4.

Table 4: Maximum shrinkage strains for the upper row

Wall notation	Location (Column number)	Maximum shrinkage strain ($x10^{-6}$)
W3	2	625
W4	19	550
W6	1 and 29	350

From Table 4 it can be seen that the location of the maximum shrinkage strains were at the edge columns where the degree of restraint is of minimum value at edge column compared to other places of the wall. Also, maximum shrinkage strain value was reduced by 13.63% when L/H increased from 6 to 8. However, a large reduction was recorded reaching 78.57% when L/H ratio was12.

The shrinkage strains in the upper row in all tested walls were recorded at selected exposure periods. The results of development of strains in the tested walls are presented in Figure 4, 5 and 6.

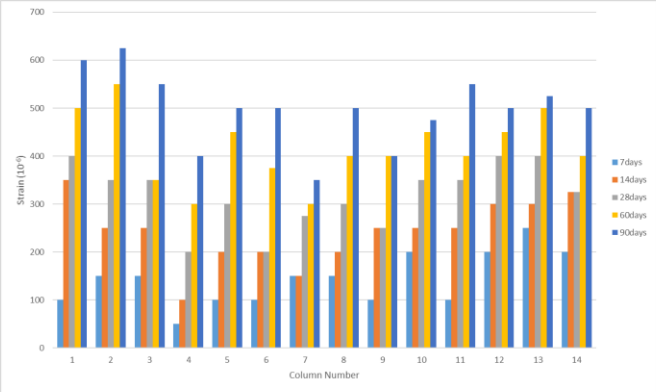

Figure 4: Development of strain in wall W3 at selected exposure periods at upper row

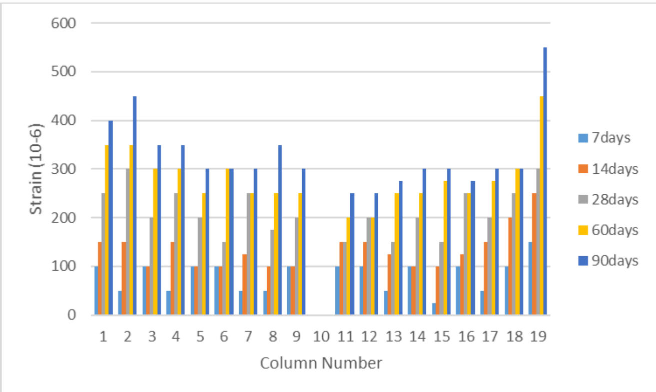

Figure 5: Development of strain in wall W4 at selected exposure periods at upper row

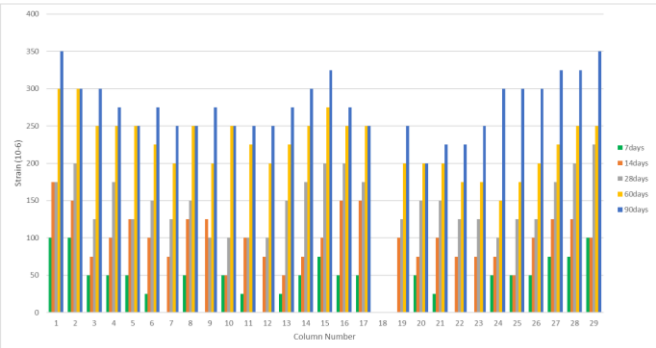

Figure 6: Development of strain in wall W6 at selected exposure periods at upper row

From Figures (4 to 6) the following notes could be defected:

1- Starting strain occurrence time varied between 7, 14 and 28days. This difference may be attributed to the distribution of stresses along the restrained walls' height.

2- For wall W3 there is a continuous increase in shrinkage strains with time with a decreasing rate, indicating that the end of shrinkage process was approached with no crack occurrence.

3- For walls W4 and W6 the shrinkage strains were increased with an increasing rate, indicating a crack occurrence when the shrinkage strain exceeds the tensile strain capacity. Crack occurrence was accompanied with positive change in strains, so the next readings were neglected and denoted by zero strain at that position.

4.3 Cracking of the walls

ACI 363 [12]stated that the first crack occurs at the central region of the wall near the restrained base due to the high value of restraining degree at that location. According to that, the crack initiation would be directed from the bottom of the wall in the upward direction where the degree of restraint is low (assuming no weak region over the wall height). Other researchers [7] [14] [15] [16] studied base restrained high strength concrete walls under shrinkage effect and found that no crack could occur at central region or other places during the observation period when L/H ratio was lower than 6. This may be attributed to the characteristics of high strength concrete since the tensile strength capacity was not exceeded by the tensile stresses caused by shrinkage. However, the results of the current study are in agreement with those researchers in case of W3 only. However, cracks did take place in walls W4 and W6 because of using L/H ratio larger than that used by those researchers.

The widths of cracks in the tested walls were measured at specified ages of concrete. The measured crack widths are shown in Figure 7 and 8.

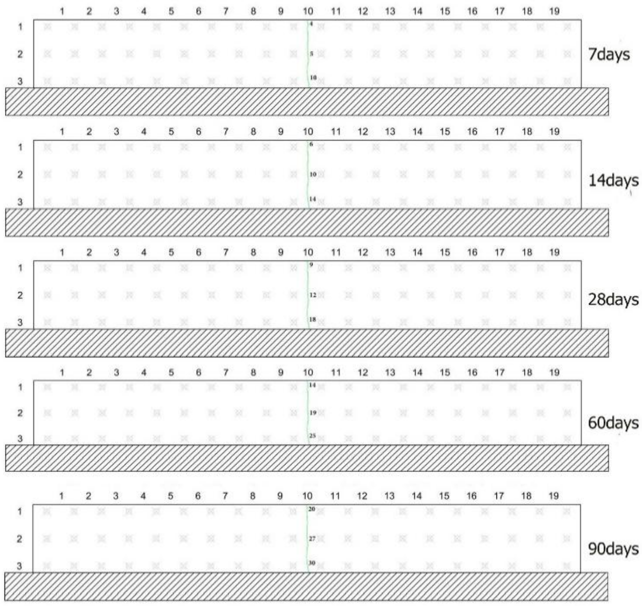

Figure 7: Crack width development with time for L/H=8 (width in 10^{-2}mm)

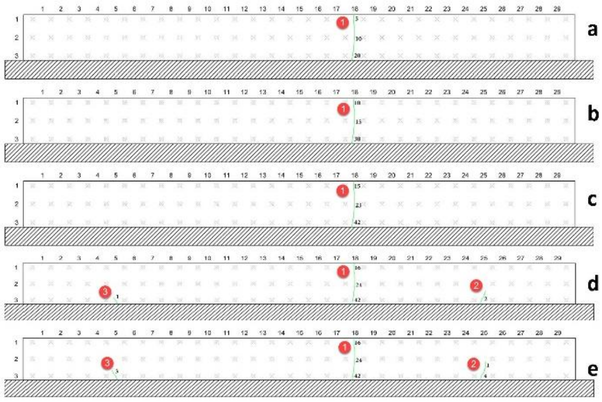

Figure 8: Crack width development with time L/H=12 (width in 10^{-2}mm)

The results show that the maximum crack widths were (0.3 and 0.42) mm for W4 and W6 respectively. The crack width increased by 40% with increasing L/H ratio from 8 to 12. Previous researchers [7] [14] [15] [16] did not develop equations to calculate the maximum crack width, minimum and maximum crack spacing for base restrained high strength concrete walls. Therefore, calculations were made for crack spacing and width using the equations developed by previous researchers for base restrained normal strength concrete walls. The results showed large differences between the observed and the calculated values, which indicates that those equations could not be suitable for base restrained high strength concrete walls.

4.4 Results of cracking of end-restrained beams

Table 5 illustrate the values obtained in the present study and those results observed by earlier researches of end-restrained high strength concrete beam models, which their mold had been shown in Figure 1.

Table 5: Shrinkage Properties of high strength concrete End-Restrained Beam of the current work and earlier researches

	Current work	Al-Taee [17]	Al-Massoudi [8]	Shrba [16]
Cracking time (days)	30	19	23	32
Crack width (mm)	0.018	0.27	0.15	0.085
Free shrinkage at cracking date ($\times10^{-6}$)	186	345	318	200
Loss of restraint ($\times10^{-6}$)	60	75	50	75
Tensile Strain Capacity ($\times10^{-6}$)	126	270	268	125
Elastic Tensile Strain Capacity ($\times10^{-6}$)	30	96	93.5	47
Creep strain at cracking time ($\times10^{-6}$)	96	174	174.5	78
Creep coefficient	0.09	0.3	0.3	0.17

As seen from Table 5 the values of crack width, free shrinkage at cracking strain, tensile strain capacity, elastic tensile strain capacity, creep strain and creep coefficient of the present work were less than the values measured by other researchers [8] [17] [16]. However, the values obtained by Shrba [16] who used reactive powder concrete approaches the values obtained in the current work. This indicates that the characteristic of the end restrained high strength concrete beam model of the present study was similar to the reactive powder concrete beam model when they were both exposed to shrinkage effect.

Elastic tensile strain capacity of concrete was also obtained indirectly from the tensile strength divided by the elasticity modulus at selected ages. These are illustrated in Table 6.

Table 6: Elastic tensile strain capacity of high strength concrete beam model (indirect method)

Age(days)	Elastic tensile strain capacity(10^{-6})
3	142.86
7	175
14	181.82
28	174.29
60	169.23
90	167.50

It can be seen from Table 6 that the elastic tensile strain capacity obtained is less than that obtained indirectly. AL-Taee [17] stated that the indirect method is not accurate due to non-linearity of stress distribution in the beam. The result of the current study agreed with previous works that deals with tensile strain capacity of high strength concrete [18] [17] [16]. However, tests on normal strength concrete showed that indirect method yielded larger strain values than the direct method [10] [19].

5. Conclusion

Based on the results obtained experimentally the following conclusions were reached:

1- Cracking may occur when L/H ratio reaches 8 or more in base restrained high strength concrete walls.
2- Increasing L/H from 8 to 12 causes an increase in maximum crack width and a decrease in maximum shrinkage strain.
3- Pervious equations that were developed to detect crack width, average spacing, minimum and maximum crack spacing for normal strength concrete are not applicable for base restrained high strength concrete walls.
4- The behaviour of high strength concrete of the present study is similar to the behaviour of reactive powder concrete under drying conditions.
5- The value of tensile strain capacity yielded employing indirect method (tensile strength / modulus of elasticity) was larger than the measured field values. So, indirect test method could not be suitable for detecting tensile strain capacity of high strength concrete.

6. Acknowledgements

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References

[1] ACI Committee 207.2R, (2007). "Effect of Restraint, Volume Change and Reinforcement on Cracking of Massive Concrete", Journal of American concrete Institute.
[2] Yogendran, V., Langan, B.W., Haque, M.N. and Ward, M.A. (1987). "Silica Fume in High –Strength Concrete" ACI Materials Journal, March-April, pp.124-129.
[3] Troxell G.E., Davis H.E., and Kelly J.W., (1968). "Composition and Properties of Concrete", Mc Graw Hill, Second Edition.
[4] Powers T.C., (1995). "Causes and Control of Volume Change", Portland Cement Association Research and Development Laboratories Vol.1, No.1, pp. 29-39 (Jan.).(Cited by Neville).
[5] Carlson, R.W., Houghton, D.L. and Polivka, M., (1979)." Causes and Control of Cracking in Unreinforced Mass Concrete", ACI Journal, V. 76, No.7, July.
[6] Mehta P.K., and Monteiro P.J.M., (1993). "Concrete Structures, Properties and Materials", Second Edition, Prentice Hall, Englewood Cliffs, New Jersey.
[7] Habeeb G. M., Essa M. S., & AL-Tai M. J., (2010), "Drying Shrinkage Behavior of Base Restrained High Strength Concrete Walls", Journal of the University of Babylon, Pure and Applied Sciences, Vol. 18, No. 2, PP. 668-689
[8] Al-Massoudi A. J. M., (2010), "Drying Shrinkage and Cracking of Restrained Reinforced High Strength Concrete Slabs", M.Sc. Thesis, University of Babylon, Iraq.
[9] Neville A.M., (1995), "Properties of Concrete" Fourth Edition, Wiley, New York and Longman, London, (Book).
[10] Al-Rawi, R.S., (1986), "Laboratory Tests on Small Beams to Study Shrinkage Cracking in Continuously Reinforced Concrete Pavement", Transportation Research Board, Annual Meeting, Washington, D.C., U.S.A., 24pp
[11] Micallef M., Vollum R. L., & Izzuddin B. A., (2017), "Crack Development In Transverse Loaded Base-Restrained Reinforced Concrete Walls", Engineering Structures, Vol. 143, PP. 522-539.
[12] ACI Committee 363. State-of-the-art report on high-strength concrete ACI 363R-92, In: ACI manual of concrete practice Part I; 2000
[13] Al-Tameemi A. A., (1987), "Control Of Cracking Due to Volume Change in Reinforced concrete", M.Sc. Thesis, University of Baghdad.
[14] Abbas K. M., (2009), "Control of Shrinkage Cracking in Restrained Base and End Reinforced Concrete Walls", M.Sc. Thesis, University of Babylon, Iraq.
[15] Al-Mashhadi S. A., & Satiq N. M., (2017), "The Shrinkage Cracking Behavior in Reinforced Reactive Powder Concrete Walls", Journal of University of Babylon, Vol. 25, No. 4, PP. 1352-1365.
[16] Shrba N. M. S., (2017) "Control of Shrinkage Cracking in Reinforced Reactive Powder Concrete Walls", M.Sc. Thesis, University of Babylon, Iraq.
[17] Al-Ta'ee M. J. M., (2009), "Drying Shrinkage of High Strength Concrete Walls With Base Restraints", M.Sc. Thesis, University of Babylon, Iraq.
[18] Al-Abdaly, N.M., (2007), "Drying Shrinkage Cracking of High Strength Concrete", M.Sc Thesis, University of Babylon, College of Engineering.
[19] Kadhum, M.M., (2003), "Drying Shrinkage of Concrete Slabs Subjected to Fire", M.Sc. Thesis, University of Babylon, College of Engineering

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