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STRUCTURAL CREEP MONITORING OF BEAMS

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Abstract: The scope of this study includes the design, fabrication, and testing of an equipment for structural creep monitoring of beams. Various equipment for creep monitoring was studied, the basic requirements for creep monitoring equipment were also studied, this facilitated the choice of this design, which is simple, functional, and economical for the study of creep on beams. After careful study of various engineering materials, steel was selected as the appropriate material for the fabrication of the equipment, this is because steel met the material basic requirement (strength and stiffness, good yield and tensile strength, low thermal coefficient, high fracture toughness, economics, and availability) for the construction. Fabrication processes included surface cleaning, cutting and machining, punching and drilling, straightening, bending and rolling, fitting and reaming, fastening (bolting and welding), finishes, quality control, and surface treatment.

The testing procedure for the equipment included batching of concrete of mix ratio 1:2:4, the concrete mix was workable with a true slump value of 10mm. The compressive test result of the batch was over 25N/mm2 for all samples at 28days. Shrinkage and Creep were monitored on a short beam of 750mm x 150mm x 150mm for 90 days (samples were waxed). Zero strain readings were recorded at the bottom of the beam, all other strain readings followed the usual pattern except for strain on the right-hand side of the beam. This was attributed to the kind of support (roller support) at the right-hand side of the beam. The study concluded that the mode of occurrence of creep on beams and columns is not similar. Also, the type of support (such as simple support, roller support, or fixed support) affects the measure of creep on beams.

Keywords: Shrinkage, creep, temperature and humidity.

1. INTRODUCTION

Creep is the tendency of solids to deform over time under constant stress, this implies the increase of strain with time. All materials tend to creep. This behavior is dependent on the degree of stress, time, and temperature. Creep testing machine/equipment measures the tendency of material after being subjected to high levels of stress e.g., high temperature, to change its form with time (creep of an object). It measures the alteration of a material after it has been put through different forms of stress.

A concrete creep testing machine is used to test concrete specimen deformation characteristics under constant temperature, humidity, and long-term constant loading. This apparatus uses a precision pressure transducer and displacement for real-time monitoring. Concrete creep is categorized into two, basic creep and drying creep. Basic creep is the deformation of concrete samples without any moisture exchange, that is the sample is completely isolated from the environment and kept at constant humidity and constant temperature. Drying creep is the total deformation of the sample when it is not isolated from the environment; that is moisture exchange is allowed to take place. It has been observed that the difference in deformation between basic creep and drying creep is not just a function of shrinkage alone, as drying creep is more than the combined effect of shrinkage and basic creep. This difference is named "the picket effect" after the man who discovered it. (Bazant et al., 1976)

The drying creep is also referred to as the picket effect which is defined as the creep increase when the specimen undergoes drying. The interpretation of the extra deformation and its mechanism has been a controversial topic for over sixty (60) years. Many hypotheses have been presented by many researchers and two major views exist in literature about the picket effect. One hypothesis explains the extra deformation by a mechanism explained by shrinkage-induced stress and associated cracking (Wittman et al., 1980) (Wittman et al., 1993). The other considers the real mechanism by which creep interacts with the drying (Bazant et al., 1994) (Bazant et al., 1988). But neither of these views explains the phenomenon fully as a combination of both views has prevailed in literature.

Today mechanism of drying creep is considered to be the combination of intrinsic drying creep and its mechanism (Bazant et al., 1988), the second is a structural drying creep caused by a micro-cracking effect due to the non-uniformity of the drying of the specimen. They appear to be two major mechanisms causing the picket effect, microcracking and stress-induced shrinkage.

Microcracking is caused when there is a shrinkage gradient through the section of a specimen where there is more shrinkage on the surface than in the inner layer of the specimen. This causes tension on the surfaces which causes micro cracking. Due to the nonlinear inelastic behavior of the concrete creep caused by tension, the micro-cracks cannot fully close when the moisture distribution finally approaches a uniform state. Consequently, the true shrinkage is always more than the shrinkage of the drying specimen. There is more shrinkage in the loaded specimen than the free shrinkage specimen, which can be falsely considered as a creep. Shrinkage in loaded specimens has been observed to be more than in unloaded specimens (Neville et al., 2010).

The stress-induced shrinkage mechanism has been defined by a detailed analysis of creep data that there are two types of moisture diffusions i.e., macro-diffusions and micro-diffusions (Bazant et al., 1985). Macro-diffusion is the movement of moisture between and through the large pores, it has no measurable effect on the deformation. Micro-diffusion is the movement of moisture between the capillary pores and gel pores. The movement of water through the gel pores increases the rebounding and de bounding process that are the source of the creep (Altoubat et al., 2002).

The recent collapse of famous historical constructions attributed mainly to the time-dependent behavior (creep) of structural members has driven the attention of technical communities over the issue (Paulo et al., 2007). Therefore, the need for equipment that monitors structural members subjected to bending and shear stresses as it occurs in beams becomes of great necessity.

2. MATERIALS AND METHODS

2.1 Design Methods

The design process involves the translation of a new idea into detailed information from which the product can be manufactured. The design process was broken down into stages, (i) Concept Design; this includes the definition of specification, determination of function structure, seeking working principles, evaluation, and selection of concept. (ii) Embodiment Design; this includes the development of layout, formation of model, analysis of assemblies, evaluation, and selection of layout. (iii) Detail design; this includes a detailed analysis of each component, final choices of material and process, detailed drawings.

2.2 Material Selection

A large variety of materials were considered at the beginning of the design. As the design became more focused, the selection criteria sharpened, and the shortlist of materials that satisfied the design narrowed down. The process by which material is to be formed, joined, finished, and otherwise treated as well as economy, shape, and function played an important role in the selection of materials, where shape includes the external (macro shape), and where necessary the internal (micro shape) as in a honeycomb or cellular structure.

The attributes of various engineering materials were studied and metal was discovered to be the most suitable because of its characteristics (high strength, high fracture toughness, high modulus, etc). Upon consideration of the economics, availability, and ease of working with steel, steel was selected as the appropriate material.

2.3 Fabrication Process

The selection of a fabrication method for any precision equipment depends primarily on material selection. Steel passes through various operations during its fabrication and the sequence of activities in the fabrication process includes (i) surface cleaning (ii) cutting and machining (iii) punching and drilling (iv) straightening, bending, and rolling (v) fitting and reaming (vi) fastening (bolting and welding) (vii) finishes (viii) quality control and (ix) surface treatment.

2.4 Testing Procedure

The concrete mix used for testing was made from ordinary Portland cement, crushed granite of igneous origin was used as coarse aggregate, the maximum size of coarse aggregate was 19mm, river sand was used as fine aggregate.

The concrete mix ratio 1:2:4 (binder: sand: granite) was prepared with a constant water-cement ratio of 0.55. Concrete cubes (150mm x 150mm x 150mm) were casted for compressive strength test. For the creep-shrinkage test, 750mm x 150mm x 150mm short beams were cast. Concrete cubes were demolded after 24hrs and put into curing tanks until the day of crushing, short beam was demolded after 24hrs, waxed, and mounted on the creep monitoring equipment.

2.4.1 Determination of Slump, Density, and Compressive Strength.

The workability of fresh concrete mixes was studied by measuring the slump height following BS 1881 (102). 150mm x 150mm x 150mm concrete cubes were cast and tested for compressive strength after curing in water for 7, 14, 21, 28, and 56 days. Procedures prescribed in BS 1881 (107) were followed. The concrete cubes were weighed before testing for compressive strength to determine bulk densities as prescribed by BS 1881 (103).

2.4.2 Shrinkage and Creep Test

The concrete beam was mounted horizontally on the fabricated equipment, dial indicators were placed on four faces of the concrete beam. A comparative reading was taken as the reference point, corresponding to "zero" strains for the measurement. Since monitoring of shrinkage started after 24hrs, strains attributed to fresh and setting of concrete such as autogenous, plastic, and thermal shrinkage were not considered in the strain measurement. The concrete beam was also waxed, therefore readings recorded were basic shrinkage not drying shrinkage. After taking shrinkage readings for a week, creep was measured for three months. Since environmental conditions are major parameters that impact shrinkage, a thermometer and hygrometer were installed to monitor the temperature and relative humidity of the testing room respectively.

3. RESULTS AND DISCUSSIONS

3.1 Working Principle of Equipment

The efficiency of the fabricated equipment in monitoring structural creep in beams is dependent on the alignment of the test specimen and the high accuracy of the dial indicator. The equipment works on the principle that a concrete beam with or without load will deform (experience strain). These strains were recorded with the help of the dial indicator when no load was applied through load hanger, strain recorded through dial indicator are results of shrinkage, while those recorded when load was applied are creep readings.

3.2 Density, Workability, and Compressive Strength of Concrete

Table 1 shows the density and compressive strength of concrete cast using a mix ratio of 1:2:4 and a water-cement ratio of 0.55. The results show that the densities ranged between 2369.82kg/m3 and 2502kg/m3, the results imply that the concrete mix can be categorized as normal dense concrete. The density of a normal dense concrete ranges between 2300kg/m3 and 2500kg/m3. The density results did not follow any particular pattern when compared with both the age and compressive strength of concrete.

The compressive strength of concrete increased with age; it was observed that the average compressive strength of concrete exceeded the characteristics strength of 25N/mm2 at 14days age of concrete.

The workability of fresh concrete was measured using the slump test, which measures the ease with which concrete flows. The result from the slump test was a true slump with a slump value of 10mm. This indicated a rich and well-proportioned concrete mix ratio.

CURING AGE (DAYS)	CUBE NO.	MASS (kg)	DENSITY (kg/m^3)	LOAD (kN)	COMP. STRENGTH (N/mm^2
7 DAYS	1	8.46	2502.96	410	18.22
	2	8.17	2417.16	421	18.71
	3	8.40	2485.21	485	21.56
	AVE.	8.34	2468.44	438.67	19.50
14 DAYS	1	8.14	2408.28	635	28.22
	2	8.25	2440.83	575	25.56
	3	8.35	2470.41	535	23.78
	AVE.	8.25	2439.84	581.67	25.85
21 DAYS	1	8.09	2393.49	620	27.556
	2	8.11	2399.41	540	24.00
	w3	8.04	2378.70	600	26.67
	AVE.	8.08	2390.53	586.67	26.07
28 DAYS	1	8.16	2414.20	570	25.33
	2	8.01	2369.82	685	30.44
	3	8.12	2402.36	625	27.78
	AVE.	8.10	2395.46	626.67	27.85
56 DAYS	1	8.13	2408.89	600	26.67
	2	8.11	2402.96	655	29.11
	3	8.21	2432.59	635	28.22
	AVE.	8.15	2414.81	630	28.00

Table 1: Compressive test result for 7, 14-, 21-, 28- and 56-days age of concrete

Figure 1: Fabricated equipment for structural creep monitoring

3.3 Temperature and Relative Humidity Results

Temperature and humidity distribution of testing room throughout period of experiment are shown in Fig 2. The relative humidity of room throughout experiment, was between 58% and 95% with standard deviation of 6.51%. The temperature throughout experiment was between 25ºC and 37ºC with standard deviation of 2.25ºC. After analysis of temperature and relative humidity data using the Chi square test of goodness of fit, the results showed that temperature and humidity variations could be said to be of no significant effect on the results of experiment with a 95% level of confidence.

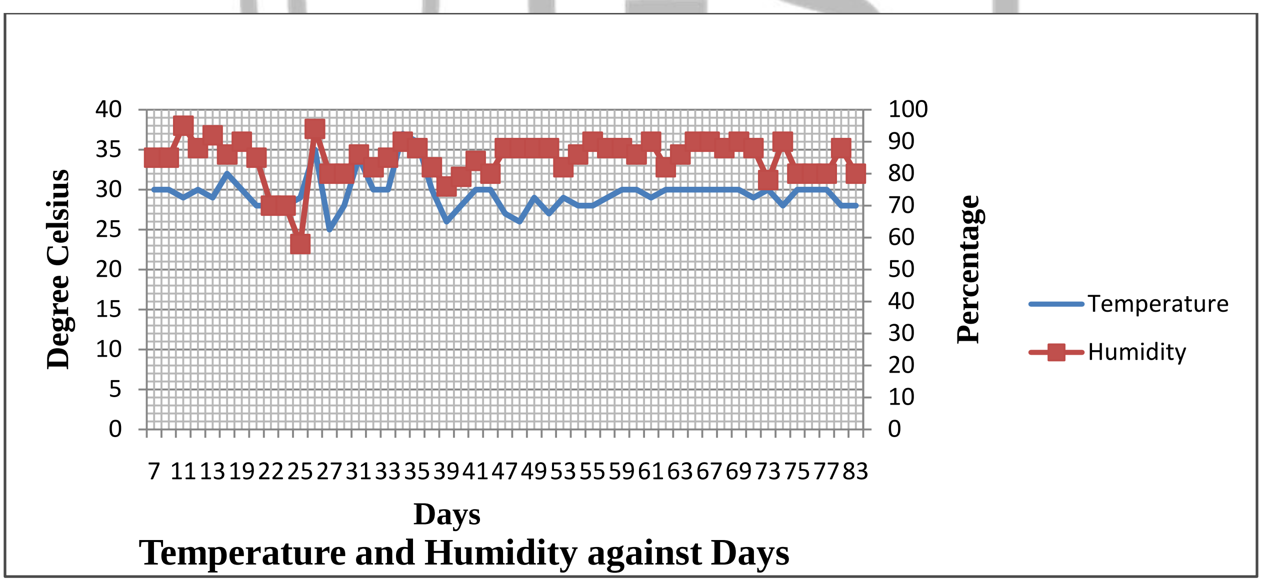

Figure 2: Temperature and humidity against days

Chi Square Table											
Temperatures (°C)											
Days/ Weeks	Monday		Tuesday		Wednesday		Thursday		Friday		Total
	Observed Data	Expected Data	Observed Data	Expected Data	Observed Data	Expected Data	Observed Data	Expected Data	Observed Data	Expected Data	
Week 1	30*	29.47	30*	29.47	30*	29.47	30*	29.47	30	29.47	150
Week 2	30	29.47	29	29.47	30	29.47	29	29.47	32	29.47	150
Week 3	29*	29.47	29	29.47	30	29.47	28	29.47	29*	29.47	145
Week 4	29*	29.47	29	29.47	35	29.47	25	29.47	28	29.47	146
Week 5	34	29.47	30	29.47	30	29.47	37	29.47	36	29.47	167
Week 6	26	29.47	28	29.47	30	29.47	30	29.47	29*	29.47	143
Week 7	27*	29.47	27	29.47	27	29.47	26	29.47	29	29.47	136
Week 8	27	29.47	29	29.47	28	29.47	28	29.47	29	29.47	141
Week 9	30	29.47	30	29.47	29	29.47	30	29.47	30	29.47	149
Week 10	30	29.47	30	29.47	30	29.47	30	29.47	29	29.47	149
Week 11	30	29.47	28	29.47	30	29.47	30	29.47	30	29.47	148
Week 12	28	29.47	28	29.47	28*	29.47	28*	29.47	28*	29.47	140
Total	350		347		357		351		359		1764

asterisked data indicates absent data that were replaced with the weekly mean.

Table 2: Chi Square Test of Goodness Fit for Temperatures

$$\varkappa^2 = \sum_{i=1}^{n}\left[\frac{(\mathrm{Oi}-\mathrm{Ei})^2}{\mathrm{Ei}^2}\right]$$

$$\varkappa^2 = \left[\frac{(30-29.47)^2}{29.47^2}\right] + \left[\frac{30-29.47)^2}{29.47^2}\right] + \left[\frac{(29-29.47)^2}{29.47^2}\right] + \ldots\ldots\ldots \left[\frac{(28-29.47)^2}{29.47^2}\right]$$

$$= 0.009532 + 0.009532 + 0.007497 + \ldots\ldots + 0.073325 = 8.778215$$

<u>Hypothesis:</u>

H_0: There is no significance difference in temperature throughout the period of testing.

H_1: There is significant difference in temperature throughout the period of testing.

<u>Decision Rule:</u>

Reject H_0 if $\varkappa^2$ calculated > $\varkappa^2$ tabulated at 5% level of significance, otherwise do not reject.

$\varkappa^2$ table at 5% level of significance level

α, (r - 1) (c - 1) where α = significance level, r = row and c = column.

$\varkappa^2_{0.05,11,4} = \varkappa^2_{0.05,44} =$ 71.8556

Decision:

Since $\varkappa^2$ calculated < $\varkappa^2$ tabulated i.e., 8.778215 < 71.8556, we accept H_0 and conclude that there is no significant difference in temperature during the period of testing.

Chi Square Table										
Humidity (%)										
Days/ Weeks	Monday		Tuesday		Wednesday		Thursday		Friday		Total
	Observed Data	Expected Data	Observed Data	Expected Data	Observed Data	Expected Data	Observed Data	Expected Data	Observed Data	Expected Data	
Week 1	85	83.27	85	83.27	85	83.27	85	83.27	85	83.27	425
Week 2	85	83.27	95	83.27	88	83.27	92	83.27	86	83.27	446
Week 3	79	83.27	79	83.27	90	83.27	85	83.27	79	83.27	412
Week 4	78	83.27	58	83.27	94	83.27	80	83.27	80	83.27	390
Week 5	86	83.27	82	83.27	85	83.27	90	83.27	88	83.27	431
Week 6	76	83.27	79	83.27	84	83.27	80	83.27	80	83.27	399
Week 7	88	83.27	88	83.27	88	83.27	88	83.27	88	83.27	440
Week 8	88	83.27	82	83.27	86	83.27	90	83.27	88	83.27	434
Week 9	88	83.27	86	83.27	90	83.27	82	83.27	86	83.27	432
Week 10	90	83.27	90	83.27	80	83.27	90	83.27	88	83.27	388
Week 11	78	83.27	80	83.27	88	83.27	80	83.27	80	83.27	406
Week 12	88	83.27	80	83.27	84	83.27	84	83.27	84	83.27	420
Total	1009		984		1042		1026		962		5023

asterisked data indicates absent data that were replaced with the weekly mean.

Table 3: Chi Square Test of Goodness Fit for Humidity

$$\varkappa^2 = \sum_{i=1}^{n} \left[\frac{(\mathrm{Oi} - \mathrm{Ei})^2}{\mathrm{Ei}^2}\right]$$

$$\varkappa^2 = \left[\frac{(85 - 83.27)^2}{83.27^2}\right] + \left[\frac{85 - 83.27)^2}{83.27^2}\right] + \left[\frac{(79 - 83.27)^2}{83.27^2}\right] + \ldots\ldots\ldots \left[\frac{(84 - 83.27)^2}{83.27^2}\right]$$

$= 0.035942 + 0.035942 + 0.218961 + \ldots\ldots + 0.0064 = 23.07$

Hypothesis:

H_0: There is no significance difference in temperature throughout the period of testing.

H_1: There is significant difference in temperature throughout the period of testing.

Decision Rule:

Reject H_0 if $\varkappa^2$ calculated > $\varkappa^2$ tabulated at 5% level of significance, otherwise do not reject.

$\varkappa^2$ table at 5% level of significance level

α, (r - 1) (c - 1) where α = significance level, r = row and c = column.

$\varkappa^2_{0.05,11,4} = \varkappa^2_{0.05,44} = 71.8556$

Decision:

Since $\varkappa^2$ calculated < $\varkappa^2$ tabulated i.e., 23.07 < 71.8556, we accept H_0 and conclude that there is no significant difference in temperature during the period of testing.

From the analysis done using Chi-Square test of goodness fit we can conclude with 95% confidence level that the little variations in temperature and humidity readings had no significant effect on the experiment, thus the experiment is valid.

3.4 Effects of Support Conditions on Creep Monitoring

From the results of shrinkage and creep, it was observed that the type of support given to a beam can affect the results of creep and shrinkage monitoring of a beam. Unusually large dial gauge readings and significant inconsistencies were observed on one of the faces of the beam, this was attributed to the simple support just below the face of the beam. Since simple support cannot resist lateral displacement, there was lateral displacement due to the load applied and also due to the shrinkage of concrete beam.

3.5 Creep and Shrinkage Results

Fig 3 shows graph of strain against time (Creep). No strain occurred at the bottom of beam throughout the experiment, strain readings recorded at the top and left side of the beam followed the usual creep curves, strain on the left rose to 0.04mm at day 9 of experiment and remained at that point till day 67 of experiment where it increased to 0.05mm and remained so till the end of the experiment.

Strain at the top rose to 0.04mm at day 11 of experiment and remained at that point till day 31 of experiment where it hit 0.06mm, it dropped on day 41 of experiment to 0.05mm, it rose back to 0.06mm at day 57 of experiment, it remained at that point till the end of experiment. Strain at the right-hand side of the beam never followed the usual creep curve. This was attributed to the kind of support (roller) at that point.

Shrinkage was studied for 7 days. The dial gauges positioned at the left-hand side and bottom of the beam gave small readings throughout the period of shrinkage monitoring, while that of the right-hand side and top of the beam gave large readings. The large dial gauge readings were attributed to the kind of support at the right-hand side of beam (Roller). Readings recorded were that of basic shrinkage, as beam was waxed therefore there was no moisture exchange with the environment.

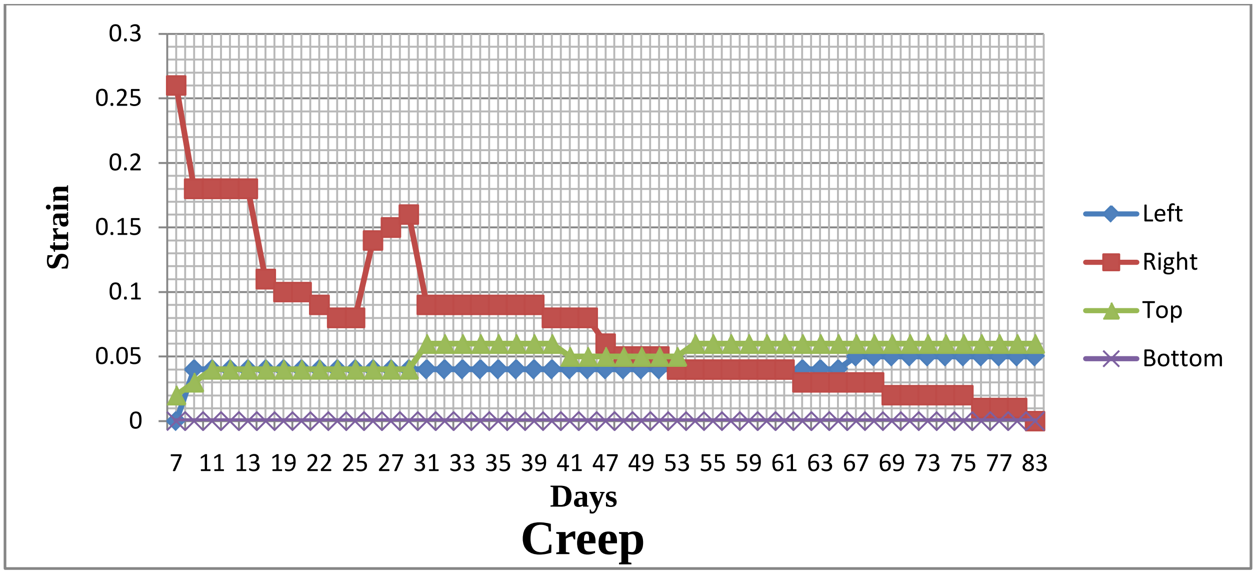

Figure 3: Creep Results

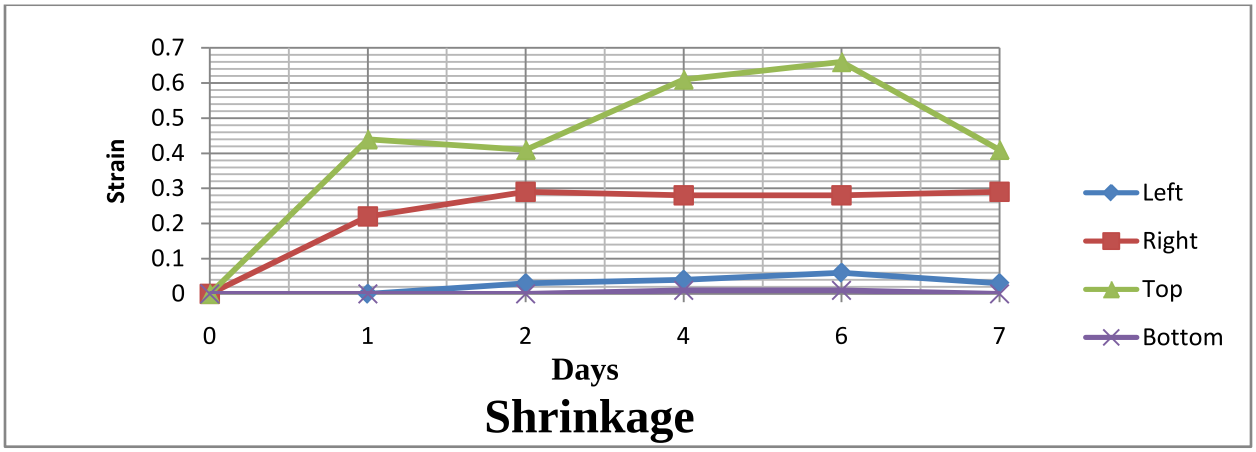

Figure 4: Creep Results

4. CONCLUSION AND RECOMMENDATION

Slump test of concrete mix 1:2:4 was a true slump with slump value of 10mm, this indicates a rich, cohesive and well-proportioned mix, the compressive test of mix was greater than the characteristics compressive strength (25N/mm^2) at 28days age of concrete.

Little fluctuations in temperature and humidity does not affect the validity of results obtained from equipment, chi square test of good fit could be used to prove the validity of results.

Roller support system does not support the study of creep in beams, because it allows for lateral displacement which has great effect on readings obtained, improvements should be made to the support system so that it can also clamp specimen.

More research should be done on this work to validate findings from this project, and further discoveries.

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Appendix

CREEP STRAIN READINGS

Days	Time	Up	Down	Left	Right	Temperature °c	Relative Humidity %
7	12:35pm	0.02	0	0	0.26	30	85
10	1:18pm	0.03	0	0.04	0.18	30	85
11	09:54am	0.04	0	0.04	0.18	29	95
12	12:30pm	0.04	0	0.04	0.18	30	88
13	12:30pm	0.04	0	0.04	0.18	29	92
14	12:30pm	0.04	0	0.04	0.11	32	86
19	02:10pm	0.04	0	0.04	0.1	30	90
20	11:30am	0.04	0	0.04	0.1	28	85
22	10:10am	0.04	0	0.04	0.09	28	70
23	10:50am	0.04	0	0.04	0.08	28	70
25	10:53am	0.04	0	0.04	0.08	29	58
26	12:30pm	0.04	0	0.04	0.14	35	94
27	10:28am	0.04	0	0.04	0.15	25	80
28	11:40am	0.04	0	0.04	0.16	28	80
31	12:20pm	0.06	0	0.04	0.09	34	86
32	11:30am	0.06	0	0.04	0.09	30	82
33	11:24am	0.06	0	0.04	0.09	30	85
34	1:04pm	0.06	0	0.04	0.09	37	90
35	1:10pm	0.06	0	0.04	0.09	36	88
38	12:07pm	0.06	0	0.04	0.09	30	82
39	11:30am	0.06	0	0.04	0.09	26	76
40	10:40am	0.06	0	0.04	0.08	28	79
41	11:26am	0.05	0	0.04	0.08	30	84
42	10:32am	0.05	0	0.04	0.08	30	80
47	9:00am	0.05	0	0.04	0.06	27	88
48	9:30am	0.05	0	0.04	0.05	26	88
49	10:47am	0.05	0	0.04	0.05	29	88
52	9:50am	0.05	0	0.04	0.05	27	88
53	1:16pm	0.05	0	0.04	0.04	29	82
54	12:23pm	0.06	0	0.04	0.04	28	86
55	8:51am	0.06	0	0.04	0.04	28	90
56	11:42am	0.06	0	0.04	0.04	29	88
59	12:38pm	0.06	0	0.04	0.04	30	88
60	11:11am	0.06	0	0.04	0.04	30	86
61	10:09am	0.06	0	0.04	0.04	29	90
62	4:05pm	0.06	0	0.04	0.03	30	82
63	2:00pm	0.06	0	0.04	0.03	30	86
66	9:48am	0.06	0	0.04	0.03	30	90

67	10:35am	0.06	0	0.05	0.03	30	90
68	3:02pm	0.06	0	0.05	0.03	30	88
69	11:00am	0.06	0	0.05	0.02	30	90
70	2:35pm	0.06	0	0.05	0.02	29	88
73	3:48pm	0.06	0	0.05	0.02	30	78
74	10:27am	0.06	0	0.05	0.02	28	90
75	3:11pm	0.06	0	0.05	0.02	30	80
76	4:29pm	0.06	0	0.05	0.01	30	80
77	1:38pm	0.06	0	0.05	0.01	30	80
80	9:09am	0.06	0	0.05	0.01	28	88
83	10:48am	0.06	0	0.05	0	28	80