Shrinkage test of concrete: Methodology and variation of strain

N Ibrahim
Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam, Selangor
noris024@uitm.edu.my

Abstract. Evaluation of shrinkage strain in long concrete structures such as prestressed concrete box girder bridges is very important for the design of such structures. A wrong evaluation may contribute to loss of prestressing force, excessive deflections, cambers and cracking of the structure. It may also affect the durability and serviceability of the structure. The value of shrinkage strain is required during design, far before the construction process. However, realistic evaluation is still a difficult problem because shrinkage strain is influenced by the concrete composition and environmental factors such as humidity and temperature. Therefore, to gain the best evaluation, an experimental program was conducted to measure the shrinkage strain of concrete versus concrete age. Several concrete specimens were collected during pouring of several box girder segments of Tauranga Harbour Link, New Zealand. Variation of shrinkage strain versus concrete age for almost two years of data collection was plotted.

1. Introduction
In the design and assessment of long structural member, shrinkage strain has to be properly evaluated to avoid unacceptable deformation. A lot of research has been done for the past years. Installation of instruments to investigate the shrinkage strain variation in real structures has been shown as well as in [3].

There are also a lot of research papers reporting about shrinkage tests such as reported in [4-10] as well as in [11]. Furthermore, prediction models to estimate the shrinkage value have also been investigated as mentioned by [12-17] as well as in [18].

To gain the best shrinkage evaluation, shrinkage results from the laboratory experiments must be obtained. Therefore, this paper focuses on the methodology utilized to obtain the variation of shrinkage strain versus time from the laboratory experiments for concrete collected during construction of a real structure. Several specimens were collected during pouring of the concrete structure and transported to the laboratory for shrinkage tests. Variation of shrinkage strain versus time was then plotted.

2. Literature
Shrinkage is the property of concrete to change in volume independent of the load it sustains. It essentially occurs due to evaporation of water from concrete and hydration of its components with time. Authors in [19] mentioned that the divides shrinkage can be divided into three types, namely drying shrinkage, plastic shrinkage and autogenous shrinkage. The writers use the term drying
shrinkage and plastic shrinkage for hardened concrete (due to drying) and fresh concrete respectively. Autogenous shrinkage is explained as shrinkage that occurs during the hydration of cement.

Authors in [20] mentioned that the concrete mixture usually contains more water than is needed for hydration and they divide shrinkage into three parts; drying shrinkage, autogenous shrinkage and carbonation shrinkage. Each part of shrinkage is explained as follows.

i) Drying shrinkage occurs when free water in the cement paste is lost into the surrounding environment.

ii) Autogenous shrinkage is a continued hydration of cement which may cause expansion if an excess of water is present.

Carbonation shrinkage takes place when water produced from the reaction of CO$_2$ (in the atmosphere) with Ca(OH)$_2$ (in the cement paste) loses to the environment.

Authors in [21] divided shrinkage of concrete into three types, namely plastic shrinkage, chemical shrinkage and drying shrinkage. This is explained as follows; plastic shrinkage occurs in the wet concrete due to capillary tension in the pore water and may result in significant cracking during the setting process. During setting, the steel is ineffective in controlling such cracks because the bond between the plastic concrete and the reinforcement has not yet been developed. Drying shrinkage is the reduction in volume caused principally by the loss of water during the drying process. Chemical shrinkage results from various chemical reactions within the cement paste and includes hydration shrinkage. Hydration shrinkage is related to the degree of hydration of the binder in a sealed specimen.

From the literature review, it is found that concrete shrinkage is a complex phenomenon which depends on the concrete composition and environmental factors. It is also interesting to see how shrinkage develops with time. To obtain a better understanding of this phenomenon, it is therefore required to observe the variation of shrinkage strain of concrete in certain duration through lab experiments.

3. Methodology
Several specimens were cast during pouring selected bridge segments of Tauranga Harbour Link, New Zealand. The selected segments were Segment 3, 4 and 22. The specimens collected from these segments were then tested to obtain several properties which include the variation of shrinkage strain versus drying age. Drying age is counted immediately after the moist curing period ends and the duration of moist curing period was 7 days. The guidelines of the American Society for Testing of Materials (ASTM) [22] were generally followed in setting up the tests and where these could not be strictly adhered to, a correction procedure was developed.

3.1. Concrete specimens preparation
All the concrete specimens were moulded and went through initial curing at the construction site or the batching plant. For Segments 3 and 4, specimens were moulded at the construction site, very close to the Casting Shed (a place where the box girders were cast) while for Segment 22, specimens were moulded at the batching plant (a place where concrete was mixed and batch). The batching plant was only about two kilometres away from the construction site. Moulding process was in accordance with ASTM C 31/C31M-08a.

3.2. Initial curing of concrete specimens
For initial curing, ASTM C31/C 31M-08a specifies that the specimens need to be stored up to 48 hours in a temperature range from 20 to 26°C. After moulding, each of the concrete filled moulds were covered immediately by individual plastic bags and tied with rubber bands to prevent moisture loss. Then, specimens were moved immediately to a place where they received initial curing and direct sunlight was avoided. Specimens from Segments 3 and 4 were stored at the sheltered place beside the
Casting Shed. Wet burlap was placed on all of them to avoid drying and evaporation [21]. The burlap was prevented from contacting the concrete surfaces. These specimens were left for a day at the place to gain initial process of hardening as shown in Figure 1(a). Temperatures were 15°C (7 a.m.) and 21°C (1 p.m.) during the beginning of moulding the specimens from Segments 3 and 4 respectively. Temperature colder than 15°C was expected during night time.

Figure 1. a) Initial curing of concrete specimens from Segment 3 (before placing wet burlap). b) Initial curing of concrete specimens from Segment 22 (before placing wet burlap).

Temperature recorded at 10.30 a.m. at the sheltered place after moulding specimens from Segment 3 was 21°C. No temperature history was recorded until the next morning. Specimens from Segment 22 were left overnight in a temperature-controlled room which was available at the batching plant as shown in Figure 1(b). The temperature in the controlled room was about 24°C. After gaining their initial hardening the specimens were all transported to the laboratory in the University of Auckland for curing and testing.

3.3. Transportation of concrete specimens
In order not to disturb the specimens in the initial process of hardening, transportation to the laboratory in the University of Auckland (UoA) was done one day after moulding. All the specimens were placed on rubber sheets to avoid vibration during transportation. Gaps between the moulds were filled in with rubber and cloth. All specimens were covered with plastic sheet. Wet burlap was placed on the plastic sheet and sprayed with water regularly during the three hours journey to prevent loss of moisture and evaporation. For Segment 3, the temperature during the journey was between 21°C to 25°C while relative humidity was 38% to 60%. No record was done for Segment 4 and 22.

3.4. Curing of concrete specimens
According to ASTM all the specimens have to be kept in a constant environmental condition throughout the tests. Therefore, all of them were placed inside the test hall basement at the Department of Civil Engineering in the University of Auckland and removed from their moulds as soon as they reached the place. According to ASTM (2008), C512-02, the specimens should be moist cured in a moist room or moist cabinet. However, none of this equipment was available at the laboratory of the university. In order to comply with the requirement, all the specimens were placed in a tank. The tank was filled with water about 10 mm height. Specimens were all supported by wood to avoid water from reaching them. They were all wrapped with wet burlap as shown in Figure 2 to create moist condition and sprayed with water regularly to avoid drying and evaporation until seven days of age.
Figure 2. Concrete specimens wrapped with wet burlap.

The record shows that the temperature and relative humidity inside the test hall basement ranged between 18°C to 25°C and 50% to 70% during the moist curing process. All the specimens from all the segments were managed to be moist cured as described above. Several specimens were taken out as scheduled for compressive strength and modulus of elasticity tests.

3.5. Arrangement of tests for concrete specimens
There were originally 15 specimens from Segments 3, 19 from Segment 4 and 8 from Segment 22. Several specimens were tested for compressive strength and modulus of elasticity but not reported here. For shrinkage tests, the specimens were divided into 4 groups based on segment number and drying age. Each group was given a name for reference as explained below and shown in table 1. Figure 3 shows the concrete specimens prepared for the shrinkage tests.

i) Segment 3 which measurement started at drying age of 10 days (S3D10)
ii) Segment 3 which measurement started at drying age of 21 days (S3D14)
iii) Segment 4 which measurement started at drying age of 24 days (S4D24)
iv) Segment 22 which measurement started at drying age of 3 days (S22D3

Table 1. Group of specimens for shrinkage tests.

| Group  | Segment | Number of specimens | Specimen size (mm) |
|--------|---------|---------------------|--------------------|
| S3D10  | 3       | ≤ 12                | 100 x 200          |
| S3D14  | 3       | ≤ 3                 | 100 x 200          |
| S4D24  | 4       | ≤ 19                | 100 x 200          |
| S22D3  | 22      | ≤ 8                 | 100 x 200          |

Figure 3. Concrete specimens for shrinkage tests from Segment 22
4. Result and discussion

Development of shrinkage strains against drying age is presented in Figure 4. The shrinkage strains are averaged over the total number of specimens measured in the respective group. As expected, S3D10 consistently shows a little bit higher strain than S3D14 due to an earlier age of measurement by four days. Although S4D24 comes from a different segment and measured at later drying age than S3D10 and S3D14 the shrinkage strain develops about the same pattern. This is obviously due to the environmental influence because S4D24 was cast only 6 days after S3D10 and S3D14. Segment 22 was cast 4 months later than Segment 3. As a result, it shows a different strain pattern. S22D3 started at the drying age of three days which could be the reason for its higher strain than other segments.

![Figure 4. Development of shrinkage strain against drying age.](image)

5. Conclusion

The paper describes the methodology used to measure shrinkage strain for concrete obtained during pouring of selected bridge segments of Tauranga Harbour Link, New Zealand. The specimens were then tested to obtain the variation of shrinkage strain versus drying age. The development of shrinkage strain for almost two years from different groups of specimens was collected and shown on a graph. From the results, it is found that the shrinkage strain develops very fast at an early age. The value has almost stabilized at the drying age of 2 years and the pattern of development may be influenced by environmental factors. Detail and analysis of the factors may be published later.

References

[1] Lee A and Robertson I N 1995 Instrumentation and long-term monitoring of the North Halawa Valley Viaduct Report UHM/CE/95-08, University of Hawaii, Honolulu, Hawaii
[2] Huo X.S, Zhu P Ung F and Edward P W 2006 Case study of a high-performance concrete bridge in Tennessee Practical Periodical on Structural Design and Construction 11(4) 229-237.
[3] Dolinajová K and Moravčík M 2013 Monitoring and numerical analysis of construction stages on the bridge realized by the free Cantilever Method Procedia Eng. 65 321-326
[4] Khan A A, Cook W D and Mitchell D 1997 Creep, shrinkage and thermal strains in normal, medium and high strength concretes during hydration ACI Materials J. 94(2) 156-163
[5] Vandewalle L 2000 Concrete creep and shrinkage at cyclic ambient conditions Cement and Concrete Composite 22(3) 201-208
[6] Altoubat S A and Lange D A 2001 Creep, shrinkage and cracking of restrained concrete at early age ACI Material J. 98(4) 323-331
[7] Turcry P, Loukili A, Haidar K, Piaudier-Cabot G and Belarbi 2006 A Cracking tendency of self-compacting concrete subjected to restrained shrinkage: Experimental study and modeling J. of Materials in Civil Eng. 18(1) 46-54
[8] Bazant Z P and Li G H 2008 Comprehensive database on concrete creep and shrinkage Structural Eng. Report No. 08-3/A210c. Infrastructure Technology Institute, McCormick School of Engineering and Applied Science, Northwestern University Evanston, Illinois 60208, USA
[9] Badrinarayan R, Shirish D, and Gangadhar, R. A 2016 A study on early age shrinkage behaviour of cement paste with binary and ternary combination of fly ash and pond ash Indian J. of Science and Technology 9(44) 1-9
[10] Kucharezykova B, Karel O, Danek P, Kocab D and Possl P 2017 Comparison of measurement methods intended to determination of the shrinkage development in polymer cement mortars Procedia Eng. 195 17-23
[11] Misak P 2017 Experimental analysis on shrinkage and swelling in ordinary concrete Advances in Materials Science and Engineering 2017
[12] Bazant Z P and Panula L 1980 Creep and shrinkage characterization for analyzing prestressed concrete structures Prestressed Concrete Inst. 25(3) 86-122
[13] Gardner N J and Zhao J W 1993 Creep and shrinkage revisited ACI Materials J. 90(3) 236-246
[14] Huo X S, Al-Omaishi N and Tadros M K 2001 Creep, shrinkage and modulus of elasticity of high performance concrete ACI Materials J. 98(6) 440-449
[15] Gardner N J 2004 Comparison of prediction provisions for drying shrinkage and creep of normal-strength concretes Canadian J. of Civil Eng. 31(5) 767-775
[16] Goel R, Kumar R and Paul D K 2007 Comparative study of various creep and shrinkage prediction models for concrete J. of Materials in Civil Eng. 19(3) 249-260
[17] He W 2013 Creep and shrinkage of high performance concrete and prediction of the long-term camber of prestressed bridge girders Masters Dissertation, Iowa State University, Ames, Iowa
[18] Zemanova A, Tej P, Pokorny P and Kolisko J 2016 Comparison of currently used prediction models for creep and shrinkage of concrete Int. Conf. on Advanced Material and Env. Eng. (AMSEE 2016)
[19] Barr B, Hoseinian S B and Beygi M A 2003 Shrinkage of concrete stored in natural environments Cement and Concrete Composites 25(1) 19-29
[20] Mokhtarzadeh A and French C 2000 Mechanical properties of high-strength concrete with consideration for precast applications ACI Structural J. 97(2) 136-147
[21] Gilbert R I 2001 Cracking and deflection - the serviceability of concrete structures Electronic J., of Structural Eng. 1(1) 2-14
[22] ASTM International 2008. Annual Book of ASTM Standards. Section 4: Construction. West Conshohocken, California: ASTM International.

Acknowledgement
The author would like to acknowledge the help she received while conducting this research from Rudolph Kotze and Kelvin Reid of Transit New Zealand, Tim Grammer, Bryce Irving and Tony Pike of Fletcher Construction and Piotr Omenzetter, Jason Ingham, Noel Perinpanayagam, Sujith Padiyara and Mark Byrami of Auckland University.