CONCRETE RESEARCH LETTERS

www.crl.issres.net

Vol. 1 (1) – March 2010

The Mechanical Properties of High Strength Concrete for Box Girder Bridge Deck in Malaysia

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Selected paper from the Asia Pacific Structural Engineering Conference, APSEC 2009

Abstract

This paper presents an experimental investigation of the mechanical properties of high strength concrete for box girder bridge deck in Malaysia. To study the Malaysia condition, high strength concrete samples were obtained from a Malaysian precast concrete factory that provides precast and in-situ concrete for box girder bridge deck construction. The mixed design properties of this type of concrete mixture were investigated; including the slump test, compressive strength, flexural strength, static modulus elasticity and Poisson's ratio. Stress-strain curve relationship was produced as well, to be used for non-linear behaviour study.

Keywords: box girder; slump; compressive; flexural; static modulus elasticity; Poisson's ratio.

1. Introduction

The purpose of this research is to provide the material properties of concrete box girder bridge deck with respect to the types and strength of concrete used in Malaysia. For mixed design proportion of this high strength concrete, a super plasticizer was used to allow the concrete to reach the 90% of the 28 days concrete strength in a period of 7 days. In the investigations, the testing of the specimens was performed in accordance to British Standards. The Euro code 2, ASSHTO LRFD Bridge Design Specification and ACI codes are used as the results comparison. Furthermore in this research, a stress-strain curve relationship was produced in order to be used for non-linear behaviour study. These results can be used as an input of material properties for studying the linear and non-linear concrete behaviour using finite element method.

2. Mix Design

The concrete mix was obtained from one of precast concrete factories in Malaysia. In the mix, the admixture or a super plasticizer was used to allow the concrete to reach the 90% of the 28 days concrete strength in a period of 7 days. Other tests have been made by Nguyen et al. [1]; the

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concrete strength develops rapidly in early stages by using superplastisizer. Compressive strength at 03 days is over 60% and at 07 days is over 85-90% of strength at 28 days. The super plasticizer used in mix is Mighty superplastisizer. Based on supertilisizer research by Hattori [2]; water reductions up to 30% were achieved with the use of this supertilisizer called Mighty-150. Since then, it has considerably contributed to produce the high-strength concrete. The proportion of mix can be seen in Table 1.

TABLE 1: MIX DESIGN PROPORTION FOR CONCRETE BOX GIRDER BRIDGE DECK IN MALAYSIA

Mix Proportion/ 1 M^3	Quantity
Sand (Kg)	814
Aggregate (20mm)	1080
Cement (Kg)	470.8
Admixture (L)	6.6
Water (L)	42.2

Based on AASHTO LRFD Bridge Design Specification; the concrete sample is classified as Class P (High Performance Concrete) where the sum of Portland Cement and other cementitious materials shall be specified not to exceed 593 Kg/m^3 [3]. The concrete mix characteristic for class P can be seen in Table 2.

TABLE 2: CONCRETE MIX CHARACTERISTIC

Class of concrete	P (HPC)
Minimum Cement Content (Kg/m^3)	334
Maximum W/C ratio (Kg/Kg)	0.49
Coarse Aggregate (mm)	4.75- 25

3. Test For Fresh Concrete

The main purpose of this test is to determine the workability of fresh concrete. Fresh concrete is a mixture of water, cement, aggregate and cementitious cement. After mixing, operations such as transportation, placing, compacting and finishing of fresh concrete can affect the properties of the hardened concrete. The ease with which a concrete mix can be handled from a mixture to its final compacted shape is termed as workability.

There are three main characteristics of workability that is consistency, mobility and compactibility. The tests commonly used for measuring workability do not measure these individual characteristics of workability. In this study, the type of test used was slump test.

The determination of slump was carried out in accordance with BS 1881: part 102 (1983) [4]. The test was conducted by using the standard size of metal mould, as prescribed in the standard. There are three types of slump that may result after the test. The test is only valid if it yields a true slump where the concrete specimen remains substantially intact and symmetric. If the concrete specimens result is in shear type or collapses, the test should be repeated with another concrete sample.

The mould for the slump test is a frustum of a cone, with 305 mm high. The base of the mould with 203 mm diameter is placed on a smooth surface while the smaller opening of 102 mm diameter at the top. The container is filled with concrete in three layers. Each layer is tamped 25 times with a standard 16 mm diameter steel rod. Rounded at the end, and the top surface is struck off by means of a screeding and rolling motion of the tamping rod. The mould must be held firmly against its base during the entire operation. This is facilitated by handles or foot rests brazed to the mould.

Immediately after filling, the cone is slowly lifted, and the unsupported concrete slumps - hence the name of the test. The test is widely conducted on site although it is virtually impossible to lift the cone vertically at the end of the test. Ideally, all slump result should be true slump. There are three types of slumps to be observed; true, shear and collapse. Based on the site test, the type of slump is true slump. The slump test measurement on site can be seen in Figure 1.


Figure 1. The process of Slump test measurement

4. Test for Hardened Concrete

The most important property of hardening concrete is the compressive strength which is commonly used for specification and quality control. Compressive strength of concrete is defined as the maximum compressive load it can carry per unit area and is determined by using standard cube (100 x 100 x 100mm) or cylinders (150 mm diameter x 300mm length).

In general, the other properties of concrete such as Flexural strength, modulus elasticity and Poisson ratio were also tested in this report. Factors such as constituent materials, method of preparation, curing and test condition can influence the concrete strength.

In order to obtain good concrete, the curing in suitable environment during early stages of hardening should follow the placing of an appropriate mix. Curing is used for promoting the hydration of cement and consists of controlling the temperature and moisture movement from and into the concrete. Curing may influence the strength of concrete both from the point of view of time for which it is applied and the effectiveness of the method used. In strength terms, for example, poor curing will be less damaging to the mass concrete than thin sections, which could dry out more quickly.

The curing process was conducted in Structural and Material Laboratory of Universiti Teknologi Malaysia for 28 days. The samples for hardened testing concrete are shown in Figure 2.


Figure 2. Hardened concrete after opening the mould for 24 hours

4.1. Compressive Strength Test

The compressive strength of normal concrete was obtained by crushing 100 x 100 x 100 mm cubes at 28 days as shown in Figure 3. The mean value obtained from the three cubes was then taken as cube compressive strength for each normal concrete mix. The tests were performed in accordance with BS 1881: Part 116 (1983) [5]. The compressive strength at the age of 7 and 28 days were also carried out for the purpose of studying the strength development of concrete. The compressive strength of normal weight cubes was calculated by dividing the maximum load (P) (attained from the test) by the cross sectional area of the cube (A). The compressive strength is given by the equation 1.

$$\sigma = P/A \tag{1}$$

It is assumed that for fully compacted concrete the compressive strength depends only upon the water/ cement ratio for a given type of cement, age, method of testing and curing.

Figure 3. Hardened cube concrete for 7 and 28 days curing

The process of compression strength test in Structural and material laboratory Universiti Teknologi Malaysia can be seen in Figure 4. The failure cube samples after compressive testing is shown in Figure 5.

Figure 4. The process of Compressive strength test

The compressive strength result at the age of 7 and 28 days can be seen in Tables 3 and 4. The results show that the concrete strength at 7 days achieved 90 % of 28 days concrete strength. It is because, the concrete box girder bridge deck requires early strength for prestressing purposes on site.

Figure 5. Failure cube after compressive testing in structure lab

TABLE 3: RESULT OF COMPRESSIVE TEST FOR 7 DAYS STRENGTH

Sample No.	Weight (Kg)	Area (mm^2)	Load (N)	Strength (N/mm^2)
1	2.465	1000	517.639	51.76
2	2.480	1000	515.672	51.567
3	2.465	1000	528.455	52.845

TABLE 4: RESULT OF COMPRESSIVE TEST FOR 28 DAYS STRENGTH

Sample No.	**Weight (Kg)**	**Area (mm^2)**	**Load (N)**	**Strength (N/mm^2)**	**Mean Cube strength**
1	2.51	1000	517.639	55.25	56.01
2	2.485	1000	515.672	57.626	
3	2.515	1000	528.455	55.154	

4.2. Flexural Strength Test

The determination of the flexural tensile strength was obtained by testing in flexure; a set of three moulded prism specimens of 100 x 100 x 500 mm at 28 days (Figure 6). The mean value obtained from the tests was taken as the flexural tensile strength of concrete. The tests were carried out in accordance with BS 1881: Part 118 (1983) [6]. Figure 7 shows the process of flexural tensile test. The flexural tensile strength of the test prism was calculated by the following equation:

$$f_b = \frac{PL}{bd^2} \tag{2}$$

where f_b is the flexural strength (N/mm^2), P is the breaking load (N), L is the distance between the supporting rollers (mm), b is the width of the cross section and d is the depth (mm). The flexural strength test results are shown in Table 5. Figure 8 shows the conditions of prism sample after the test.

Figure 6. Hardened prism for flexural testing after curing for 28 days

TABLE 5: FLEXURAL STRENGTH TEST RESULTS

No	F_b (n/mm^2)	Average
1	6.212	6.6478
2	7.1312	
3	6.6	

The values reported by various investigators for the modulus of rupture of normal weight high-strength concretes fall in the range of 7.5 √fc to 12√fc where both the modulus of rupture and the compressive strength are expressed in psi. The equation 3 was recommended for the prediction of the tensile strength of normal weight concrete.

$$f_r = 0.94\sqrt{f_c'} \text{ MPa} \quad (3)$$

For 21 MPa < f_c' < 83 MPa

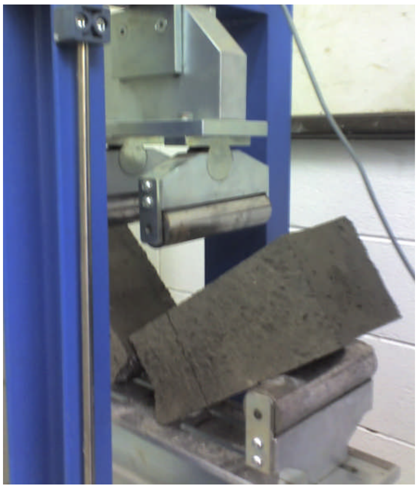

Figure 7. The process of flexural Strength Test

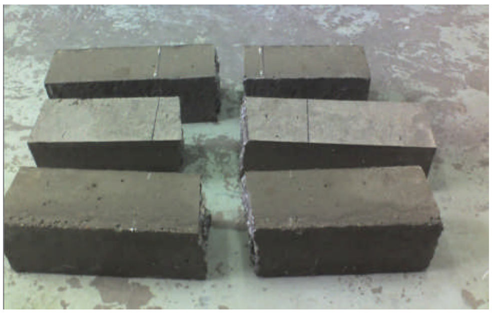

Figure 8. The prism failed after flexural testing

4.3. Static Modulus of Elasticity

The modulus of elasticity is defined as the ratio of the normal stress to corresponding strain below the proportional limit. For practical purposes, only the deformation which occurs during loading is considered to contribute to the strain in calculating the normal load rate modulus of elasticity. The compressive strength was calculated by the following equation:

$$E = \frac{\sigma}{\varepsilon} = \frac{F/A_0}{\Delta L/L_0} = \frac{FL_0}{A_0\Delta L} \quad (4)$$

Where E is the modulus elasticity, F is the force applied to the object, A0 is the original cross-sectional area through which the force is applied, ΔL is the amount by which the length of the object changes, and Lo is the original length of the object. The modulus of elasticity of concrete and its corresponding compressive strength are required in all calculations for the design of concrete structures. The modulus of elasticity can be determined by measuring the compressive strain when a sample is subjected to a compressive stress.

Figure 9 shows the concrete cylinder samples for modulus of elasticity test. The static modulus of elasticity test is depicted in Figure 10. The crushed sample after modulus of elasticity test can be seen in Figure 11. The relationship between stress and vertical strain can be seen in Figure 12.

Figure 9. Hardened cylinder concrete samples

Figure 10. Stress strain relationship test

Figure 11. Static modulus of elasticity test

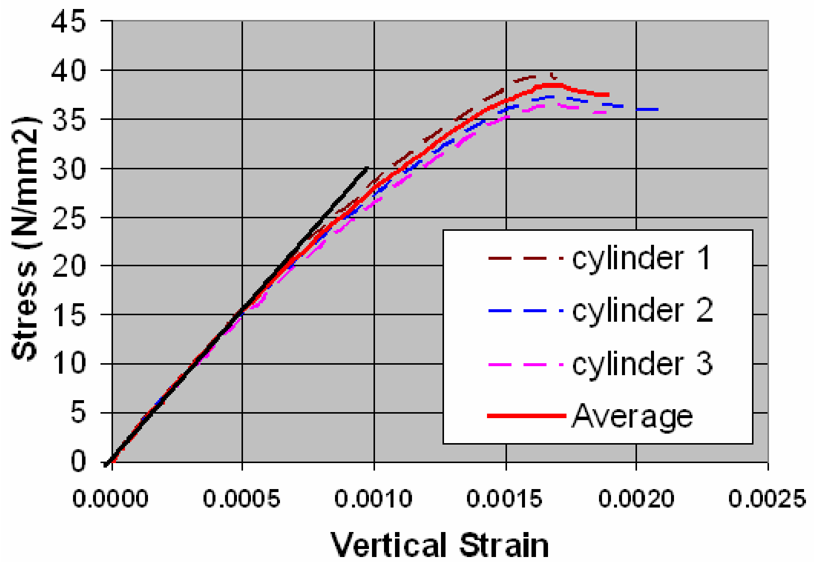

Figure 12. Stress versus vertical strain

Many investigators have reported values for the modulus of elasticity of high-strength concrete of the order of 31-45 MPa, depending mostly on the method of determining the modulus [7]. From the sample test, the modulus elasticity for concrete box girder bridge deck is about 33 GPa. Table 6 shows the comparison of modulus of elasticity empirical formula based on Euro code and ASHTO LRFD bridge design specification.

TABLE 6: THE COMPARISON OF MODULUS ELASTICITY EMPIRICAL FORMULA BASED ON EUROCODE AND AASHTO LRFD BRIDGE DESIGN SPECIFICATION.

EUROCODE	AASHTO
$E_{cm} = 22[(f_{cm})/10]^{0,3}$ (f_{cm} in MPa)	E_c $0.043\ K_1\ \gamma_c^{1.5}\sqrt{f'_c}$
$f_{cm} = f_{ck}+8$(MPa)	
37,846 Mpa	37,085 Mpa

4.4. Poisson's Ratio

Poisson's ratio is a ratio between the lateral and axial strains of an axially and/or flexurally loaded structural element. The normal method in determining Poisson's ratio is by a static test in which a specimen is subjected to compressive forces and simultaneous measurements of both the longitudinal and lateral strains are made. If the material does not obey the Hooke's law, and the stress strain relationship is curved, then static value of Poisson's ratio will depend on the stress, unless the relationship of lateral strain to longitudinal stress is similar to that of longitudinal strain.

The design and analysis of some types of structures require the knowledge of Poisson's ratio. The ratio of the lateral strain accompanying and an axial strain to the applied axial strain. The sign of train is ignored. We usually interested in applied compression and therefore have axial contraction and lateral extension.

Based on AASHTO, if Poisson's ratio is not determined by physical test, Poisson ratio may assume as 0.2 [3]. It is also similar to Euro code, Poisson's ratio may be taken equal to 0.2[8]. Based on the result obtained, the relationship stress and lateral strain can be seen in Figure 13. From the relationship of stress, vertical and lateral strain (Figures 5 and 6), the Poisson's ratio value is about 0.26.

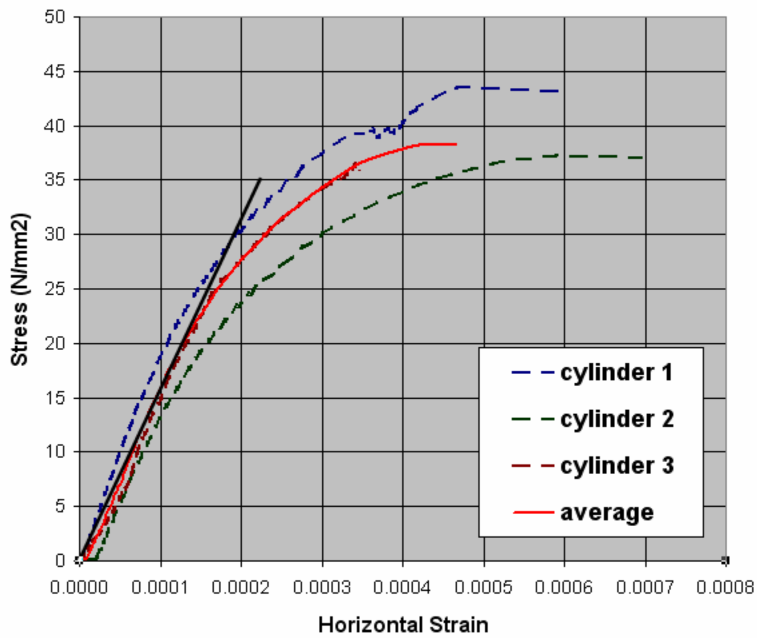

Figure 13. Stress versus horizontal strain

5. Conclusion

The mechanical properties of high strength concrete for box girder bridge deck construction in Malaysia for a period of 28 days have been evaluated and the results are still in the range of previous high-strength concrete properties studies. The following conclusions have been made:

(1) The Normal compressive strength (fcu) used for concrete box girder bridge deck is about 56 N/mm^2.
(2) The Normal flexural strength used for concrete box girder bridge deck is 6.65 N/mm^2.
(3) The Normal static modulus of elasticity used for concrete box girder bridge deck is about 33 GPa.
(4) The Normal Poisson's ratio used for concrete box girder bridge deck is about 0.26.
(5) The stress strain curve relationship has been produced and can be used for nonlinear behavior study for concrete box girder bridge deck using finite element method.

References

[1] Nguyen Van huynh, Pham Vinh Nga, and Thai Hong Chuong. *Research on Making High Strength Concrete Using Silica Colloid Additive*. In *2008 Proceedings of the 3rd ACF International Conference-ACF/VCA 2008*. 2008, Ho Chi Minh city, Vietnam.
[2] Hattory, K, Experiences with Mighty Superplasticizers in Japan, SP-62, 1979, pp37-66.
[3] AASHTO, AASHTO LRFD Bridge Design Specifications. Third Edition, American Association of State Highway and Transportation Officials, Washington, D.C, 2005, pp 5-1 – 5-16.
[4] British Standard Institution, Testing Concrete Part 102: Methods for Determination of Slump. London: (BS1881: Part 102:1983), 1983, pp 1-3.
[5] British Standard Institution, Testing Concrete Part 116: Methods for Determination of Compressive Strength of Concrete Cubes. London: (BS1881: Part 116:1983), 1983, pp 1-3.
[6] British Standard Institution, Testing Concrete Part 118: Methods for Determination of Flexural Strength. London: (BS1881: Part 118:1983), 1983, pp 2-5.

[7] ACI Committee, State of the Art Report on High Strength Concrete, (ACI 363R-92), 1997, pp 5-1 – 5-3.
[8] Euro code 2, Design of Concrete Structures part 1-1. London: (BS EN 1992-1-1:2004), 2004, pp 27-36.