STRENGTH BEHAVIOUR OF HARDENED CONCRETE

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ABSTRACT:- Testing plays an important role in controlling the quality of hardened concrete. Systematic testing of the raw materials, the fresh concrete and the hardened concrete are inseparable part of any quality control programme for concrete which help to achieve higher efficiency of materials used and greater assurance of the performance of the concrete in regard to both strength and durability. The compression tests were carried out on the concrete cylinders drilled out from the dam body constructed in the State of Assam, North Eastern part of India in the year 1990. The stress-strain behaviour was studied and elastic parameters were determined, which were required by the designer for the rehabilitation of the dam for increasing the height of dam for storing more water and also due to modified hydrology of the project. The results and important conclusions drawn are presented in the paper.

INTRODUCTION

The stress-strain behavior is dependent on a number of parameters which include material variables such as aggregate type and testing variables such as age of testing, loading rate, strain gradient and others. Higher strength and corresponding strain are achieved for crushed aggregate from fine-grained diabase and limestone formation as compared to concretes made from smooth river gravel and from crushed granite that contained inclusions of soft mineral.

Many investigations were carried out to obtain the complete stress-strain curves in compression with compressive strengths up 140 MPa. For concrete of higher strength, the shape of the ascending part of the curve becomes more linear and steeper, the strain at maximum stress is slightly higher, and the slope of the descending part becomes steeper. This is true whether the aggregate is normal weight or lightweight.

To obtain the descending part of the stress-strain curve, it is necessary to avoid specimen-testing machine interaction. One approach is to use a closed-loop testing system with a constant rate of axial strain as a feedback signal for closed-loop operation. For very high strength concretes it may be necessary to use the lateral strains as a feedback signal rather than the axial strains. Another successful approach is to test high strength concrete cylinders in parallel with two or more instrumented auxiliary high strength steel tubes as reported by Banthia, N and Sicard, V. (1989),

A comprehensive and simple way of characterizing the stress-strain response of concrete in compression is the fractional equation which has been described clearly in the state-of-the-art report by Zia, P, Leming, M. L. and Ahmad, S. H. (1991).

Since high strength concrete is increasingly being used in members subjected to high compressive stress, the question of its ductility has become an issue of considerable interest. Several studies on high strength concrete with different degrees of lateral confinement have been conducted and the results were used to modify the previously proposed stress-strain models for confined high strength concrete. Due to the effective lateral confinement, the descending part of the stress-strain curve rises, becoming less steep, and the ultimate limiting strain is also increased.

STRESS-STRAIN BEHAVIOUR

Figure 1 shows a typical stress-strain diagram for a concrete specimen loaded and unloaded in compression or tension. The Young's Modulus of Elasticity can strictly be applied only to the straight part of the stress-strain curve, or when no straight portion is present, to the tangent to the curve at the origin. This is the initial tangent modulus, but it is of little practical importance. It is possible to find a tangent modulus at any point on the stress-strain curve, but this modulus applies only to very small changes in load above or below the load at which the tangent modulus is considered.

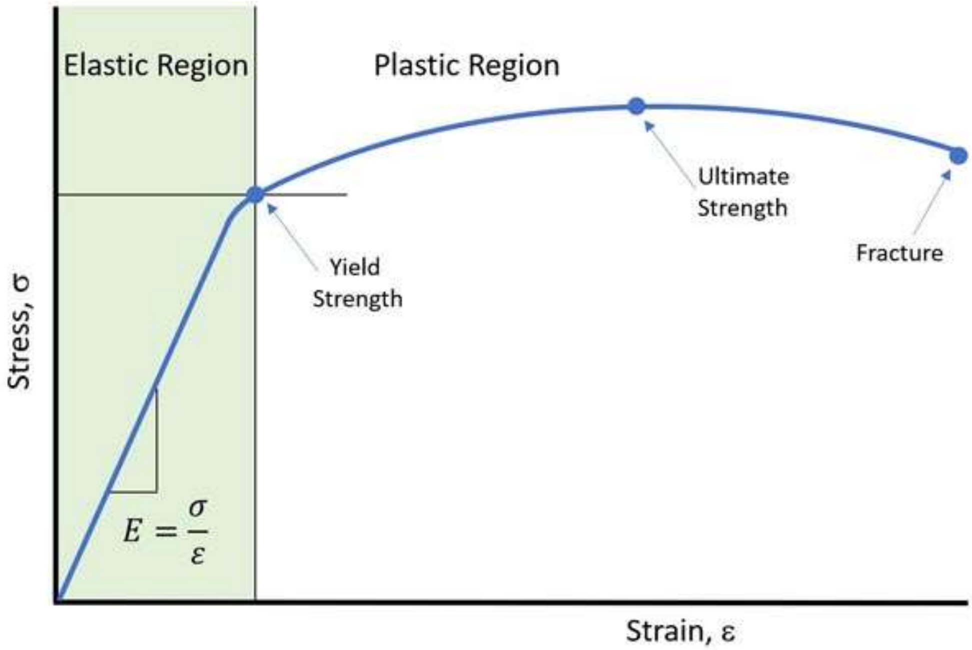

Figure 1 Typical Stress-Strain Curve of Concrete

The magnitude of the observed strains and the curvature of the stress-strain relation depend, at least in part, on the rate of application of stress. When the load is applied extremely rapidly, recorded strains are greatly reduced, and the curvature of the stress-strain curve becomes extremely small. An increase in loading time can increase the strain greatly.

TESTING PROGRAMME

Concrete core samples of about 100 mm diameter and different lengths drilled out from the body of concrete dam by the project authorities from three locations having different grades of concrete were subjected to the following specific tests:

1. Unit weight,
2. Water absorption,
3. Ultrasonic pulse velocity,
4. Elastic modulus,
5. Poisson's ratio, and
6. Crushing strength

The core samples were cut and the ratio of length/diameter ratio were kept fixed as 2. The ends of samples were polished to make it perpendicular to the length. The specimens were stored in water at a temperature of 24^0 to 30^0 C for 48 hours before testing to get saturation. Ten core samples were tested.

The compression testing machine (250 tonnes UTM) were utilized in all respect with the requirements as laid down in IS: 516-1959 (Ninth Reprint – March 1981) and in addition, it has the capability to maintain the load at any desired value. Three cylinders for determining the compressive strength were tested and the average compressive strength was recorded. Immediately on removing the cylinders from the water and while it was still in a wet condition, the strain gauges were pasted on opposite sides and parallel to axis, in such a way that the gauge points are symmetrical about the center of the cylinder and in no case were nearer to either end of the cylinder than a distance equal to half the diameter of the cylinder. The strain gauges were connected with the recording unit using the quarter/half Wheatstone bridge configuration. The cylinders were then placed in the 250 tonnes UTM and accurately centered. The load was applied continuously and without shock at a rate of 14 $N/mm^2/min$. The load and strains were recorded.

RESULT AND DISCUSSIONS

Ten samples were tested in accordance with IS: 13311-1992 [Part 1] and IS: 516 1959 (Ninth Reprint – March 1981) for unit weight, water absorption, pulse velocity, stress-strain behaviour, modulus of elasticity and poisson's ratio of concrete cylinders. The results of unit weight, water absorption, ultrasonic pulse velocity, modulus of elasticity, poisson's ratio and crushing strength of concrete cylinders are given in Table I.

The stress-strain behaviour of two concrete cylinders is shown in Figures 2 and 3.

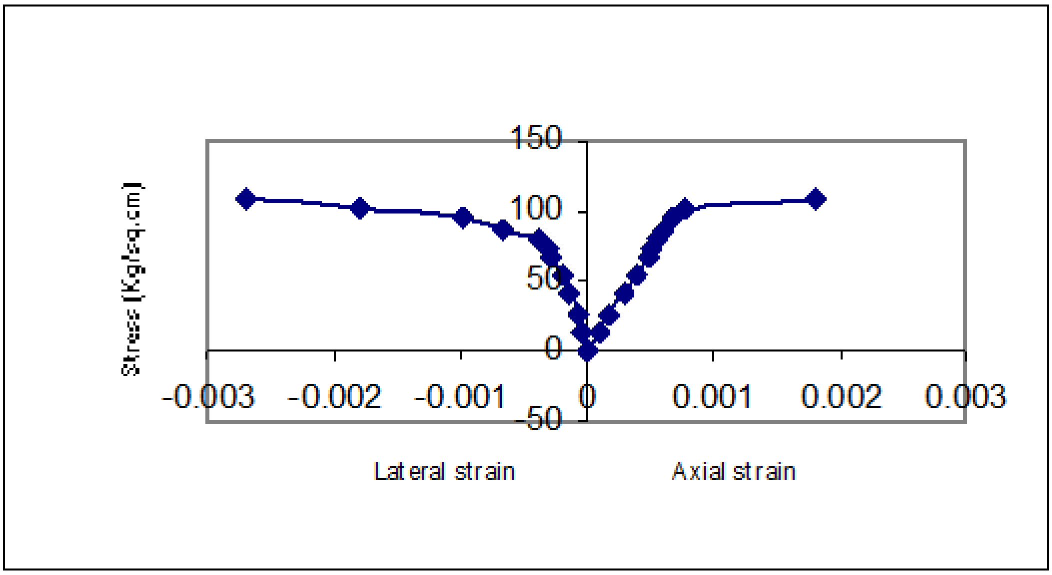

Figure 2 Stress-strain Behaviour of concrete cylinder C2 (4)

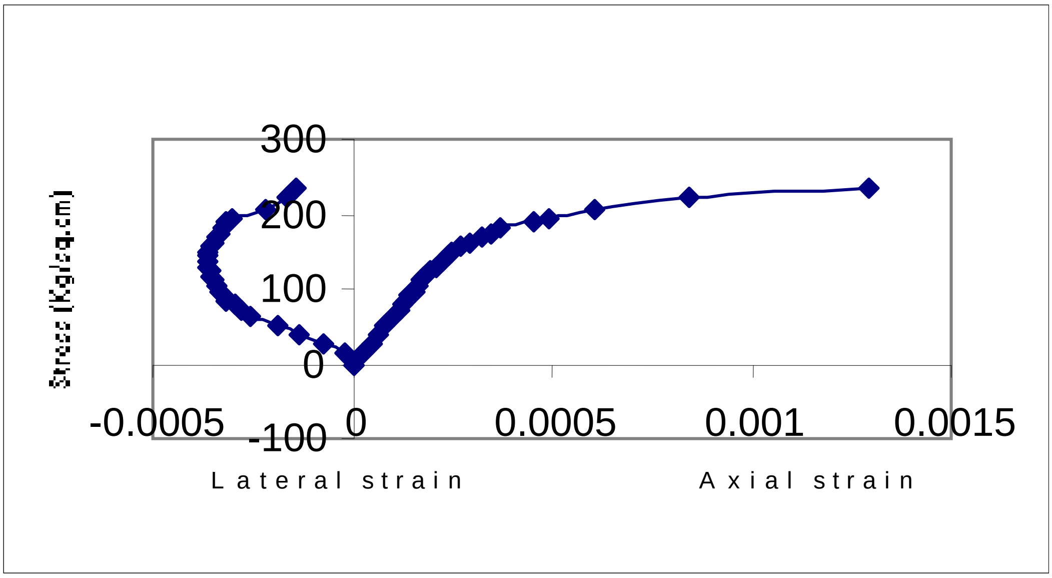

Figure 3 Stress-strain Behaviour of concrete cylinder C2 (5)

Two of the concrete samples [C2(4) and C2(5)] were tested in the stiff testing machine under controlled strain condition and the stress-strain behaviour has been presented in Figure 4. The post failure behaviour of the samples was also monitored and represented in the figure. It clearly shows that the strain at failure has increased more than twice that of samples tested by the conventional machine.

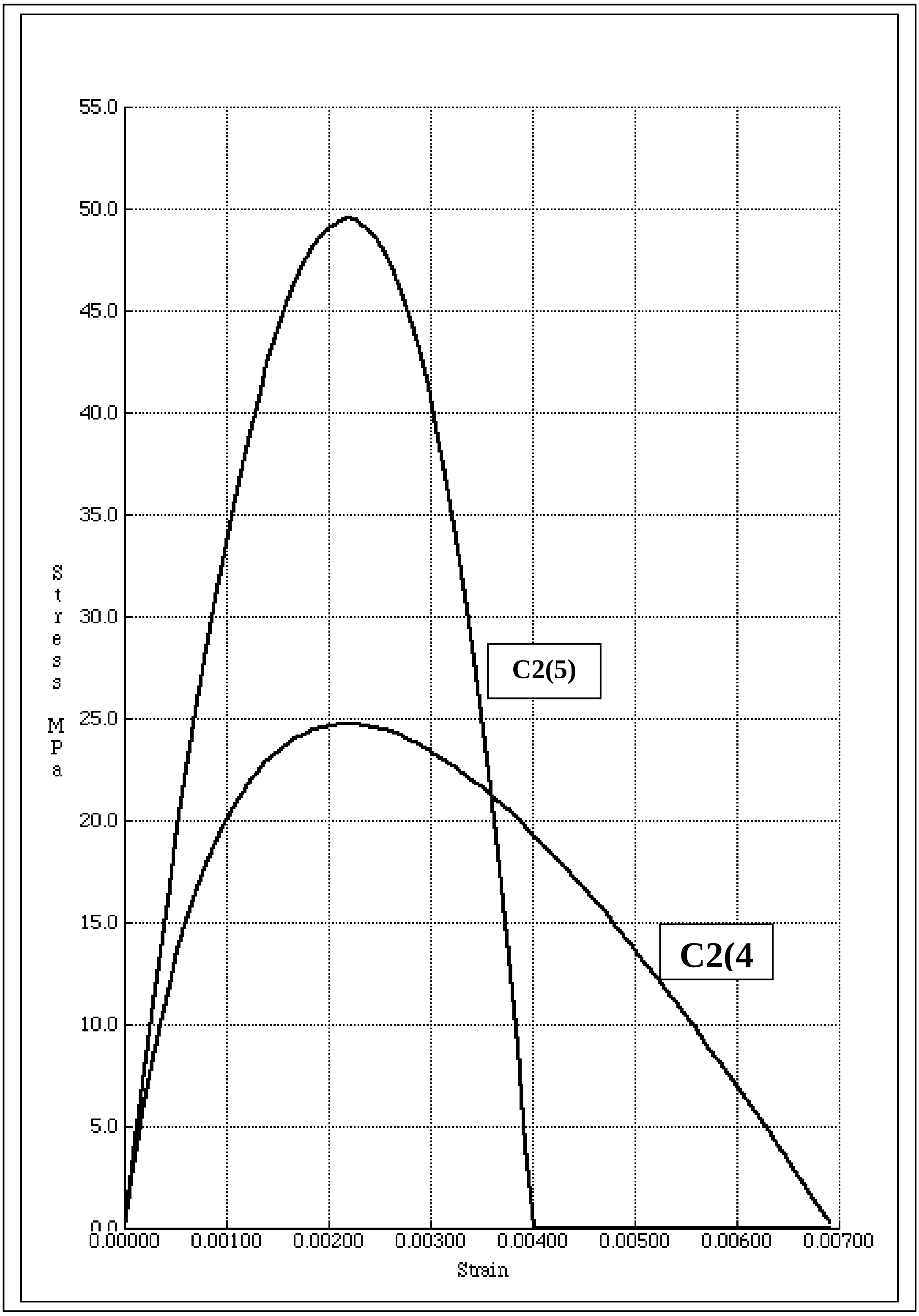

Figure 4 Behaviour of concrete cylinders C2 (4) and C2 (5) under controlled strain condition

Table 1 Test results of tests on concrete cylinders

Sl. No	Lab sample No.	Grade of concrete	Unit Weight gm/cc	Water Absorption %	Ultrasonic Pulse Velocity Km/sec	Elastic Modulus $N/mm^2 x10^5$	Poisson's ratio	Crushing strength of cylinder N/mm^2
1	C2 (1)	$M_{12.5}$	2.225	4.88	4.42	--	--	18.38
2	C2 (3)	$M_{12.5}$			4.52	--	--	15.99
3	C2 (4)	$M_{12.5}$			4.67	0.135	0.40	12.59
4	C2 (5)	$M_{12.5}$			4.83	0.617	0.39	24.69
5	C2 (6)	$M_{12.5}$			4.60	0.174	0.39	21.45
6	C3 (3)	$M_{16.5}$	2.182	4.615	4.53	0.601	0.97*	24.42
7	C3 (4)	$M_{16.5}$			4.74	0.201	0.31	19.89
8	C4 (4)	$M_{16.5}$	1.92	5.481	4.12	0.196	0.16	18.92
9	C4 (5)	$M_{16.5}$			4.43	0.256	0.43	18.84
10	C4 (6)	$M_{16.5}$			4.20	0.131	0.26	18.47

To be rejected due to high value of modulus and poisson's ratio.

As per Para 6.2.3.1 of IS: 456-2000, the approximate value of elastic modulus of concrete cylinder can be estimated by the empirical formula:

$E = 5000\sqrt{f_{ck}}$ Where f_{ck} is the characteristic strength of concrete in N/mm^2 and E in N/mm^2

CONCLUSIONS

The drilled concrete cylindrical specimens received in CSMRS were having small holes, which indicate the honeycombing or poor quality of compaction of concrete during the construction of dam.

The results of ultrasonic pulse velocity values of the cylinders depict that concrete cylinders are of good quality concrete, whereas the unit weight of the concrete cylinders has been found to be low and the water absorption has been found to be high. The results of elastic modulus, poisson's ratio and crushing strength of cylinders are also showing a large variation, which may be due to honeycombing in the concrete cylinders. Generally, the poisson's ratio of concrete shall be around 0.2 to 0.25. The values are found to be high.

There is a sudden change in the behaviour of concrete after crossing the elastic limit, which may be due to stress concentration in the holes due to honeycombing and air bubbles. Due to sudden failure of concrete cylinders, the post failure behaviour could not be recorded. Efforts were made to monitor the post failure behaviour of concrete by stiff testing machine which clearly shows that the stress and strain at failure has increased more than twice that of conventional machine.

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REFERENCES

1. Banthia, N and Sicard, V. (1989), "Effects of Curing Temperature on the Complete Stress-Strain Plots for High Strength Concrete. Fracture of Concrete and Rock: Recent Developments**",** Papers presented at the International Conference, Sep 20-22, 1989, University of Wales, College of Cardiff, School of Engineering; Ed. by S. P. Shah, S. E. Swartz, and B. Barr; Elsevier Applied Science, London, pp. 587-595

2. Dalibor Kocaba, Barbara Kucharczykova A, Petr Misaka, Petr Zitta and Monika Kralikovaa (2016), "Development of the Elastic Modulus of Concrete under Different Curing Conditions", 18th International Conference on Rehabilitation and Reconstruction of Buildings 2016, CRRB

3. Hatanaka, S., Hattori, H., Yoshida, N. and Tanigawa, Y. (1990), "Compressive Deformation Capacity of High Strength Concrete under Low Lateral Confinining Pressure", Transactions of the Japan Concrete Institute, Vol. 12, pp. 151-158

4. Hatanaka, S., Hattori, H., Kondo, Y. and Tanigawa, Y. (1991a), "Stress-Strain Model for Normal and High Strength Concrete under Triaxial Compression", Transactions of the Japan Concrete Institute, Vol. 13, pp. 125-132

5. Hatanaka, S., Hattori, H., Kondo, Y. and Tanigawa, Y. (1991b), "Effective Lateral Stress and Stress-Strain Relation of Laterally Confined High-Strength Concrete", Transactions of the Japan Concrete Institute, Vol 13, pp. 141-148

6. Horia Constantinescua,b, Oana Ghermanb and Camelia Negrutiua (2015). "Mechanical Properties of Hardened High Strength Concrete", 9th International Conference Interdisciplinarity in Engineering, INTER-ENG 2015, 8-9 October 2015

7. IS: 13311-1992 [Part 1], "Indian Standard Non-Destructive Testing of Concrete Methods of Test Part I: Ultrasonic Pulse Velocity", Bureau of Indian Standards, New Delhi, India

8. IS: 516-1959, "Indian Standard Methods of Testing for Strength of Concrete", (Ninth Reprint – March 1981), Bureau of Indian Standards, New Delhi, India

9. Koike, S. and Hatanaka, S. (1991), "Effect of Size and Slenderness Ratio of Specimen on Stress-Strain Behavior of Confined High Strength Concrete", Transactions of the Japan Concrete Institute, Vol. 13, pp. 133-140

10. Muguruma, H., Watanabe, F.and Komuro, T. (1989), "Applicability of High Strength Concrete to Reinforced Concrete Ductile Column", Transactions of the Japan Concrete Institute, Vol. 11, pp. 309-316

11. N. Krishna Murthy, A.V.Narasimha Rao, M.Vijaya Sekhar Reddy and P.Pamesh (2012), "The Influence of Metakaolin on the Modulus of Elasticity of Concrete", IOSR Journal of Engineering (IOSRJEN) e-ISSN: 2250-3021, p-ISSN: 2278-8719, www.iosrjen.org Volume 2, Issue 11 (November 2012), PP 18-23

12. Pintea Augustin*1, Traian Oneţ (2012), "Elastic deformation of concrete, Determination of secant modulus of elasticity in compression", Acta Technica Napocensis: Civil Engineering & Architecture Vol. 55, No. 2

13. Sun, Y. P. and Sakino, K. (1993), "Axial Behavior of Confined High-Strength Concrete", Transactions of the Japan Concrete Institute, Vol. 15, pp. 463-470

14. Tehmina Ayub, Sadaqat Ullah Khan and Fareed Ahmed Memon (2014), "Mechanical Characteristics of Hardened Concrete with Different Mineral Admixtures: A Review", The Scientific World Journal Volume 2014, Article ID 875082, 15 pages

15. Zia, P, Leming, M. L. and Ahmad, S. H. (1991), "High Performance Concretes, A State of the Art Report. Strategic Highway Research Program", National Research Council, Washington, D.C., pp. 251 (SHRP-C/FR-91-103; PB92-130087)