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Experimental Andtheoric Approach to Slanted Concrete Cylinders Subjected to Uniaxial Pressure

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Abstract: In this study, one of the parameters whichinfluence concrete compressive strengthwas investigatedby using 50 standard high strength concrete cylinder specimens. This effect is inclinationat one-end. When concrete filled molds are put on a sloping place, fresh-mixed concrete starts flow and inclination emerges after hardening.It is observed that failure loads are related with inclination. Angled cracks occurred in inclined specimens.Experimental behavior was presented by an exponentialcurve.

Key words: Slanted cylinders ・ Standard cylinder specimen ・ Compression strength ・ Concrete

INTRODUCTION

Standard cylinder specimens, d=150mm and h=300mm, are used world-wide to determine concrete compressive strength by means ofuniaxial compression tests.Concrete must be allowed to harden about twenty-four hours in moldsand cured for 28 days. At the 28th day, specimens are testedin order to determine compression strength. It is the most widely-used mechanical property in projectswhen concrete is the load-bearing material. There are some factors affecting concrete's compressive strength, such as the type of cement,water-to-cement ratio, rate of loading, addition of cementitious materials, aggregate, moisture, temperature conditions during cure, age of concrete and capping. If cylinder specimenstaken from the same concrete mix were exposed to different curing conditions, their strength valueswould become different [1, 2]. Under variable-rated loading, sometimes more than one peak points occur at stress-strain diagrams. High speed loading causes larger compression strength measurements [3]. Capping is another effect on compressive strength [4]. In order to minimalize the variations, specimens must be carefully-treated to testing, such as the same curing conditions andthe same loading rate. But there can be still variations betweenthe strength values of the same-treated specimens. Distribution of aggregates in concrete mix, cavities in matrix or disorder in geometryshould be consideredbesides many influencing factors. In this regard, a type of geometric-disorder is investigated in this study. Mentioned disorder is inclination at one-end of the cylinder.

In practice, properly lubricated cylinder molds are filled in 3 levels with compaction. Fully stuffed molds areput in a suitable place to harden andunraveledafter twenty-four hours [5,6]. Studied problem emerges at this waiting period. When molds are put on a sloping surface, wet concrete starts flow to be parallel where they are placed.Emerge of inclination can be seen in Fig. 1.

At the closed-endof mold, concrete has no inclination. Depending compaction, it has smooth surface.Concrete flows and hardensat the open-end of mold. One half rises and the otherhalf descends. These elliptical surfaceare separated by a line which heighted 300 millimeters from bottom and parallel to the bottom surface. This line is called in this study as "zero inclined line". It isdenoted in figures as "s-s". Maximum and minimum heighted points from bottomcanbe unified by a line. This line must be perpendicular to the zero line as to thegeometry, Fig. 2.

Fig. 1: Emerge of inclination

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Fig. 2: Maximum - minimum heighted points and zero line of cylinder

MATERIALS AND METHODS

Mixing Proportions of Concrete: Many aggregates can be used to produce high-strength concrete, such as the natural sand, granite,limestone, or dolomite. Although higher compression strength is generally achieved by using granite [7], the limestone aggregate was chosen due to the easy-found and common usage in Northern-Black Sea Region, Turkey. Aggregateswere taken from the Macka/Meryemana region. The maximum aggregate size is16 mm. Physical properties of aggregate aregiven in Table 1. CEM I 42,5 portland cement was used. The number 42.5indicatesits characteristic compressive strength in MPa. Properties of this cement is given in Table 2. In addition to these, silica fume and superplasticiser (ASTM C-494 F type) were used in high performance concrete. Chemical properties of silica fume are given in Table 3.Mixing proportions of concretesare given in Table 4.

Inclination Measurements: Cylinders were placed on a horizontal and smooth surface. Zero lines, max.-min. directions and their downwards extensions were determined. Most inclination values were easily-visible and represented real cases. In this study, it is aimed to demonstrate the probable and overlooked circumstances. But extreme inclinations have also been evaluated, to make generalizations on this problem.

Table 1: Physical properties of aggregate

Aggregate size	Loose density (kg/m^3)	Dry density (kg/m^3)	Saturated density (kg/m^3)	Water absorption (%)
Coarse(>4mm)	1445	2706	2720	0,43
Fine(<4mm)	1485	2675	2682	0,50

Table 2: Properties of CEM I 42,5R portland cement

				Mechanical properties	
Physical properties					
Density,(g/cm^3)		3.10	Age (day)	Flexural strength (MPa)	Compressive strength (MPa)
Specific surface (Blaine) cm^2/g		3682	2	5.74	29.02
Setting	Initial (hours)	2.10	7	7.57	43.69
time (vicat)	Final (hours)	4.15	28	8.74	52.92

Table 3: Chemical properties of silica fume

Component	S_iO_2	Fe_2O_3	Al_2O_3	CaO_3	MgO_3	CrO_3	Loss on ignition	Free CaO
(%)	82	1.8	3.2	1.4	5	3	2.2	1.2

Table 4: Mixing proportions of concrete

						Admixtures	
Concrete	W/C	Cement (kg/m^3)	Water (kg/m^3)	Total aggregate (kg/m^3)	Absorbed water (kg/m^3)	SP (kg/m^3)	SF (kg/m^3)
HPC	0.30	500	150	1789	4.2	22	50

HPC: high performance concrete,

SP : superplasticizer admixture, SF: silica fume

RESULTS AND DISCUSSION

Six specimens with minimum inclinationsweretested to obtain mechanical properties. Because of the ease-of-use and common-usage, all of the cylinders werecapped byhaving usedsulphur mortar from both-ends. Tests were carried out for all cylinders when the concrete was 28-days-old. One of these specimens is shown in Fig. 3 with strain-gages. Average stress-strain curves are given in Fig.4 for high strength concrete, Young Modulus (E_c) and Poisson's ratio (í) were determined and given with othermechanical properties in Table 5.

Cylinders weretested to determine failure loads.Loading rate was the same in every specimen as 0,24 MPa/sec.Failure loads at corresponding inclinations are given in Fig. 5.

To observe strain variation through sections,six strain gageswereplacedonan anotherspecimen. It is shown on Fig. 6. Zero-line had horizontal strain gage. By counter-clockwise with 15°, A(s)-A(s) cross section, anotherhorizontal gagewasplaced. Maximum-minimum section has two longitudinal strain gages. And finally, counter-clockwise 15° with maximum-minimum section, two strain gages wereplaced longitudinally. It can be noticed that, A(max)-A(min) cross section is also perpendicular to A(s)-A(s).This specimen has 0,476° of inclination and high performance concrete.

Circumferential strains at different two sections, s-s and A(s)-A(s),are given in Fig.7. Strain valuesdecreasefar from zero line. Through downward direction of minimum heighted point, the least circumferential strain values areobtained at corresponding loads.

Fig.8 presents longitudinal strains of cylinder in specifiedsections. At the vertical line of maximum heighted point, more shortening is achieved. It is seen that underthe maximum heighted point, greater strain values are achieved compared to the 15° placedsection. But these variationsare not greater thanthe ones of the circumferential strains.

Strain variations of three specimens with different inclinations are given in Figs.9, 10,11,12 and 13.

Strain capability decreases for bigger inclination values. This situation also can be seen in Fig.10for longitudinal strain values under minimum heighted point.

Circumferential strain variations aregiven in Figs. 11, 12 and 13. For an inclined cylinder, biggestcircumferentialstrains are achieved in the downwards direction of300 mm heighted, zero line.

Due to the non-uniformlydistributed stresses, concrete cylinders were not able to bear greater loads as much as lesser-inclined ones. Concrete reaches its maximum strain at lower loads.Some crack patterns can be seen in Fig. 14.

There are many influences onconcrete compression strength, such as the specimen sizes, specimen shapes and placement directions [8-10]. When inclination occurs, both-ends of cylinder are no-more the same. However, the volume of cylinder isstillthe same. Inclined surface becomesellipse. Bottom surfaceremains circular.

In this study it is maintained that there is a relation between inclination and failure load based on test data.This relationcan beexpressed best by anexponential line. If these values arelinearly connected, the line intersects with the vertical axis at 5.35 degrees for high

Fig. 3: Strain-gage placements

Table 5: Mechanical properties of concrete

Concrete	Number of specimens	Average compressive strength (Mpa)	Standard Deviation (Mpa)	Coefficient of variation	Modulus of elasticity (GPa)	Poisson's Ratio
HPC	50	69.49	14.16	0.21	32.2	0.237

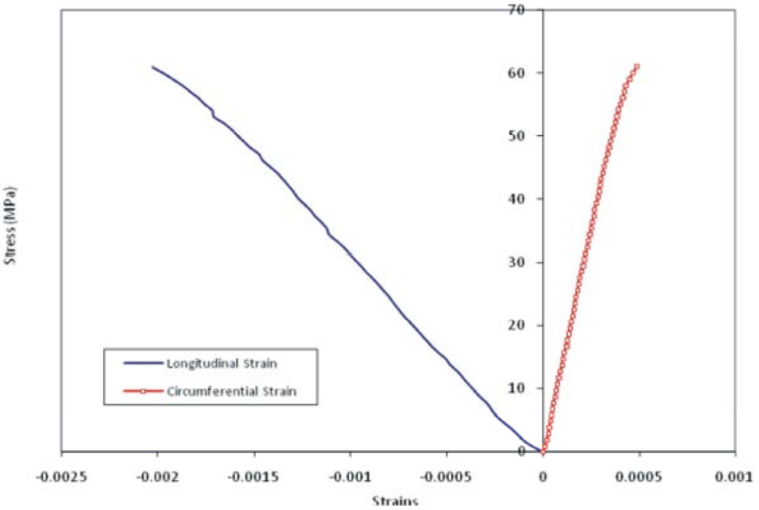


Fig. 4: Average stress-strain behavior of high performance concrete

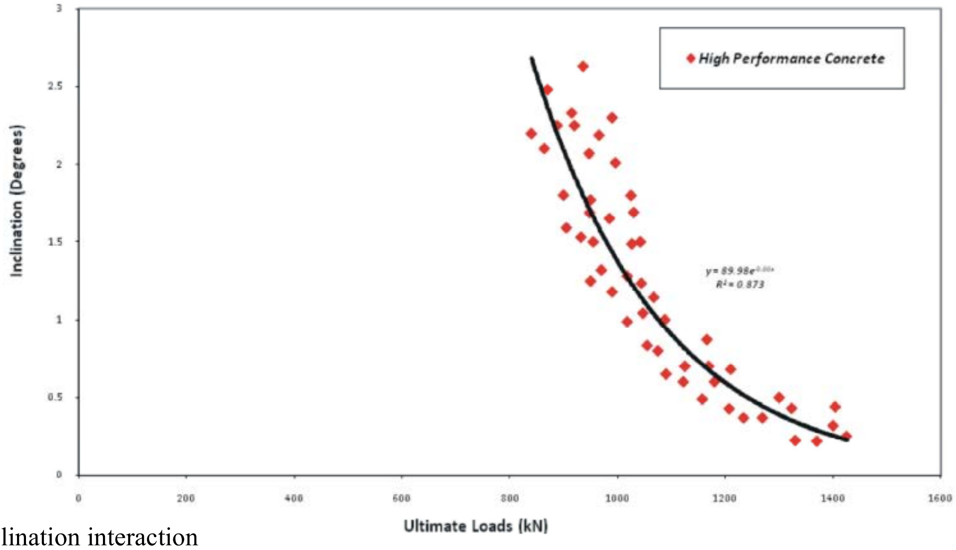


Fig. 5: Load-inclination interaction

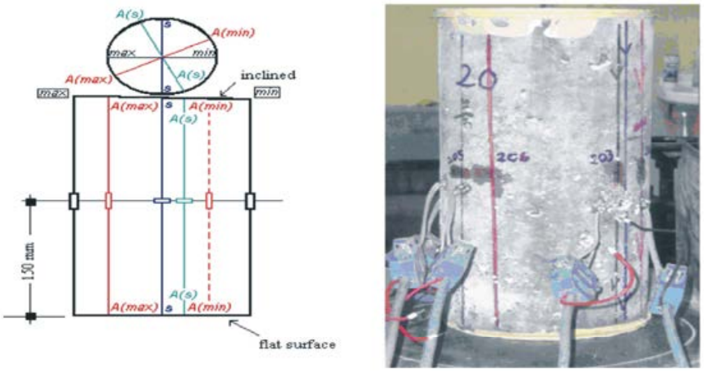


Fig. 6: View of strain-gage placements on a cylinder

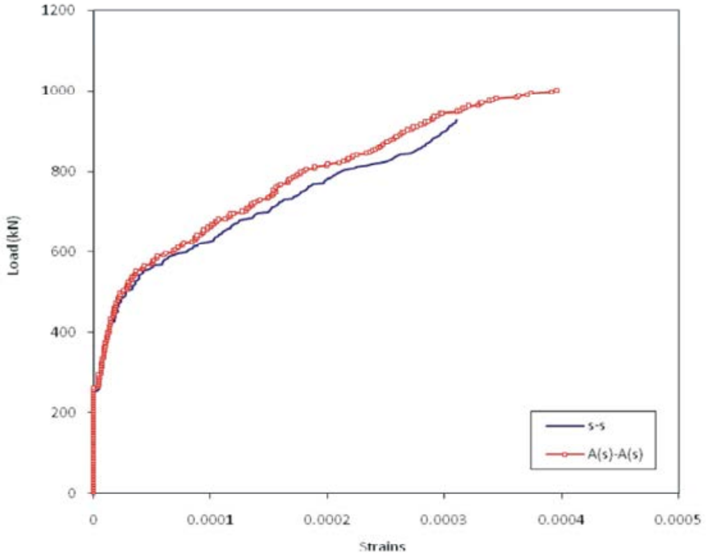


Fig. 7: Circumferential strains of cylinder

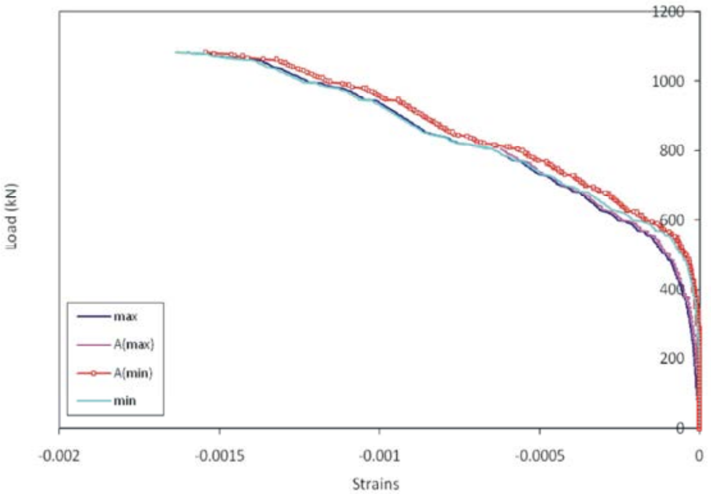


Fig. 8: Unit shortening (longitudinal strain) of cylinder

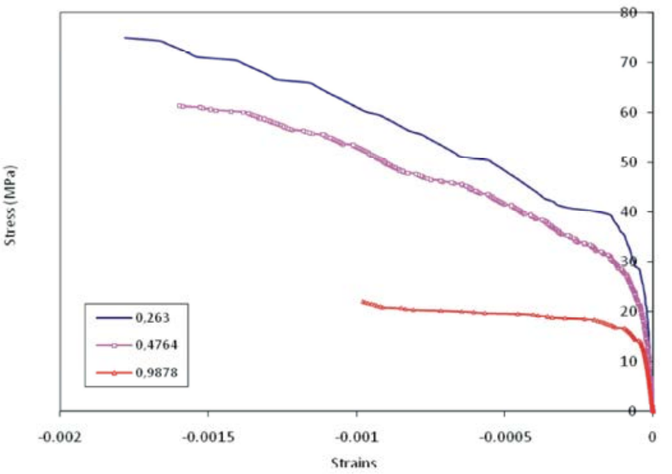


Fig. 9: Longitudinal strains under maximum heighted point

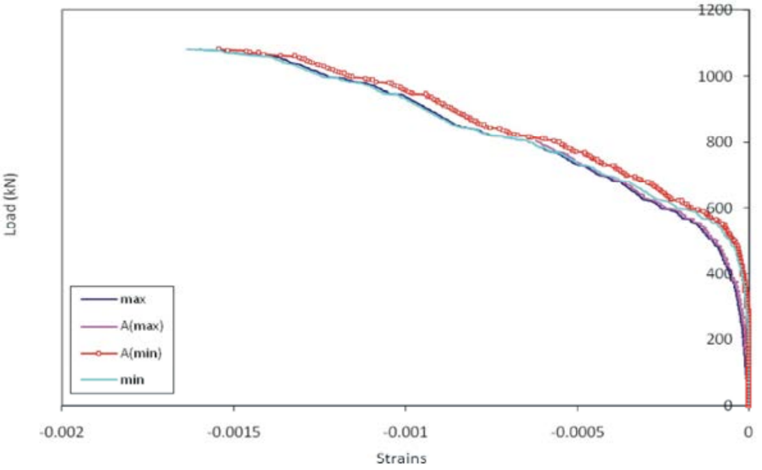


Fig. 10: Longitudinal strains under minimum heighted point

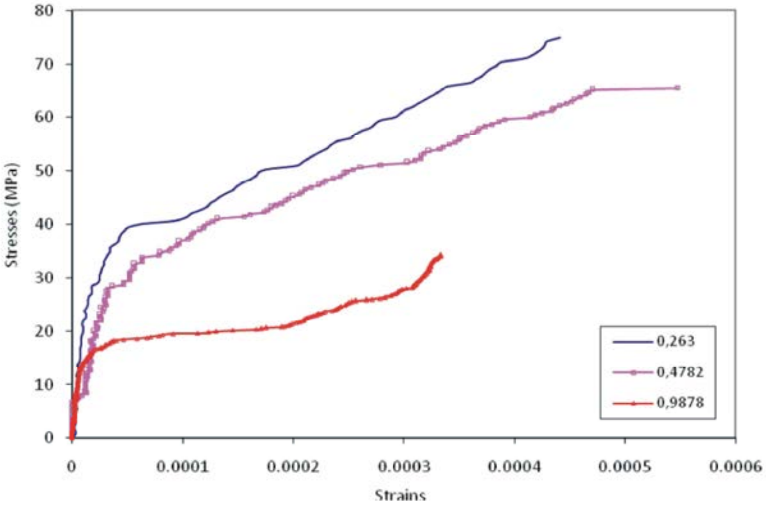


Fig. 11: Circumferential strains under maximum heighted point

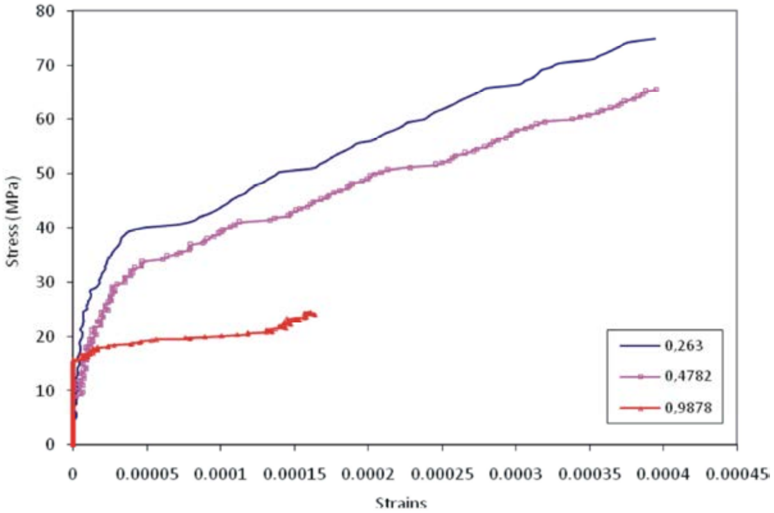


Fig. 12: Circumferential strain under minimum heighted point

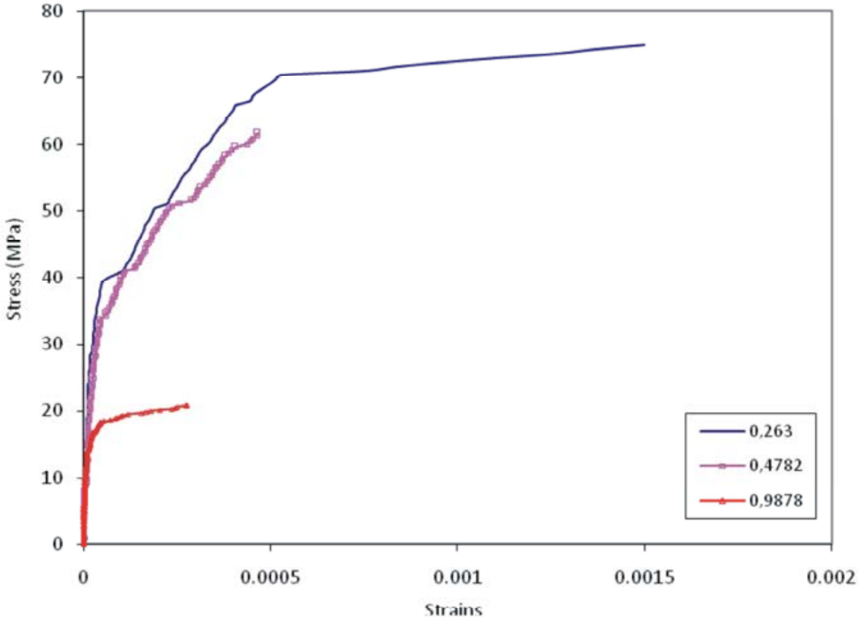
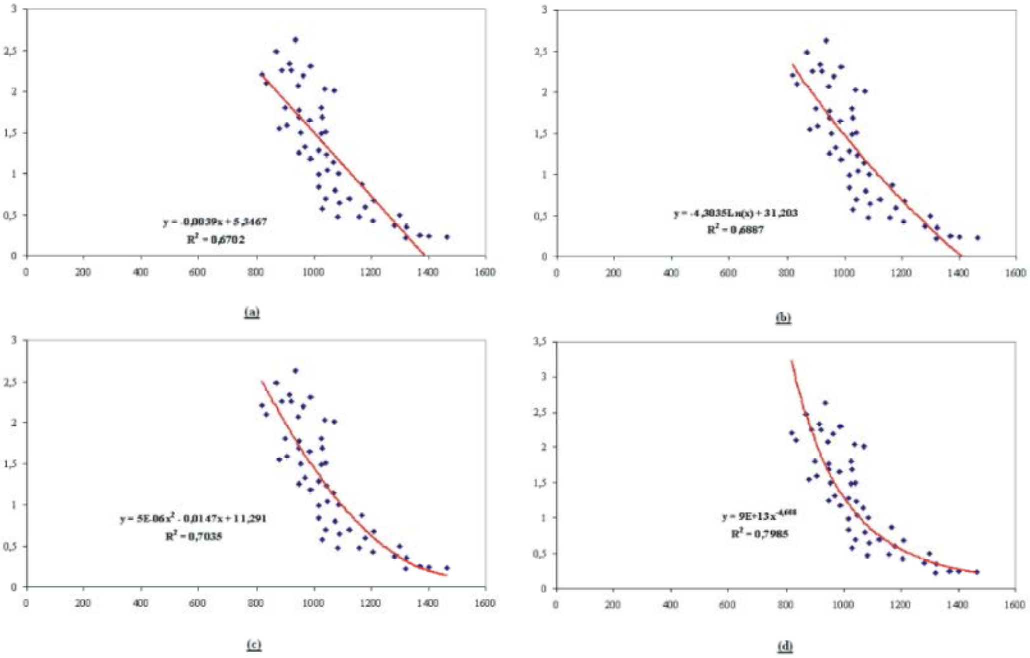


Fig. 13: Circumferential strains under 300 mm heighted line

Fig. 14: Crack patterns of some specimens

performance concrete, which represents maximum inclination. This meansthat zero-strength matches a cylindrical shape, which has maximum height of 307.2 mm and minimum height of 292.8 mm. A specimen with these geometric properties must have load-bearing capacity. Similar problems emerge when polynomial or logarithmic relations are used, Fig 15.

Exponential function is the most appropriate solution. Because, the inclination of cylinder, expressed as α, is limited to 90 degrees. When inclination is step by step increased to 90°, infinite long strip with an infinitesimal thickness emerges. This theoric body has zero strength.At very near 90°, like 89,99°, specimen must have extremely- long height, very small thickness and nearly



(a) (b) (c) (d)

Fig. 15: Relating Failure Load to Inclination by Different Ways

zero load-bearing capacity. Average-relation between inclination and failure load is shown in Fig. 6 for high performance concrete as $y=89.980e^{-0.0042x}$. On the other hand, by the failure load point-of-view, line cannot intersect directly with any point in horizontal axis. Because, every cylinder has some amount of inclination whether too small or big.

CONCLUSIONS

Conclusions obtained from this study are given below.

There is no a perfect-shaped cylinder, namely, every concrete cylinder has some amount of inclination. Inclination values must be kept minimal in order to prevent variations in compression strength.In an inclined cylinder, very different compressive strength measurements could be obtained for the same concrete mix. There are also variations in Poisson's Ratio and Young Modulus.

When concrete cylinder specimens are tested under uniaxial load, similar strain distributions occur. And similar relation could be build by this way for lower concrete quailtiesby using the relation presented in this study. Curve would be still tangent to vertical axis at a point according to units. General form of relation is $\alpha=\alpha_{max}e^{-cf}$, where "c" denotes material coefficient ; "f" is failure load and α_{max} is maximum inclination. When unit is degree for inclination, α_{max} equals to 90. If inclination is represented in radians, α_{max} becomes $\pi/2$ and the relation becomes $\alpha=(\pi/2)e^{-cf}$.

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