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A treatise on irregular shaped concrete test specimens

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Abstract. An experimental program has been carried out to investigate the effect of edge-slope on compressive strength of concrete specimens. In this study, effect of such slope was investigated by testing 100 standard cylinder specimens and 40 standard cubes. When molds are put on a slanted place, wet concrete starts to flow through the open end of mold. It keeps flowing until it reaches to a parallel surface with the place over which it was placed. That creates a sloped surface over the loading area. Experimental results revealed significant relationships between failure loads and slope of loading surface for cylinders. Angled cracks occurred in sloped cylinder specimens. Tension cracks occurred in cube specimens. Fracture mechanisms were also evaluated by using finite element analyses approach. Experiments yielded an exponential curve with bandwidth for cylinders. Average value of curve is $y = \frac{\pi}{2} e^{-cf}$ between slope and compressive strength. Inclination is much effective parameter for cylinders than cubes.

Keywords: concrete; high strength concrete; compressive strength; slope; cylinder specimen

1. Introduction

World-wide used cylindrical concrete compressive strength specimens have a standard diameter of 150 mm and height of 300 mm, a=150 mm for cubes. These specimens are used in uniaxial compression tests. Concrete specimen is kept inside the mold for 24 hours and then cured for 28 days. Compression tests are carried out at 28th day with uniaxial loading tests. Since concrete is a load bearing material in constructions, compressive strength is the most significant parameter in design processes. There are several factors effecting compressive strength of concrete. Some of these factors are type of cement, shape of specimen, water to cement ratio, loading rate, type of aggregate, moisture, curing, age of concrete, existence of a loading cap and etc (Del Viso *et al.* 2008, Nikbin *et al.* 2014, Papadakis and Demis 2013 and Van der Vurst *et al.* 2014). Cylindrical specimens taken from the same concrete mixture may yield different strengths under different curing conditions (Zhutovsky *et al.* 2013, Patil *et al.* 2014 and Husem and Gozutok 2005). Such differences are also observed under different loading conditions. More than one peak point may exist under different loading rates. Higher loading rates may yield higher strengths (Cotsovos and

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Pavlović 2008). Compressive strength measurements are effected by pre-test capping of concrete specimens (Gesoglu *et al.* 2002). Aggregate size in concrete is also effective on compressive strength (Sim *et al.* 2013, Meddah *et al.* 2013). Varying results may be observed even all specimens are treated at the same fashion (Muthukumar and Kumar 2014). Aggregate distribution, age of concrete, fragmentation, pores or unnoticed geometric irregularities can cause such differences (Momber 2000, Wang and Yan 2013, Rao and Prasad 2011). In present study, a geometrical irregularity – slope formation at an end – was investigated and effect of such slope on compressive strength and fracture mechanism was evaluated. Although it was recommended in several specifications (ACI 318-95 1995, Eurocode 2 2004, TS-EN 12390-3 2002, TS-EN 12390-4 2002, ASTM C-39 2014) that slope formation should be limited, there are not any studies on slope formation and potential impacts of such slopes over concrete cylinder specimens.

In practice, greased cylinder molds are filled with concrete at three steps by compaction. Cube samples are filled with two steps. Full molds are placed for 24 hours to harden the concrete then taken out of the mold for curing (TS-EN 12350-1 2002, TS-EN 12390-3 2002). The slope formation case occurs during the initial 24 hours of molding. If there is an inclination over the surface where the molds are placed, fresh concrete flows through by viscosity until it reaches to equilibrium with the bottom surface of the place. That creates a sloped surface over the top of the specimen from which the axial loading is applied. Formation of such slope is presented in Fig. 1 for cylinders and cubes, respectively.

Slope is almost linear at very low sloping angles and one half of upper circular surface is inclining while the opposite half is declining. These two semi-circles can be separated by a plane passing through right at the middle of 300 mm height cylinder. Boundary of such plane at the sloped-upper surface was called zero-line and indicated with “s” in present study. This line has a zero slope and parallel to bottom surface. Beside this, maximum and minimum “points” from the bottom of the cylinder are located at two ends of the cylinder. They are perpendicular to geometric zero line. Geometrical definition of slope considered in this study is presented in Fig. 2. The angle of max-min line from the horizontal plane is considered as the angle of slope. For cubes, detailed inclination mechanism is also presented in Fig. 2.

Fig. 1 Slope formation

Fig. 2 Geometrical definition of slope for cylinders and cubes

Table 1 Aggregate physical characteristics

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

Table 2 Cement characteristics

Physical Characteristics			Mechanical Characteristics		
Density (g/cm^3)		3.10	Age (day)	Bending Strength (MPa)	Compressive Strength (MPa)
(Blaine) cm^2/g		3682	2	5.74	29.02
Time(vicat)	Start (hour)	2.10	7	7.57	43.69
	End (hour)	4.15	28	8.74	52.92

Table 3 Chemical characteristics of silica fume

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

Table 4 Concrete mixture calculations

Concrete	W/C	Cement (kg/m^3)	Water (kg/m^3)	Total aggregate (kg/m^3)	Absorbed water (kg/m^3)	Admixtures SP (kg/m^3)	Admixtures SF (kg/m^3)
HSC	0.30	500	150	1789	4.2	22	50
OC	0.50	350	175	1828.5	4.2	35	-

HSC: high performance concrete OC : ordinary concrete
SP : superplasticizer admixture SF: silica fume

2. Experimental study

2.1 Sample preperation

Cylinder and cube molds was filled, placed randomly over an unlevel surface. After 24 hours specimens were un-molded and cured for 28 days. Samples were taken out of the curing pool and capped for testing from both ends. Tested slopes were very low but visibly noticeable. An unnoticed case was tried to be investigated in this study. Therefore, the specimens with high top slopes were not tested. Since concrete spills over the mold, cause a volume loss at high slopes. It is also hard to test high slope specimens with standard test devices since such devices are fixed at one point and have a limited rotation capacity. However, high slope specimens were also analyzed in this study by using finite element analysis approach and member behavior was evaluated for such cases. Cylinders' and cubes' zero lines, maximum - minimum heights and their projections over cylindrical surface were determined.

2.2 Concrete mixture

Many aggregates can be used to produce high-strength concrete, such as the natural sand, granite, limestone, or dolomite (Beushausen and Dittmer 2015, Teng *et al.* 2014). Calcareous aggregate was used as concrete aggregate. Maximum aggregate diameter is 16 mm and physical characteristics are presented in Table 1. CEM I 42.5 R Portland cement was used as the cement material of the study. Characteristic compressive strength is 42.5 MPa and cement characteristics are presented in Table 2. Silica fume and super plasticiser were also used in concrete mixture. Chemical characteristics of silica fume are presented in Table 3 and concrete mixture calculations are presented in Table 4.

3. Results

3.1 Experimental results

Six cylindrical specimens with the lowest slopes were tested by axial loading to determine the mechanical characteristics of concrete. Sulphur capping was applied to both ends of specimens. Tests were carried out at 28th day of curing. An average stress-strain curve for high-strength and ordinary concrete is presented in Figs. 3 and 4. Concrete mechanical characteristics (initial modulus of elasticity, Poisson ratio, etc.) are given in Table 5.

Measurements made over cylinders with three different slopes are presented in Figs. 5 and 6. Strain capacity of specimens was inversely related to increasing slopes. Results indicated that lower Young Modulus values could be calculated over a sloped-cylinder.

Table 5 Concrete mechanical characteristics

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
OC	50	27.35	1.74	0.063	21.5	0.250

HPC: High performance concrete
OC: Ordinary concrete

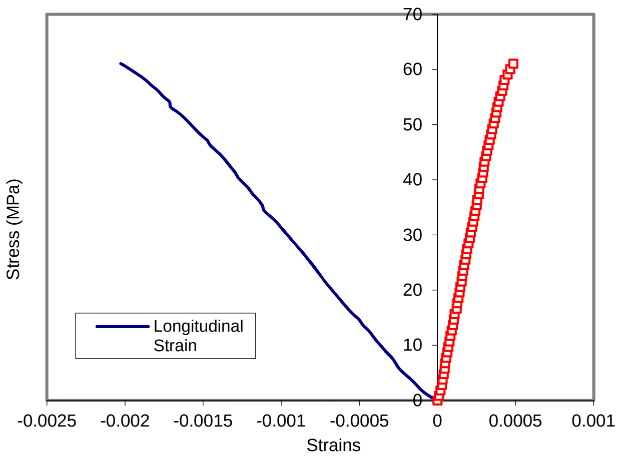

Fig. 3 Stress-strain curve for high-strength concrete

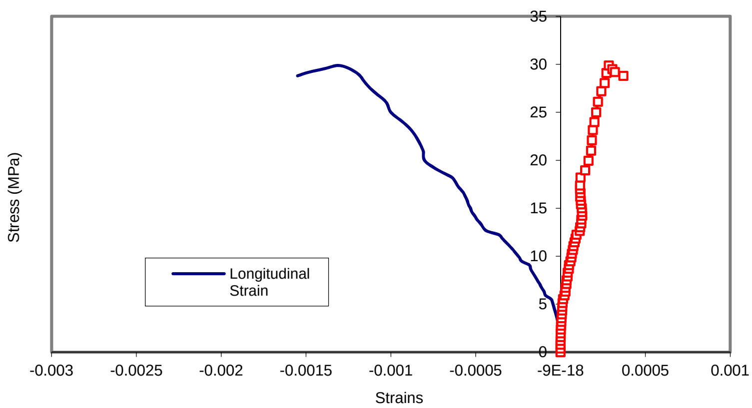

Fig. 4 Stress-strain curve for ordinary concrete

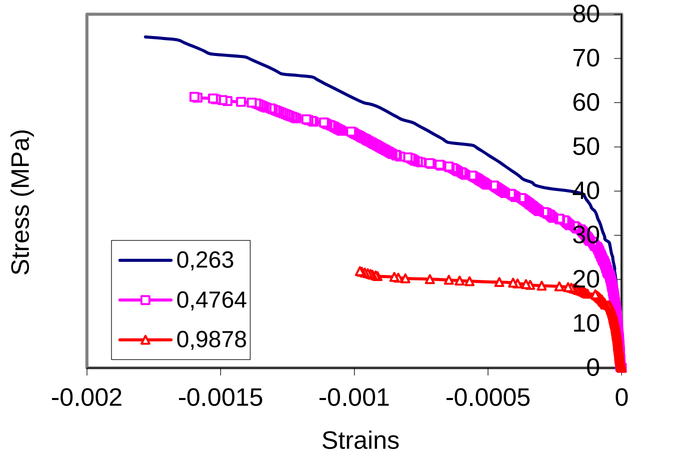

Fig. 5 Unit strains at vertical projection of maximum height point (Görkem 2012)

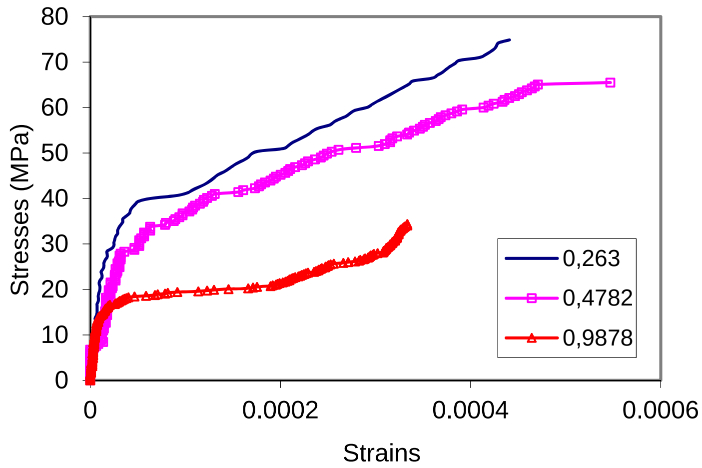

Fig. 6 Horizontal strains at vertical projection of maximum height point (Görkem 2012)

3.2 Finite element analyses and crack patterns

Finite element analysis was performed by using ANSYS software. Cylinders were modeled by SOLID 187 members with 10 points each. Typical finite element meshes used in this study are presented in Fig. 7.

Material properties, which used as program inputs, were taken from mechanical tests results (i.e. Poisson's ratio, Young Modulus of Concrete, failure loads and test specimen geometry). Failure loads were converted than applied as uniform pressure over the sloped surface. Bottom of the cylinder was modeled as fully restrained. While experiments allow measurement at limited locations, finite element analysis yields unit strains all around the cylinder. Linear analyses were performed to observe/validate strain distribution at failure.

Distribution of unit strains over cylinders in Figs. 5 and 6 are presented in Fig. 8. Distribution gets complicated and over-loaded regions enlarge with increasing slopes. In addition to other cracking modes (Murray *et al.* 2007), in this case, under increasing slopes, the highest unit strain was reached at lower loads. Just to make comparisons, experimental fracture mechanisms of concrete cylinders are presented in Fig. 9.

A cube specimen with 1.212 degrees slope is tested and analyzed by finite element method. Analysis result and crack pattern were given in Figs. 10 and 11. Inclination changes the loading areas. Therefore one face of cube is exposed to tension. Opposite face is exposed to compression. Fracture patters which given in Fig. 11 endorse finite element analyses in Fig. 10.

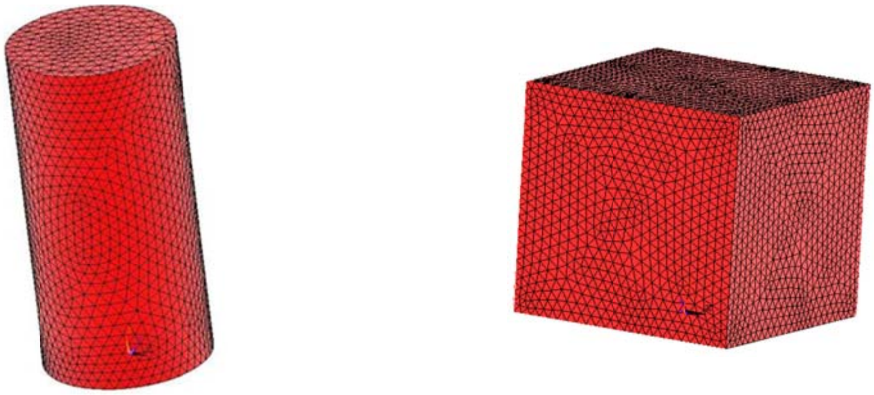

Fig. 7 Finite element meshes

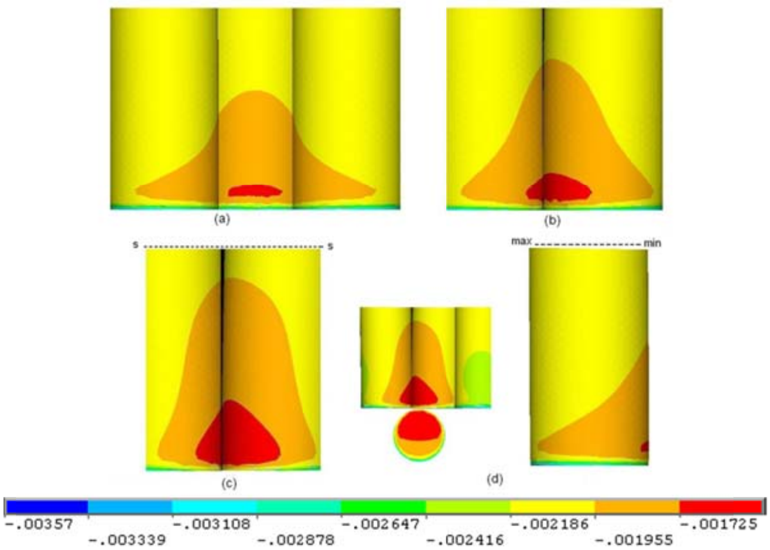

Fig. 8 Unit strain distributions at S-S sections of high-strength concrete cylinders with slope angles of (a)0.263° (b) 0.4782° (c) 0.9878° (d) at Max-Min section of 0.9878°

Fig. 9 Fracture patterns of cylinder specimens (Görkem 2012, Zandi and Görkem 2013)

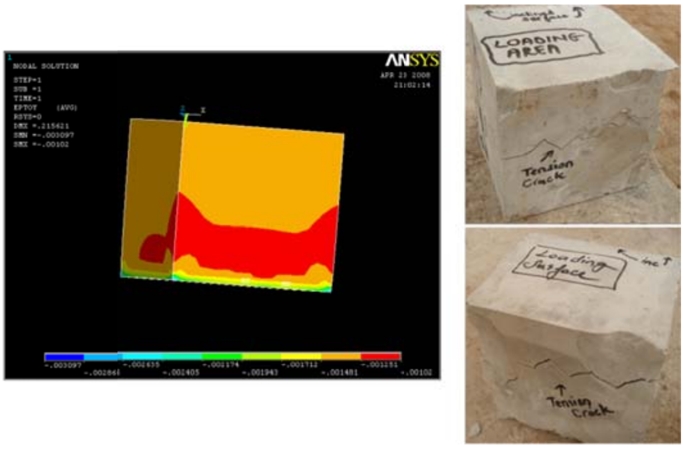

Fig. 10 Unit strain distribution of a sloped cube specimen

Fig. 11 Fracture patterns of cube specimens

4. Discussion

In present study, an empirical relationship was proposed between fracture loads and slopes. This relationship for high-strength concrete and ordinary concrete used in this study was presented in Fig. 12 for cylinder specimens and Fig. 13 for cube specimens as follows;

If slope is increased step by step while keeping the volume constant, slope "α" can be maximized at 90°. In this case, the testing object will look like a stripe with an infinite length and infinitely small thickness (Fig. 12(b)). Such stripe will have fixed ends and loaded with distributed load along the length perpendicular to its axis. Resultant load that can be beared by this concrete stripe should be zero. Additionally, it is obvious that a cylinder with perfect geometry cannot be created with current technology. Therefore, it was assumed that an amount of slope will definitely exist over the top surface of every concrete cylinder. That's why slope can not be equal to zero. In other words, this curve can not intersect horizontal axis (also it is a mathematical rule for exponential function). Due to distribution of fracture loads, this behavior curve must have a band-width (Figs. 12(a) and 12(c)). The steeper is the curve; the narrower is the band width. Similarly, lower slopes will yield greater distribution. These characteristics are expressed best with exponential function.

R^2 values found from test results for ordinary and high strength concrete cylinders are 0,8491 and 0,873, respectively. These correlation values are too low for cube specimens, varies between 0,0015 to 0,0377 (Fig. 13). It is clearly seen that inclination is much effective on cylinders rather than cubes. There is a possibility for cubes that a cube may not be loaded on its inclined surface. When a cube has sloped surface, it can be basically turned into another surface for loading. That's why inclination has nearly no effect (Fig. 13) on cube's compressive strength. It only changes loading area and affects cracking mechanism.

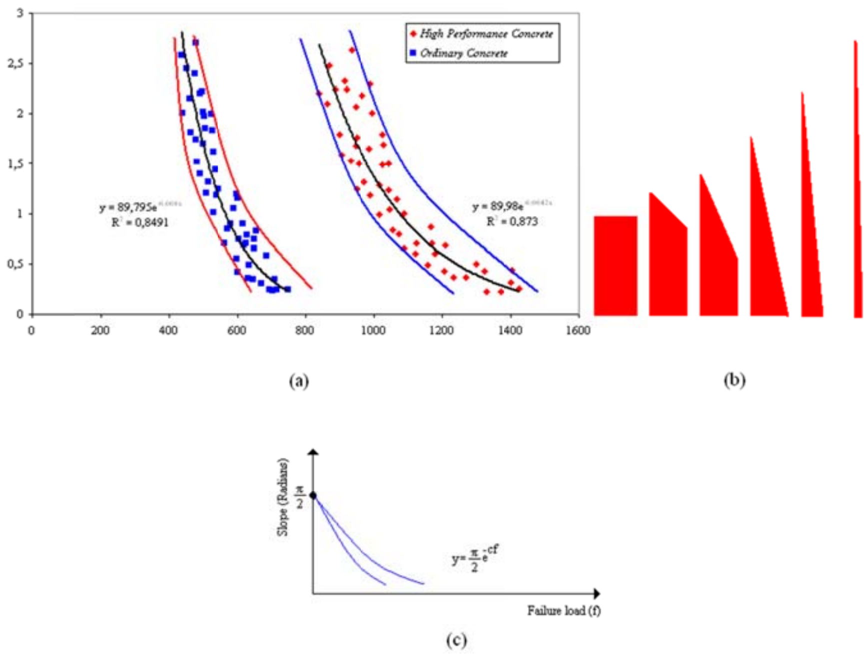

Fig. 12 Slope-fracture load relationship for cylinder specimens

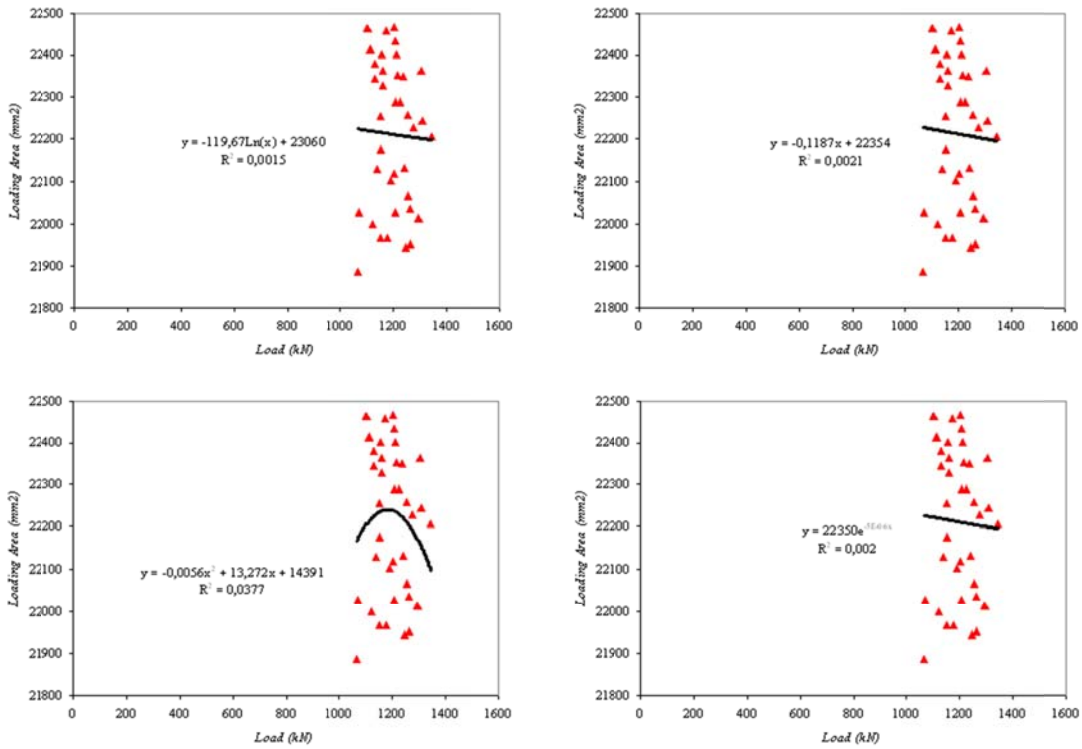

Fig. 13 Slope – Fracture load relationship for cube specimens

5. Conclusions

There are some specifications (ACI 318-95 1995, Eurocode 2 2004, TS-EN 12390-3 2002, TS-EN 12390-4 2002, ASTM C-39 2014) recommends that “slopes must be kept in minimum or not allowed in cylinders test specimens”. But the reason is not mentioned. In this study “what is the behaviour of a sloped cylinder under uniaxial pressure?”question was tried to be answered. Test results and recommended behaviour curve can be useful not only for concrete but also some other materials i.e. rock test cores. There would be the same loading conditions (uniaxial loading) and the same geometrical properties (standard cylinder). Only different thing is the material type. This affects that “is that a leaning curve or a steeper curve?” Behavior curve must intersect the vertical axis at $\pi / 2$ and can not intersect horizontal axis. $\pi / 2$ is the limit of slope (Fig. 12(b)) and perfect cylinder cannot be created by using current technology. These characteristics expressed best with exponential function. Additionally this curve must have a bandwidth because of variation of failure loads.

In cube specimens no obvious effect is observed by compressive strength point of view. Slope affects cracking mechanism by changing cube’s loading areas. Therefore one face of cube is exposed to tension. Opposite face is exposed to compression.

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