STRENGTH

- Natural aggregates are generally dense and strong. Therefore, it is the porosity of the hardened cement paste matrix and as well as the transition zones between the matrix and coarse aggregate which usually determines the strength characteristics of normal weight concrete.

Definition

- In concrete, strength is related to the stress required to cause fracture and is synonymous (same thing) with the degree of failure at which the applied stress reaches its maximum values. 形態で定義するのが非常に難しい。

Significance

- In concrete design and quality control, strength is a property generally specified,
- Also, testing of strength is relatively easy.
- Many properties of concrete are directly related to strength. (Sometimes, not.)
- A majority of concrete element are designed to take advantage of the higher compressive strength.

Strength- porosity relationship

- There exists a fundamental inverse relations between porosity and strength of solids
- S=So*exp(-kp)
- The strength porosity relationship is applicable to a very wide range of materials such as irons, stainless steels, etc.

Failure modes in concrete

- In compression, the failure mode is less brittle than in tension, because considerably more energy is needed to form and to extend cracks in the matrix.
- It is generally agreed that in a uni-axial compression test on medium- or low strength concrete, no cracks are initiated in the matrix up to about 50(-60)% of the failure stress.

- At higher stress levels, cracks are initiated within the matrix; their number and size increases progressively with increasing stress levels
- The cracks in the matrix and transition zone eventually join up, and generally a failure surface develops at about 20-30 degree (depend on the strength and the stiffness of loading machine) from the direction of the load.

1/27

- 余ったコンクリートはどうするのか？
- 普通は、生コンクリート工場内の処理槽（水槽）に廃棄して、最近は骨材とスラッジ（水和物の混ざった溶液）として一部再利用している。これも費用がいる。
- 現場で固めてから処理する場合もある。

Compressive strength and factors affecting it

- From the standpoint of strength, ***the water-cement ratio -porosity relation*** is undoubtedly the most important factor, however direct determination is not practical. And very complex.
- To simplify an understanding of these factors, they are discussed separately under three categories
- (1)characteristics and proportions of materials
- (2)curing conditions, (3)testing parameters

(1)Characteristics and proportions of materials

- It should be noted that in practice many mix design parameters are independent, therefore, their influences cannot really be separated.
- water cement ratio
- Abram's water/cement ratio rule $fc = K1/K2^{(w/c)}$
- The water/cement: weakening of the matrix caused by increasing porosity with increase in the water/cement ratio.

- This explanation does not consider the influences on ITZ.
- in low and medium strength concrete the influence of w/c on ITZ is same.
- Lower than 0.3, the strength increase is mainly on the improvement of ITZ.
- 骨材が問題ない場合

Air entrainment

- At a given w/c, high strength concrete suffers a considerable strength loss with increasing amounts of entrained air, whereas low strength concrete suffer only a little, or may actually gain.
- On the other hand, by improving workability and compactibility of the mixture entrained air tends to improve the strength of the transition zone, especially in mixtures with low water and cement content .
- 高強度では有害、低強度(ITZ改良説)では有利

Cement type

- OPC, high early strength, low heat, etc blended cement (portland blast-furnace slag cement).
- Strength bands shown in fig.3-5 were developed by Portland Cement Association (USA). (OPC.vs.HPC, Non air.vs. Air enrained)

Aggregates

- An overemphasis on the relationship between w/c ratio and strength has caused some problems.
- However, aggregate characteristics other than strength, such as the size, shape, surface texture, grading, and mineralogy which are known to affect concrete strength in varying degrees.

- From theoretical considerations, they would influence the characteristics of the ITZ and therefore affect concrete strength
- Maximum aggregate size: larger then w/c less, however, ITZ is worse
- Aggregate grading: influence bleeding and ITZ
- Rough textured: stronger however consistency worse. Longer age the strength will be closer.
- Mineralogical composition: the substitution of calcareous for siliceous aggregate resulted in substantial improvement in strength .

Mixing water

- Impurities in water, efflorescence (deposits of salts) , corrosion.
- should be fit for drinking
- the best way to determine the suitability of a water of unknown performance for making concrete is to compare the setting time of cement and the strength of mortar
- seawater: not harmful to the strength but risk of corrosion of steel.
- Sugar

Admixtures

- adverse effect of air entraining admixtures
- water-reducing ads has a positive influence on the rate of hydration and early strength development
- The presence of mineral ads usually retards the rate of strength gain
- The ability of mineral ads to react with calcium hydroxide and to form additional CSH can lead to significant reduction in porosity of both hcp and ITZ, improvement in ultimate strength and impermeability
- especially effective in tensile strength

(2) Curing conditions

- The term curing of concrete stands for ***procedures devoted to promote cement hydration***, consisting of control of time, temperature, and humidity condition
- At a given w/c ratio, the porosity of a hydrated cement is determined by the degree of cement hydration.

- The hydration reactions slow down considerably when the products of hydration coat the anhydrous cement grains, it almost stops vapor pressures of waters in capillaries falls ***below 80% RH***.
- Time and humidity are therefore important factors in the hydration processes controlled by water diffusion.
- Temperature has an accelerating effect .

Time

- The time-strength relations in concrete assume moist curing conditions and normal temperature.
- There are several equations .(3-4,3-5)

- Humidity:

- The influence is obvious from the data Fig.3-9.
- After 180 days, the strength of the continuously moist-cured concrete was 3 times greater than the strength of the continuously air-cured concrete.
- A minimum period of 7days(JSCE 5 days) of moist curing is generally recommended for concrete containing normal portland cement.
- For blended portland cement or a mineral ads, a longer period would be desirable because of pozzolanic reaction.

Temperature

- For moist cured concrete, the influence of temperature on strength depends on the time-dependent history of casting and curing.
- It is generally observed that up to 28days, the higher the temperature, the more rapid is the cement hydration and the strength gain resulting from it
- As explained before, the higher in the casting and curing, the lower will be the ultimate strength
- Since the curing temperature is far more important to strength than the placement temperature, ordinary concrete placed in cold weather must be maintained above a certain minimum temperature for a sufficient of time.

(3) Testing parameters

- It is not always appreciated that the results of concrete strength tests are significantly affected by parameters involving test specimens and loading conditions.

Specimen parameters

- The larger the diameter the lower will be the strength.
- The specimen with the height/diameter ratio of 1 showed about 15% higher strength.
- In compression test : the air dried specimens show 20 to 25% higher strength than corresponding specimens tested in a saturated conditions. Probably due to the existence of disjoining pressure within the cement paste.

Loading conditions

- ASTM, JSCE, the load is progressively increased to fail the specimen within 2 to 3 min.
- In practice, most structural elements are subjected to a dead load for an indefinite period and at times to repeated loads or to impact loads.

Behavior of concrete under uniaxial compression 以下略

- only a summary is presented here
- a linear-elastic behavior up to about 30% of the ultimate strength
- under short-term loading the micro-cracks in the transition zone remain undisturbed
- the curve shows a gradual increase in curvature up to 0.75 to 0.9. (this value is changeable.)
- then it bends sharply descends until the specimen is fractured.

- It seemed that ,for a stress between 0.3 to 0.5,the micro-cracks in the ITZ show some extension due to stress concentration at crack tips.
- no cracking occurs in mortar matrix, until this point crack propagation is assumed to be stable
- between 0.5to0.75: the crack system tends to be unstable as the ITZ cracks begin to grow again: the system becomes unstable
- the stress level about 0.75: termed critical stress:critical stress also corresponds to the maximum value of volumetric strain, resulting in a volumetric expansion

- above the critical stress level: under sustained stress conditions, crack bridging between the ITZ and the matrix would lead to failure at a stress that is lower than the short-term loading strength
- in regard to the effect of loading rate, the more rapid, the higher the observed strength value
- within the range of customary testing, the effect of rate of loading is not large.

- the impact strength of concrete increases greatly
- repeated or cyclic loading has an adverse effect at stress levels greater than 0.5.
- progressive microcracking in ITZ and matrix are responsible for this phenomenon.
- fig.3-16 shows that the s-s curve for monotonic loading serves as an envelope for the peak values of stresses for concrete under cyclic loading.

Behavior of concrete under uni-axial tension

- as the uniaxial tension state of stress tends to arrest cracks much less frequently than the compressive state.
- The interval of stable crack propagation is expected to be short, explaining relatively brittle fracture behavior of concrete in tension.

Testing methods for tensile strength

- direct tension tests are seldom carried out.
- splitting tension test/third point flexural loading test
- splitting test: the compressive load produces a transverse tensile stress
- compares to direct tension, overestimste 10 - 15%
- relationship between the compressive and tensile strength
- JSCE ft=0.23 fc*exp(2/3)
- no direct proportionality

- the higher the compressive strength the lower the ratio, the ratio decreases with the curing age
- the tensile strength of concrete with a low porosity ITZ will continue to be weak as long as large numbers of oriented crystals of calcium hydroxide are present there.

Behavior of concrete under various stress states

- Even before any load has been applied, a large number of micro-cracks exist especially in the transition zone.
- This characteristic of the structure of concrete plays a decisive role in determining the behavior of the material under various stress states. If necessary, you should study more details, beyond this course.