Proportioning concrete mixes

Commonly referred to as mix design

Introduction

- Mix design is a process that consists of two interrelated steps: narrow meaning
- ***Wider: performance of members and concrete should be considered***
- (1) selection of the suitable ingredients (cement, aggregate, water and admixtures) of concrete
- (2) determining their relative quantities (proportioning) to produce, as economically as possible, concrete of the appropriate workability, strength and durability

Cont.

- These proportions will depend on the particular ingredients used.
- Other criteria, such as designing to minimize shrinkage or for special chemical chemical environment, may also be considered.
- Although a considerable amount of work has been done on the theoretical aspects of mix design, it still remains largely an empirical procedure. (So, you can develop your own.)

Cont.

- Although many concrete properties are important, most design procedures are based on achieving a specified compressive strength at some given workability and age.
- 従来は、圧縮強度と施工性のみ
- It is assumed that if it is done, the other properties will also be satisfactory. Except perhaps resistance to freeze and thaw or other durability problems, such as chemical attack, ASR, thermal cracks, etc.

Basic considerations

- It is worthwhile to examine the basic design considerations.
- **Economy:**
- The cost of concrete is made up of the costs of materials, labor and equipment. The costs of labor and equipment are largely independent of the type and quality of concrete.人件費と装置費は変らない （Over 50MPa, a little difference. One more storage tank for better admixture.)
- Therefore, the material costs are most important in determining the relative cost of different mix designs.

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- Since cement is more expensive than aggregate, cement is the most important factor in reducing concrete costs. 単位セメント量をできるだけ少なくする。
- This can be done by using lowest slump that will permit adequate placement, by using the largest practical maximum size of aggregate, by using the optimum ratio of coarse to fine aggregates, and by using appropriate admixtures. 単位水量も少なくなる。

Cont.

- It should be noted that there are other benefits to use a low cement content; shrinkage will in general be reduced and there will be less heat of hydration.
- The economy should also be related to the degree of quality control that can be expected on a job.
- On small jobs it may be cheaper to “ over design” the concrete than to implement a quality control with a more cost efficient concrete. How do you think about?
- 面倒なので、品質のよいもの（高めの強度）で統一（価格は安いものに統一）

Workability

- A good mix must be capable of being placed and compacted with the equipment available.
- 施工条件(機材を含めて)による
- Finish-ability must be adequate and segregation and bleeding should be minimized.
- Also, the concrete should be supplied at the minimum workability that will permit adequate placement.

Cont.

- For concretes without mineral admixtures, the water requirement for workability depends mostly ***on the characteristics of the aggregate*** rather than those of cement.
- Where necessary, workability should be improved by redesigning the mix ***to increase the mortar content*** rather than by adding water or more fine minerals.

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- A deaf ear should be turned to the frequent pleas from any job site for more water.
- However, prudent planning is needed to ensure that concrete with the required workability is delivered.

Strength and Durability

- In general, concrete specifications will require a minimum compressive strength.
- They may also impose limitations on the permissible w/c ratios and minimum cement content.
- These requirement are not mutually incompatible (mutual compatibility is possible).
- Specifications also require certain durability requirement, freeze and thaw, ASR, chloride attack, carbonation or chemical attacks.

Cont.

- These considerations may provide further limitations on the w/c ratio or cement content or the use of admixtures.
- These requirements cannot all be optimized simultaneously.
- Some ***compromises*** (as between strength and workability それと費用、高級な混和材料の使用など) will be necessary.
- It must be noted that even ‘prefect’ mix will not perform properly unless the ***proper placing, finishing, and curing procedures*** are carried out.

2. Fundamentals of mix design

- There has been 2 aspects of mix design in which most of the theoretical work has been done.
- "***Water content*** and ***Aggregate grading***"
- Most of the modern empirical design methods depend heavily on these two considerations.
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Water cement ratio

- In 1918, D.Abrams developed his water cement ratio law:
- For given materials, the strength depends only on "For given materials, the strength depends only one factor – the ratio of water to cement."

$$\sigma_c = \frac{A}{B^{1.5(w/c)}}$$

Cont.

- Usually, A is taken to be 96.5 MPa,
- B depends on the cement properties, but may be taken to be about 4.
- This observation, that strength is inversely proportional to the w/c ratio, (Then c/w) remains the basis for most mix design procedures.
- The w/c ratio determines (roughly) the porosity of the cement paste.
- It also, largely control the durability.

Cont.

- 普通はw/cが小さいほどいろんなものが良い。
- 特に、硬化コンクリートで、
- 例外：アルカリ骨材反応などの反応

Aggregate grading

- Grading of granular materials to produce dense packing is of broad industrial interest.
- An ideal curve is given by $Pt=(d/D)^{1/2}$
- (Fuller curve)
- Pt: fraction of total solids finer than d
- D: maximum particle size
- The Fuller curve is a special case of a more general equation developed by Anderson.
- $Pt=(d/D)^q$ $0<q<1$

The lowest practical value is about 1/2

- The reason is that minimizing void content , to give more economical concrete that has a minimum cement, results in concrete with poor workability.
- In terms of packing, the gradations used in ASTM C33 can only approximate the Fuller curve as shown in Fig.10.1.

Cont.

- The grading limits for fine and coarse aggregate shown in Figure10.1 are based on practical experience rather than on theory.
- It is possible to make a satisfactory concrete from ***almost any type of aggregate grading***, although gradations outside the limits of Figure10.1 may be uneconomical and difficult to handle with regard to segregation, consolidation and finishing.

ACI method of mix design
(I expect You may know JSCE method.)

- There are a number of methods. Although they are not directly comparable, they do give approximately the same relative proportions of materials and all are capable of yielding suitable concrete mixes.
- ***It must be remembered that any mix design method will provide only a first approximation of proportions.***
- These must be checked by trial batches in the laboratory or in the field and then adjusted.

Introduction of mix design process

- The mix design process consists of
- (1) determining the job parameters – aggregate properties, maximum aggregate size, slump, w/c ratio and admixtures
- (2) calculating the batch weights
- (3) adjusting to the batch weights based on a trial mix made according these calculations

Mix design procedures
(1). Required information

- Information is required on both the materials to be used and the structure into which the concrete will be placed.
- Raw material propertied: sieve analysis, unit weight of coarse aggregate, bulk specific gravities, absorption capacities,
- Structure: type and dimensions of the members, the minimum spaces between steel bars, required concrete strength, the exposure conditions,

(2). Choice of slump

- Slump will be specified for a particular job, to take into account the anticipated methods of handling and placing the concrete.
- However, where slump has not been specified, appropriate values can be chosen form Table10.1.
- It is becoming increasingly common to design a concrete for a lower slump and then increase it to higher value using a water-reducing admixtures.

(3). Maximum aggregate size

- Generally, the largest maximum size of aggregate available should be used, as this will minimize the required cement paste.
- The limitations are as follows:
- A. For reinforced concrete, the maximum size may or not exceed one-fifth of the minimum dimension between forms, three-fourths of the minimum clear spacing between bars, strands, or between the steel and the formwork.

Cont.

- B: For slabs, the maximum size may not exceed one-third the slab depth.
- At a given w/c ratio, higher strength can be achieved with smaller maximum sizes.
- ***Thus there is a trend toward the use of reduced maximum aggregate sizes, especially for high strength concrete.***

(4).Estimation of mixing water and air content

- The workability of concrete is dependent primarily on the paste content of the concrete; the amount of entrained air, and the maximum size, grading, and particle shape of of the aggregate.
- An estimate of the water requirement to produce different slumps for ***both air-entrained and non-air-entrained concrete can be obtained from Table10.2***.

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- When water-reducing admixtures are used, these values (water contents) should be decreased according to the amount of water reduction anticipated.

(5) Water/cement or water/cementitious material ratio

- The selection of the appropriate w/c or w/cm ratio may be governed not only by strength but also by durability requirement.

- A: In the absence of strength vs w/c ratio data, a conservative estimate can be made for the expected 28-day compressive strength from Table10.3, when type Ⅰ portland cement is used.

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- The designer must develop data for other cases, or when the design is governed by a flexural strength requirement.
- It is always more desirable to develop the appropriate strength-time-w/cm ratio for the materials that are actually to be used on the job.
- In this way, the effects of admixtures can also be determined.

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b: durability

- If there are severe exposure conditions, such as freezing and thawing or exposure to sea water or sulfates, the more severe w/c ratio requirement ratio requirements of Table10.4 may govern.
- Other standards may have somewhat different requirement.
- Air contents for severe conditions

(6) Calculation of cement or cementitious material content

- Once the water content and w/c ratio are determined, the amount of cement (+ mineral admixture) is determined simply by dividing the estimated water requirement by the w/c ratio.
- Many specifications, in addition, require a minimum cement content.
- When a portion of the cement is replaced by a mineral admixture, the replacement can be made based on mass (weight) (or volume).

(7) Estimation coarse aggregate content
- ***different from JSCE method*** -

- It has been found empirically that aggregates having the ***same maximum size and grading will yield workable mixes in concrete in volumes*** (***on a dry-roded basis***) ***shown in Table10.8***.
- For the same workability, ***the volume of coarse aggregate depends only on its maximum size and on the fineness modulus of the fine aggregate***.

(8) Estimation of fine aggregate content - different from JSCE -

- We can establish fine aggregate content in 2 ways:
- A. "Mass" ("weight") method: I pass. B may be better.
- This requires a knowledge of the weight (per m3) of the fresh concrete. Table10.9 may be used as a first estimation.
- An exact calculation of the weight can be obtained as follows.
- (10.6) may be wrong. The unit (or dimension) of each term is strange.
- I guess (Um=0.01Ga(100-A)+Cm+Wm)
- Please check by yourself.

Cont.

- Um: weight of fresh concrete
- Ga: weighted average bulk specific gravity (SSD) of combined fine and coarse aggregate.
- Cm: Cement content
- Wm: water content
- If the first estimate of the fresh concrete is not very good, an iterative procedure may be required to obtain Ga.

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- The weight of fine aggregate is then the difference between the total weight of the fresh concrete and the weight of the other gradient.

- My impression is to get reasonable Ga is very difficult and it requires much experimental works.

B: volume method

(I prefer this method. Same as that of JSCE)

- It is a somewhat more exact procedure.
- The volumes of the cementitious material, water, air and coarse aggregate are subtracted from the total volume; the difference is the volume of fine aggregate.
- Then the volume is multiplied by the density of the fine aggregate.
- About air content, an iterative procedure may be necessary.

(9) Adjustment for moisture in the aggregates

- If the aggregates are air dry, they will absorb some water.
- These effects must be estimated and the batch weights adjusted to take them into account.
- The adjustment will leave the actual mix proportion unchanged on a SSD basis.

(10) Trial batch (mix)
- Different from that of JSCE -

- The next step is to prepare a trial batch using these estimates, using only as much water as is needed to reach the desired slump. Even if it causes the permissible w/c ratio to be exceeded (much difference from JSCE).
- The concrete should be tested for slump, unit weight, and air content, as well as observed for segregation tendencies and finishing characteristics

Cont.

- 28-day compressive strength should also be determined.
- Adjustments can now be made in the batch proportions for those requirements that were not satisfied by the original estimates, as follows:

A: for any deviation in slump

- A new water content can be estimated. (6kg/m3 vs 25mm in slump)
- If the correct slump is obtained at a lower content, it is permissible to reduce the cement content to reach the design w/c.
- If the water content must be increased, then c will also be increased. In this case, additional cement must be added until the designed w/c is again achieved (or the entire mix redesigned).

B: if the desired amount of entrained air is not achieved,

- The amount of air entraining admixture should be re-estimated.
- The mixing water required should then be increased or decreased by 3 kg/m3 for each decrease or increase of 1% air entrainment, because of the influence of entrained air on workability.

- C: omitted.

D: any adjustment

- New batch weights must then be calculated, following the foregoing procedure from step 5 on.

- Then you should check “ Example mix design” and check the difference against JSCE method.

Example of mix design

- For an exterior column to be located above ground level
- It will be wet and subjected to freezing and thawing.
- 30 MPa
- Slump: 75 - 100mm
- A minimum clear space for aggregate: 50mm

The properties of materials

- Cement: Type 1, specific gravity 3.15
- Fine aggregate: Bulk specific gravity (SSD) 2.63, absorption capacity 1.3%, surface moisture 4.2% based on SSD, fineness modulus 2.70,
- Coarse aggregate: Maximum size 19mm, bulk specific gravity 2.68, absorption capacity 1.0%, surface moisture 0.5% based on SSD, dry rodded unit weight 1600kg/m3

Step1

- Required material information.
- This is already given.
- Within the limit specified in ASTM.

Step 2

- Choice of slump
- Also given
- 75-100 mm

Step 3

- Maximum aggregate size.

- 19mm
- It meets the limitation of one fifth (1/5) of the minimum dimension between forms and three fourths (3/4) of the minimum clear space.

Step 4

- Estimation of mixing water and air content

- Freezing and thawing condition
- It must be air entrained.
- From table 10.2, 6.0%
- The water requirement is 180kg/m3.

Step 5 - water cement ratio

- From table 10.3, the conservative estimate of the required w/c ratio to give 30MPa is 0.45.

- This does not exceed the limit based on durability (table 10.4 or 10.5).

Step 6 – calculation of cement content

- 180/0.45 = 400 kg/m3

Step 7 – estimation of coarse aggregate content (**different from JSCE**)

- Interpolating in table 10.8 for the fineness modulus of fine aggregate of 2.70, the volume of dry rodded coarse aggregate per unit volume of concrete is 0.63. therefore, the coarse aggregate (OD rodded) will occupy 0.63m3/m3.
- The OD weight of coarse aggregate is 0.63x1600=1008kg/m3.
- The SSD weight is 1008x1.01=1018kg/m3

Step 8 – estimation of fine aggregate content

- By the absolute volume method (b)
- We can calculate the volumes per m3 occupied by the different ingredients (same as JSCE).

- 1-0.747=0.253
- 0.253x2.63 (SSD) x1000= 665kg/m3

Step 9 – adjustment for moisture in the aggregate

- Since the aggregates will be neither SSD nor OD in the field, it is necessary to adjust the aggregate weights for the amount of water contained in the aggregate.

Step 10 – Trial batch

- A trial batch is now made using the proportions calculated.
- The properties of the trial mix must be compared with the desired or expected properties, and the mix design must be corrected.
- Details are roughly shown in the copy.