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RECOMMENDED PRACTICE FOR EXPENSIVE CONCRETE

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SYNOPSIS

The Committee on Concrete of the Japan Society of Civil Engineers published "Recommended Practice for Expansive Concrete (Draft)" as Publication No.45 of the Society's Concrete Library in 1979.With these Providing momentum, expansive concrete have come to be widely used for civil structures.

In recent year, much progress has been made in applying technologies of expansive concrete, and new higher levels of performance have been required. It was under such circumstances that in 1989 the Committee on Concrete of the Japan Society of Civil Engineers was requested by the Association of Expansive Admixture to revised the Recommended Practice for Expansive Concrete (Draft).

The Committee on Concrete, on accepting the request, established a Subcommittee for High Quality Concrete -Expansive Concrete Working Group in December 1989 and commenced investigations and studies in relation to this subject.

The Subcommittee carried out various tests and studies to ascertain the practical natures of these expansive concrete, and using the results, revised "Recommended Practice for Expansive Concretes" and the Committee on Concrete, upon carrying out deliberations, approved the Recommended Practice.

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RECOMMENDED PRACTICE FOR EXPANSIVE CONCRETE

CONTENT

RECOMMENDED PRACTICE FOR EXPANSIVE CONCRETE

CHAPTER1 GENERAL

1.1Scope

(1) This Recommended Practice provides general standards for matters especially necessary in design and construction of concrete Structures using expansive concrete. Matters not given in this Recommended Practice shall be in accordance with Standard Specifications for Design and Construction of Concrete Structures-1991 (hereinafter referred to as "Standard Specifications") of the Japan Society of Civil Engineers. As for design by the allowable stress method it shall be done in accordance with Chapter11.

(2) Expansive concrete as taken up in this Recommended Practice shall be shrinkage compensating concrete and chemical prestressing concrete having the qualities stipulated inChapter2,

[Commentary]

Regarding (1) and (2) Expansive concrete is the general term for concrete consisting of an expansive admixture mixed together with cement, water, fine aggregate, coarse aggregate, and other admixtures, and which expands in volume even after hardening. Expansive concretes are of various qualities depending upon materials and mix proportions, but when expansive concretes are classified based on size of expansive force, they may be broadly divided into shrinkage compensating concrete and chemical prestressing concrete. And when reinforced concretes using expansive concretes are Classified from the standpoint of function, they may be broadly divided into shrinkage compensated concrete and chemically prestressed concrete.

By restraining expansion of expansive concrete with objects such as reinforcing bars, chemical prestress of compressive stress will be induced in the concrete, while in the objects such as reinforcing bars, chemical prestrain of initial tensile strain will be induced. Shrinkage compensated concrete is reinforced concrete imparted with a small chemical prestress of a degree to offset or reduce tensile stress occurring due to drying shrinkage or other causes. As for chemically prestressed concrete, it is a reinforced concrete having chemical prestress imparted with a large chemical prestress by addition of a large amount of expansive admixture compared with shrinkage compensated concrete so that chemical prestress will remain even when drying shrinkage has been offset. Consequently, with chemically prestressed concrete, it is possible for the effects of chemical prestress and chemical prestrain to be directly reflected in design of members and structures.

Even when the same expansive concrete is used for reinforced concrete, as shown in Commentary Table1.1, it is possible for either shrinkage compensated concrete or chemically prestressed concrete as classified from the standpoint of function in accordance with the degree of restraint by objects such as reinforcing bars to be made the objective. That is why expansive cement concrete was broadly divided into shrinkage compensating concrete and chemical prestressing concrete according to size of expansive force and differentiated from classification according to function.

Chemical prestressing concrete of large expansive force will not experience lowering of quality such as regarding strength of concrete due to expansive action if proper restraining objects are provided, but when the provision of restraining objects is improper, there will be extreme deterioration of quality due to expansive action, In contrast, shrinkage compensating concrete is concrete using expansive admixture in a range that roughly equal strength as a concrete of identical mix proportions not using the expansive admixture is exhibited.

Expansive concrete, through its expansive effect, is capable of reducing cracks due to drying shrinkage and other causes, and since cracking strength can be improved, application to water tanks water purification plants, underground structures bridge deck slabs, tunne1 linings, structures such as pavement slabs, watertight concrete, and mass concrete will be effective.

As actual cases of use of expansive concrete (mortar), application to shrinkage compensated concrete in cast-in-place concrete, application to shrinkage compensated concrete and chemically prestressed concrete in factory products, and application to fill mortar in gaps of inverted linings and undersides of bridge supports may be cited, while also there have been some applications to chemically prestressed concrete in cast-in-place concrete. However, sufficient data have not been obtained for writing recommended practices for all of these expansive concrete s, and therefore, this Recommended Practice will take up for consideration shrinkage compensating concrete and chemical prestressing concrete having the qualities indicated in Chapter2, and provisions are to be made for cases of applying these expansive concrete to shrinkage compensated concrete and chemically prestressed concrete. However, there are numerous performance records concerning fill mortar and fill concrete, and since data are also available and organized, although not within the scope of application of this Recommended Practice, separate stipulations have been provided as a manual for work execution in an appendix to the Recommend practice.

Furthermore, since expansive cement concrete has many aspects in common with ordinary concrete, needless to say, matters not stipulated in this Recommended Practice must be in accordance with the Standard Specifications for Design and Construction of Concrete Structures-1991of the Japan Society of Civil Engineers (hereinafter referred to as "StandardSpeciBations"). As for design techniques the basis is for the limit state design method to be used, but taking into consideration the track record up to this time, design according to the allowable stress method is touched upon in Chapter11.

Commentary Table 1.1 Classification of Expansive Concrete Based on Expansive Force and Function

Expansive Force	Function
Shrinkage compensating concrete	Shrinkage compensated concrete
Chemical prestressing concrete	Chemically prestressed concrete

1.2 Definitions of Tens

Terms used in this Recommended Practice are defied as follows:

Expansive Admixture - An admixture having the action of expanding concrete by producing ettringite or calcium hydroxide due to hydration reaction when mixed with cement and water.

Expansive Concrete - Concrete made using an expansive admixture.

Chemical Prestress - The compressive stress induced in concrete when expansion of expansive concrete has been restrained by restraining object such as reinforcing bars.

Chemical Prestrain - The initial strain induced in the restraining object when expansion of expansive concrete has been restrained by a restraining object such as a reinforcing bar.

Shrinkage Compensating Concrete - An expansive concrete having an expansive force with a size of degree that chemical prestress will offset or reduce tensile stress caused by drying shrinkage.

Chemical Prestressing Concrete - An expansive concrete still having an expansive force with a size of a degree that chemical prestress will remain even when drying shrinkage occurs.

Shrinkage Compensated Concrete - A reinforced concrete imparted with small chemical prestress of a degree to offset or reduce tensile stress occurring due to drying shrinkage or other cause by using mainly shrinkage compensating concrete and restraining expansion of concrete by objects such as reinforcing bars.

Chemical Prestressed Concrete - A reinforced concrete imparted with a large expansive force by using mainly chemical prestressing concrete in a manner that chemical prestress induced in concrete and chemical prestrain induced in objects Such as reinforcing bars by restraining expansion will remain even when parts of them have been offset by drying shrinkage.

Unit Expansive Admixture Content - The mass of expansive admixture used for making 1 m^3 of expansive concrete.

Unit Binder Content - The sum of cement and expansive admixture used for making 1 $m^3$of expansive concrete, including the masses of fly ash and granulated blast-furnace slag fine powder when these are used as admixtures.

Water-Binder Ratio - The ratio of water to binder in paste of expansive concrete.

CHAPTER 2 QUALITY OF EXPANSIVE CONCRETE

2.1 General

Concrete shall possess the required strength, expansive capacity, durability, watertightness and the capacity to protect steel, and have little scatter in quality, When placing, the concrete shall possess workability suitable for operations.

2.2 Expansion Rate

(1) As a standard the expansion rate of shrinkage compensating concrete shall be not less than 150×10^{-6} and not more than 200×10^{-6}

(2) As a standard the expansion rate chemical preshessing concrete shall be not less than200×10^{-6} and not more than 700×10^{-6}

(3) Chemical prestressing concrete used for factory products may have an expansion rate of not less than 200×10^{-6} and not more than 1000×10^{-6}

(4) The expansion rate of concrete shall generally be based on test values at 7-day age.

(5) Tests of the expansion rate of concrete shall be in accordance with Method A specified in Reference 1,"Method of Test for Restrained Expansion and Shrinkage of Expansive Concrete "of JISA 6202 "Expansive Additive for concrete "

[Commentary]

Regarding (1) and (2) The expansive force required as shrinkage compensating concrete or chemical prestressing concrete was Stipulated on ruling that the expansive force of expansive concrete is to be expressed in terms of uniaxial-restraint expansion rate. The expansion rates given here are averages of values obtained by the expansion rate test method according to (5). The two concretes overlap in the range of expansion rates from 200×10^{-6} to 250×10^{-6},and which concrete is to be used is left the judgment of the user.

Regarding (3) For chemical prestressing concrete to be used for factory products, it was made permissible for the upper limit of expansion rate to be 1000×10^{-6} which is higher than the 700×10^{-6} for cast-in-place concrete in consideration of performance records since control of expansion rate control of arrangement of reinforcing bars, etc. are superior compared with cast-in-place concrete.

Regarding (5) The rate of cross-sectional areas of the restraining bar used as the restraining implement and concrete in Method A is 0.95%.

2.3 Strength

(1) Concrete strength shall generally based on compressive strength at 28-dayage.

(2) The compressive strength test for shrinkage compensating concrete in accordance with JIS A 1108.The method of making specimens shall be in accordance with JIS A 1132.

(3) The compressive strength of chemical prestressing concrete shall be in accordance with Reference 2 of JIS A 6202.

[Commentary]

Regarding (3) Since chemical prestressing concrete has a large expansive force, when compression tests are conducted in accordance with JIS A 1108 and JIS 1132,there will be cases where extreme lowering of strengths will be caused due to excessive free expansion, and it will differ greatly from the actual condition of use. Hence, it was stipulated that compressive. Strength is to be determined on specimens restrained in a condition close to triaxial restraint by molds until immediately before testing in accordance with Reference 2, "Method of Test for compressive Strength by Restrained Curing of Expansive concrete " of JIS A 6202,”Expansive Additive for Concrete.”

CHAPTER 3 MATERIALS

3.1 General

Materials for concrete shall be those which have been confirmed as to quality.

3.2 Cement

Cement shall conform to any one of JIS R 5210, JIS R 5211, JIS R 5212, and JIS R 5213, and shall be capable of providing the performance required as expansive concrete.

3.3 Expansive Admixture

(1) The expansive admixture shall as a rule conform to JIS A 6202.
(2) An expansive admixture other than according to (1) shall be one the quality of which has been ascertained and the method of use thoroughly studied.

3.4 Storage of Expansive Admixture

(1) The expansive admixture shall generally be stored in a manner that it will not become mixed with cement and other materials in a silo having a humidity-proof structure for exclusive use of the expansive admixture.

(2) Bagged expansive admixture shall be stacked in a manner not to be in direct contact with the floor inside the storeroom, and stored according to an arrangement convenient for hauling out and inspection. Stacking shall be done to not more than a height of 15bags.

(3) Bagged expansive admixture shall be removed from bags immediately before using as a rule, while admixture in bags broken during storage shall not be used.

(4) In the event the storage period has become long, tests Shall be performed and it shall be confirmed that the required qualities are possessed.

[Commentary]

Regarding (2) general, strict care is given to prevention of weathering for bagged expansive admixture and bags laminated with plastic or inner bags of polyethylene are used. It has been ascertained that such a bagged expansive admixture will remain practically unchanged in quality up to 5 months according to the results of stacked weathering tests conducted at a factory.

Regarding (4) The storage period of a bagged expansive admixture is to be not longer than 3 months in case of storage in a storeroom, and not longer than 1 month in other cases. The storage period for a mixture of bulk expansive admixture and cement made in advance is to be not longer than 1 month.

3.5 Admixture

(1) An air-entraining agent, a water-reducing agent, or an air-entraining, water-reducing agent shall be used as a rule for the concrete. These admixtures shall conform to JIS A 6204.

(2) In the event of using fly ash as an admixture, it shall conform to JIS A 6201,and in the event of using granulated blast-furnace slag fine powder, it shall conform to the Japan Society of Civil Engineers Standard, "Standards on Granulated Blast-Furnace Slag Fine Powder for concrete (Draft) ".

(3) In the event of using a superplasticizer or a rust inhibiting agent as an admixture, it shall conform to the Japan Society of Civil Engineers Standard, "Standard on Quality of Superplasticizer for Concrete," or JIS R 6205,respectively.

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(4) With regard to admixtures other than those of(1) to (3),the qualities shall be ascertained and the methods of use thoroughly studied.

3.6Reinforcing Bars

(1) Reinforcing bars shall as a rule conform to the deformed steel bars stipulated in JIS G3112.
(2) In the event of using reinforcing bar conforming to the rerolled deformed bars of JIS G 3117,tests shall be performed to determine whether using them will be permissible.

[Commentary]

Regarding (1) and (2) Reinforcing bars used for expansive concrete are required to effectively restrain expansion of concrete , and therefore, it was made the rule that deformed bars are to be used.

CHAPTER 4 MIX PROPORTIONS

4.1 General

Mix proportions of concrete shall be selected for unit water content as small as practicable within limits that the required strength, expansive capacity, durability, watertightness, capacity to protect steel, and workability suitable for operations will be possessed.

4.2 Unit Expansive Admixture Content

The unit expansive admixture content shall be determined as a rule by testing for the required expansion rate to be obtained.

[Commentary]

It may be said that the shrinkage compensating effect and chemical prestress induction effect of expansive concrete in a structure will be more excellent the higher the expansion rate. However, when the expansion rate is too high, the compressive strength of concrete will decline compared with concrete of the same mix proportions but not using expansive admixture, and an appropriate expansion rate within limits that strength decline will not be caused will be needed.

It is known that the expansion rate of an expansive concrete, when restraint and other conditions are constant, will have a roughly proportional relationship with the unit expansive admixture content. Consequently, if the required expansion rate is set for a structure in which expansive concrete is to be used, it will be possible for a unit expansive admixture content corresponding to this expansion rate to be determined. However, it is not possible to unqualifiedly set the expansion rate since the expansion rate required for a structure will differ depending on the environmental conditions in which the structure will be placed and on cross-sectional dimensions in the structure.

In past examples of shrinkage compensating concrete application, unit expansive admixture content has often been made about 30kg/m^3. The expansion rates according to Method A in those cases, at 7-day age, indicate values of around 200 to 700×10^{-6}. In case of using in factory products, with unit expansive admixture content at around 30 to 65 kg/m^3, the expansion rates in such cases will frequently indicate values of around 200 to 1000×10^{-6} at 7-day age.

It was made the rule that determining the unit expansive admixture content would be based on tests. When air content and slump are constant, the expansion rate of expansive concrete is more or less decided by the unit expansive admixture content even though water-cement ratio and unit cement content may differ. Consequently, to determine unit expansive admixture content by tests, it a suffice to select suitable mix proportions and test expansion rate at 7-day age by Method A prescribed in

Reference 1,"Method of Test for Restrained Expansion and Shrinkage of Expansive Concrete," of JIS A 6202 for concrete with unit expansive admixture content varied at 3 1evels.

Further, when testing is difficult to perform, it will be permissible to determine the unit expansive admixture content at which the required expansion rate can be obtained from reliable data.

4.3 Water-Binder Ratio

Water-binder ratio shall be selected in consideration of the required strength and durability of concrete. With a structure required to be watertight, watertightness of concrete shall further be considered.

(1) When selecting the water-binder ratio W/(C+E)(W: unit water content, C: unit cement content, E: unit expansive admixture content) based on the compressive strength of concrete, the procedure below shall be followed:

(a) The relationship between compressive strength and water-binder ratio shall as a rule be determined by tests. Concrete to be used for these tests shall have the unit expansive admixture content mentioned in 4.2. The age at testing shall be 28 days as standard.

(b) The water-binder ratio W/(C+E) used for proportioning shall be the inverse number of the binder-water ratio corresponding to the average strength required f_{cr} in the relationship of binder-water ratio (C+E)/W and compressive strength f'_c at the age made the basis. This f'_{cr} shall be the specified concrete strength f'_{ck} amplified multiplying by a suitable factor.

This factor shall be set for probability of the test value of concrete compressive strength being less than the specified concrete strength to be not more than 5% in accordance with the coefficient of variation of concrete expected in the field, and generally, shall be the value obtainable from the curve in Fig.4.

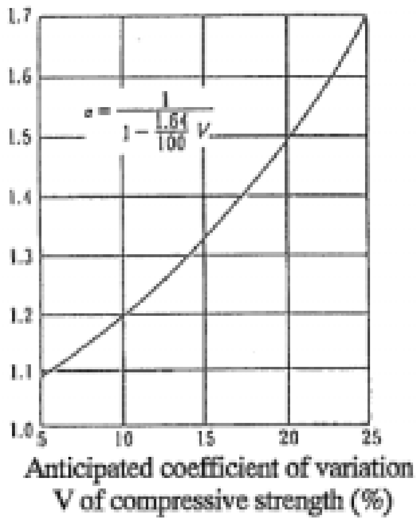

Fig.4.1Amplification Factor in General Case

(2) In case of selecting water-binder ratio based on the resistance to frost damage of concrete, the value shall be not more than the value according to Table 4.1

Table4.1 Maximum Water-Binder Ratio of Air-entrained Concrete when Selecting Water-Binder Ratio Based on Resistance to Frost Damage of Concrete

Exposure Condition of Structure	Meteorologic Condition: When meteorological actions are severe or when freezing and thawing is repeated frequently — Cross Section: Thin[2)]	Ordinary	When meteorological actions are not severe, when air temperature seldom drops below freezing — Thin[2)]	Ordinary
(1) Portion continuously or frequently saturated with water[1)]	0.55	0.60	0.55	0.65
(2) Of ordinary exposure conditions and not belonging to (1)	0.60	0.65	0.60	0.65

1) Parts of waterways, water tanks, bridge abutments, retaining walls, tunnel 1inings,etc.which are close to water surfaces and are saturated, and these structures them selves, and otherwise girders, slabs, etc. which are apart from water surfaces, but which are saturated with water due to snow melt, water flow, water spray, etc.
2) Parts of structures of cross-sectional thicknesses less than about 20cm,

(3) When selecting the water-binder ratio based on durability of concrete against chemical action, the procedure below shall be followed.

(a) For concrete to be in contact with soil or water containing 0.2% or more sulfates in terms of SO_4, the values as given under (c) in Table 4.2 or less shall be taken.

(b) For concrete on which it is expected a deicing chemical will be used, the values as given under (b) in Table 4.2 or less shall be taken,

Table 4.2 Maximum Water–Binder Ratio of Offshore Concrete as Determined Based on Durability

Environment Classification	Working Condition: Field placement in general	Factory product or case of equal quality as factory product assured in selection of material and in execution of work
(a) In marine atmosphere	0.45	0.50
(b) Splash zone	0.45	0.45
(c) In sea water	0.50	0.50

Note: For cases ascertained by performance records, research results, etc., maximum water-binder ratios determined from durability may be values in Table 4.2 raised by 0.05 to 0.10.

(4) When selecting water-binder ratio based on watertightness of concrete, the ratio shall be not more than 0.55.

(5) When selecting the water-binder ratio of reinforced concrete used in an offshore structure the value shall be not more than given in Table 4.2 as standard.

[Commentary]

Regarding (1)(a) The relationship between compressive strength and binder-water ratio of an expansive concrete of constant expansive admixture content and restraining method is linear within a certain range and coincides approximately with the relationship of compressive strength and cement-water ratio of an ordinary case of concrete .Therefore, it was made a rule for the straight line indicating the relationship between compressive strength and binder-water ratio of concrete to be determined by tests. The concrete used in the tests in this case is to be that with the unit expansive admixture content of 4.2 as a rule, but when the unit expansive admixture content is not more than $30kg/m^3$, it will be permissible to use known test results of concrete not containing an expansive admixture.

Regarding (1)(b) It is permissible to consider the coefficient of variation of the compressive strength of an expansive concrete similarly to the case of ordinary concrete.

Regarding (2) to (5) Not only mechanical properties such as strength, but also durability properties such as watertightness, resistance to frost damage, resistance to chemical action, and resistance to sea water of expansive concrete will differ depending on expansive force, restraining method, curing method, etc. of the expansive concrete. It has been show from past research results and actual performances that when expansion rate has been held down to not more than about 1000×10^{-6} by an appropriate restraining method, watertightness will be superior compared with ordinary concrete, and that resistance to frost damage, resistance to chemical action, and resistance to sea water are not very much different, and therefore, the provisions were made the same as for ordinary concrete. However, when concrete of large expansive force is used, the expansion rate of the concrete will be exceedingly. high depending on the restraining method, and not only strength, but also durability and other properties will be impaired. Hence, when using chemical prestressing concrete which would have a high unit expansive admixture content, the quantity and arrangement of reinforcing bars must be appropriately selected, and it be made for maximum expansion rates produced in the cross section of the member during placement and after completion to be not more than about 1000×10^{-6}.

4.4Unit Water Content

Unit water content shall be selected based on tests to be as low as practicable within limits that work can be performed.

4.5 Unit Binder Content

Unit binder content shall be selected from unit water content and water-binder ratio.

[Commentary]

The unit binder content may be considered to correspond to the unit water content in the "Construction Volume" of the Standard Specifications. In effect, it is to be expressed as follows:

Unit Binder Content=C+E

where, C : unit cement content
E : unit expansive admixture content

Furthermore, when using an admixture such as fly ash at the same time, it is to be expressed as follows:
Unit Binder Content = C+F = C+E+F'
where, F' : unit content of admixtures other than expansive admixture.

4.6 Unit Cement Content

(1) Unit cement content shall be determined deducting unit expansive admixture content from the unit binder content.

(2) The unit cement content of chemical prestressing concrete shall be not less than 260 kg/m3

4.7 Method of Expressing Mix Proportions

(1) The method of expressing mix proportions shall generally be according to Table 4.3 below.

Table 4 . 3 Method of Expressing Mix Proportions

Max. size coarse agg. (mm)	Range of slump (cm)	Range of air content (%)	Water–binder ratio $\frac{W}{C+F}$ (%)	Sand–agg. ratio s/a (%)

Unit content (kg/m^3)							
Water	Cement	Admixture F		Fine agg.	Coarse agg. G		Chemical Admixture
		Expansive admixture	Other admixture		mm | mm	mm | mm	
W	C	E	F	S			

Note: The dosage of admixture shall be expressed in terms of ml/m^3 or g/m^3, indicating material not diluted or dissolved.

(2) The specified mix shall indicate fine aggregate all passing a 5-mm sieve and coarse aggregate all retained on a 5-mm sieve, with both in saturated surface-dry condition.

(3) When converting specified mix to field mix, the moisture content of aggregate, the quantity of fine aggregate retained on the 5-mm sieve and the quantity of coarse aggregate passing the 5-mm sieve, and the quantity of water for diluting the admixture shall be considered.

CHAPTER 5 BATCHING,MIXING AND CONVETING

5.1 Batching

5.1.1 General

The various materials for concrete shall be correctly batched in order that concrete of the required quality will be obtained.

5.1.2 Batching Apparatus for Expansive Admixture

(1) Before using, the batching apparatus shall be confirmed to possess the specified batching accuracy.

(2) The batching apparatus shall be inspected prior to using, and after using, shall be thoroughly cleaned in order that there will be no expansive admixture adhered to it.

5.1.3 Batching of Expansive Admixture

(1) The expansive admixture shall be batched by mass for one batch at a time.

(2) When using bagged expansive admixture, direct introduction from bag to mixer may be done only when the entire contents of a bag accurately weighed in advance is applied to a single mix.

(3) Errors in batching expansive admixture shall be not more than 2% per batch.

5.2Mixing

5.2.1 General

The materials of concrete shall be thoroughly mixed in order that mixed concrete will be of uniform quality.

5.2.2 Mixing

(1) The sequence of introducing expansive admixture into a mixer shall properly decided in advance.

(2) Introduction of expansive admixture into a mixer shall be by a method precluding adherence and hardening of the expansive admixture along the way.

(3) Mixing time shall be set based on testing.

(4) In commencement of mixing, as a rule, mortar shall be coated on the inside surface of the mixer in advance.

(5) Materials shall not newly be introduced into the mixer until after all of the concrete inside the mixer has been discharged.

[Commentary]

Regarding (3) Expansive concrete must be thoroughly mixed to be uniform. If mixing is insufficient, even when batching of expansive admixture is accurate, the condition will be that of expansive admixture becoming excessively applied locally, so that after hardening of concrete, there will be a risk of strength decline and expansive failure at parts, and the specified mixing time must be strictly observed. The mixing time for sufficient mixing to be done will differ according to the mixer used, and so it was made the rule for this to be decided by testing. The mixing time when not selected by testing must generally be not less than1minute after introduction of the materials into the mixer in case of a forced mixing type mixer and not less than 1 minute 30 seconds in case of a tilting mixer,

5.3 Transportation

Transportation of concrete shall be performed quickly, by a method minimizing segregation as much as possible.

[Commentary]

The yardsticks for normal transportation time of concrete are 90 minutes when outside air temperature is not higher than $25^{\circ}C$ and 60 minutes when higher than $25^{\circ}C$, but in case of expansive concrete, it will be desirable for these times to be shortened. As for the time from mixing until completion of placement, it will advisable for 30 minutes to be added to the transportation time.

CHAPTER 6 READY-MIXED CONCRETE

6.1 General

When using ready-mixed concrete, it shall be in accordance with JIS A 5308 as a rule.

[Commentary]

Expansive concrete is a high-quality concrete imparted with expansive effect, and in order to secure the required quality at all times, it is necessary to select a ready-mixed concrete plant of a high technical level.

6.2Designations Regarding Quality

When ordering expansive concrete, the purchaser, in designating the appropriate combination of maximum size of coarse aggregate, nominal strength, and slump from Table1 and Table2 of JIS A 5308,shall select the variety of expansive admixture to be used and the quantity to be used upon discussions with the producer. With regard to the following items, they shall be specified upon discussions with the producer.

(a) Variety of cement

(b) Variety of aggregate

(c) Maximum size of coarse aggregate

(d) Classification according to alkali-silica reaction of aggregate; when using aggregate of Classification B, the method of suppressing alkali-aggregate reaction

(e) Variety of admixture

(f) When differing from the upper limit value of chloride content as prescribed in 3.2 of JISA5308, that upper limit value

(g) The age guaranteeing nominal Strength

(h) When differing from the air content prescribed in Table 4 of JIS A 5308, that value

(i) In case of lightweight concrete, the unit mass of concrete

(j) Maximum or minimum temperature of concrete

(k) Upper limit value of water-cement ratio or water-binder ratio

(1) Upper limit value of unit water content

(m) Lower limit value or upper limit value of unit cement content

(n) In case of superplasticized concrete, the amount of slump increased over the slump of the ready-mixed concrete before superplasticization

(o) Other necessary items

[Commentary]

In JIS A 5308, the variety of ready-mixed concrete is given by o marks in Commentary Table 6.1 and Commentary Table 6,2 according to combinations of maximum size of coarse aggregate, nominal strength, and slump.

For expansive concrete, the variety of expansive admixture and unit expansive admixture content are to be selected upon discussions with the producer. To look for the effect of expansive concrete it is desirable for nominal strength to be not less than 180{18}, and it is advisable not to use concrete of nominal strength 160{16}.

Commentary Table 6.1 Variety of Ready–Mixed Concrete

(Applicable until March 31,1995)

Variety of Concrete	Max Size Coarse Agg. mm	Slump cm	Nominal Strength 160	180	195	210	225	240	255	270	300	350	400	Flex45
Ordinary Concrete	20, 25	5	o	–	–	–	–	–	–	–	–	–	–	–
		8,10,12	o	o	–	o	o	o	o	o	o	o	o	–
		15,18	–	o	–	o	o	o	o	o	o	o	o	–
		21	–	–	–	o	o	o	o	o	o	–	–	–
	40	5	o	o	–	o	o	o	–	o	o	–	–	–
		8	o	o	o	o	o	o	–	o	o	–	–	–
		12,15	o	o	–	o	o	o	–	o	o	–	–	–
		18	–	–	–	–	–	–	–	–	o	–	–	–
Lightweight Concrete	15,20	8,12,15, 18,21	–	o	–	o	o	o	o	o	o	–	–	–
Expansive Concrete	40	2.5, 6.5	–	–	–	–	–	–	–	–	–	–	–	o

Commentary Table 6.2 Variety of Ready–Mixed Concrete

(Applicable from April 1,1995)

Variety of Concrete	Max Size Coarse Agg. mm	Slump cm	Nominal Strength 16	18	21	22.5	24	25.5	27	30	35	40	Flex4.5
Ordinary Concrete	20, 25	8,10,12	o	o	o	o	o	o	o	o	o	o	–
		15,18	–	o	o	o	o	o	o	o	o	o	–
		21	–	–	o	o	o	o	o	o	–	–	–
	40	5,8,12,15	o	o	o	o	o	o	–	o	o	–	–
Lightweight Concrete	15,20	8,12,15,18,21	–	o	o	o	o	o	o	o	–	–	–
Expansive Concrete	40	2.5, 6.5	–	–	–	–	–	–	–	–	–	–	o

CHAPTER 7 PLACING, CURING, FORMWORK AND SUPPORTS

7.1 Placing

Before placing concrete, a thoroughgoing placing plan shall be set out, concrete shall be placed by a method to minimize segregation and loss of materials as much as possible, and thoroughly consolidated.

7.2 Curing

7.2.1 General

(1) Concrete shall be thoroughly cured after placing in order not to be subjected to deleterious effects due to low temperature, drying, sudden changes in temperature, etc.

(2) Concrete shall be protected in a manner not to be subjected to vibration, impact, and load during hardening.

[Commentary]

Regarding (1) and (2) Curing of expansive concrete may be done in the same manner as for ordinary concrete, but it is necessary for care to be exercised to maintain a moist condition especially at early age,

7.2.2 Moist Curing

(1) After placement and until hardening begins, concrete shall be protected from loss of moisture due to direct sun, wind, etc.

(2) Exposed surfaces of concrete shall be kept moist at all times for a minimum of 5 days after placement.

(3) When there is fear of sheathing boards being dried, they shall be sprinkled with water and maintained in a moist condition. When removing sheathing boards within 5 days of placement, exposed surfaces shall be maintained in a moist condition until a minimum of 5 days have elapsed after placement.

[Commentary]

Regarding (2) With expansive concrete moist curing at the initial stage is especially important for obtaining the required expansion rate and not only to show strength gain.

7.2.3 Special Curing

In the event of thermal1y insulated curing, heat-supplied curing, steam curing, and other accelerated curing, it shall be the rule to ascertain that the required quality is obtained by that method.

7.3 Formwork and Supports

Formwork and supports shall be designed and constructed to possess the required strength and rigidity, together with which the location, shape, and dimensions of the completed structure are accurately maintained.

[Commentary]

Expansive concrete has unit mass and a hardening rate more or less the same as ordinary concrete, and since expansive pressure is not produced in the condition before hardening begins, the lateral pressure of expansive concrete applied to sheathing may be considered in the same manner as in the case of ordinary concrete. And, even when hardening of expansive concrete has commenced and expansion has started, the expansive pressure applied to sheathing will be reduced greatly by a slight deflection of the sheathing. Normally, when performing structural calculations of formwork, the expansive pressure of expansive concrete generally need not be considered as design load.

CHAPTER 8 QUALITY CONTROL AND INSPECTION

8.1 General

Concrete materials, steel, mechanical equipment, and operations shall be controlled in order to economically make an expansive concrete structure having the required quality.

8.2 Tests of Expansive Concrete

(1) Prior to start of work, together with performing tests of materials to be used for the work and tests to select proportions for concrete, the capacities of machines and equipment shall be ascertained,
(2) During construction, the following tests shall be performed as necessary:

(a) Aggregate test
(b) Slump test
(c) Air content test
(d) Chloride content test of fresh concrete
(e) Compressive strength test
(f) Expansion rate test
(g) other tests

(3) In case of necessity for determining the suitability of testing and time of removal of forms, or for ascertaining whether safe when loading at an early age, strength tests shall be conducted using specimens cured as much as practicable under the same conditions as the concrete placed.

[Commentary]

Regarding (1) Quality tests of an expansive admixture are to be according to testing methods prescribed in JIS A 6202, “Expansive Additive for concrete.”

Regarding (2) The shrinkage compensating effect and chemical prestressing effect of expansive concrete are greatly governed by the expansion rate, and expansion rate tests are necessary to ascertain whether expansive concrete placed on the job possesses the specified expansion rate.

8.3 Control of Expansive Concrete by Expansion Rate

(1) The expansion rate of concrete shall generally be based on test values at 7-dayage.

(2) The test value from a single round of tests of the expansion rate used in control of concrete in a general case shall be the average of test values of three or more specimens collected from the same batch.
(3) The timing and number of times of collection of samples for testing shall be determined in advance taking into consideration the quantity of concrete to be placed, the degree of importance of the structure, the scale of the project, etc.

[Commentary]

Regarding (1) it is recommended that tests of expansion rate at 7-day age be conducted to ascertain whether the concrete has the required expansive performance. However, when this is done, test values cannot be obtained until 7-days have elapsed after co1lecting specimens, so that in quality control where it is necessary to quickly reflect test results, it is advisable to perform control tests using expansion rates of an early age. When carrying out control using the expansion rate of an early age, there is a necessity for the correlation between expansion rate for the early age and the expansion rate for 7-day age to be determined in advance.

The expansion rate at 2-day age or 3-day age is desirable with respect to the point that the test value can be obtained at an early time, but these are susceptible to being affected by variations in specimen temperature after molding, and thorough care is necessary in handling of test values.

Regarding (3) The timing and number of times of collecting samples for control tests of concrete by expansion rate may generally be similar to the case of compressive strength. However, unlike compressive strength, since there are little data concerning coefficient of variation of expansion rate, it is advisable to conduct as many tests of concrete as possible for measurement of expansion rate. Even when the quantity of concrete placed in one day is small, it is desirable at least for one test value to be obtained for each day that concrete is placed.

Regarding expansion rate, it is advisable for a control chart to be prepared and make efforts to know the quality of concrete at an early stage as possible. For the control chat, as a general yardstick, in case of shrinkage compensating concrete, borderlines of upper limit vales of 300×10^{-6} and lower limit values of 100×10^{-6} are to be drawn, and the test vales obtained are to be entered on the chat. Normally, the average of test values is at 150 to 250×10^{-6},and if all of the test values are within the border1ines, it maybe considered that the shrinkage compensating concrete has been controlled to an extent concerning expansion rate. In case of chemical prestressing concrete, border1ines are 'to be drawn at ±0.25 x (specified expansion rate), from the specified expansion rate, and the test values obtained entered on this chart. Normally, when the average of test values is in the range of ±0.15 x (specified expansion rate), and moreover, if the various test values are within the borderlines, it may be considered that chemical prestressing concrete is being controlled to an extent. In the event a test value goes outside the border lines, it is important for the cause to be ascertained and suitable measures to be taken as necessary. Further, test values are greatly affected by the temperature of the place of measurement of specimen length. Therefore, the room temperature of the length measurement location must be thoroughly controlled to $20 \pm 2^{\circ}C$ as prescribed in JIS. As for shrinkage compensating concrete, when the unit expansive admixture content is set with the specified expansion rate as 200×10^{-6}, and if the dosage of expansive admixture is controlled at the specified precision, it has been shown by performances in the past that expansion rate will settle within the range indicated here.

When an abnormality is recognized on the control chart, in order to grasp the cause as quickly as possible, it will be convenient if there were to be supplementary data on curing temperature, materials, especially of hatched values of the expansive admixture, etc. to grasp the cause as quickly as possible.

8.4 Control of Expansive Concrete by Compressive Strength

(1) Control of concrete by compressive strength generally shall be done by compressive strength at an early age. In such case, specimens shall be collected in a manner to be representative of concrete of the structure.

(2) The values from one round of compressive strength tests used for control of concrete, in general, shall be the average of compressive strengths of 3 specimens collected from the same batch.

(3) The timing and number of times samples are collected for testing in a general case should be at least once for concrete placed each day, or once for every 20 to $150\,m^3$ of concrete placed continuous1y in accordance with the importance of the structure and scale of the project.

(4) It will be advisable to use control charts and histograms when controlling quality of concrete by testing.

[Commentary]

Regarding (4) For controlling expansive concrete it is advisable to prepare control charts and histograms concerning compressive strength, slump, etc. besides expansion rate of concrete, making efforts to learn of the variations in quality of concrete as quickly as possible.

8.5 Quality Inspection of Expansive Concrete

(1) The quality of concrete shall be confirmed as a rule by test values of expansion rate and compressive strength.

When inspecting the quality of concrete based on test values of expansion rate and compressive strength, all of the test values obtained and a number of consecutive test values shall be inspected as one lot, The timing and number of times samples are to be collected for testing and the number of specimens to obtain a test value shall be determined considering the quantity of concrete to be placed, the degree of importance of the structure, etc.

(2) To inspect the quality of concrete when unit expansive admixture content has been determined based on expansion rate, it may be considered that the concrete has specified expansive capacity if the average of test values is in the range of not less than 150×10^{-6} and not more than 250×10^{-6} in case of shrinkage compensating concrete, and ±0.15 x (specified expansion rate) from the specified expansion rate in case of chemical prestressing concrete.

(3) To inspect the quality of concrete when water-binder ratio has been selected based on compressive strength, it may be considered that the concrete has the required quality if it can be estimated that the probability of the compressive strength being less than the specified concrete strength is lower than 5%.

(4) To inspect the quality of concrete when water-binder ratio has been determined based on durability and watertightness, it may be considered that the concrete possesses the specified quality if the average of test values is higher than the compressive strength corresponding to the specified water-binder ratio.

(5) In the event it is judged the quality of concrete is not suitable as a result of inspection, appropriate measures shall be taken such as to modify mix proportions, make performance inspections of mechanical equipment, and improve operation methods, it shall be ascertained whether the concrete placed in the structure an achieve the specified purpose, and suitable measures shall be taken as necessary.

[Commentary]

Regarding (1) and (3) Quality inspection when water-binder ratio has been selected based on the compressive strength of expansive concrete may be considered to be the same as for ordinary concrete. Regarding (4) With regard to expansive concrete, since the method of testing the water-binder ratio of fresh concrete has not been established, if it is possible to confirm that the test value of compressive strength exceeds the compressive strength corresponding to the specified water-binder ratio, it is to be deemed that the concrete possesses the specified quality.

CHAPTER 9 FACTORY PRODUCTS

9.1 General

9.1.1 Scope of Application

This chapter presents general standards on matters necessary in particular in manufacture of factory products using expansive concrete.

[Commentary]

This chapter concerns expansive concrete factory products made continuously in large quantities at plants where manufacturing processes are subject to integrated control.

When expansive concrete is used it is possible to increase crack strength so that member thickness for obtaining the required strength can be made small, which is highly effective for a factory product. Moreover from the fact that the manufacturing process is controlled throughout, expansive concrete in factory products generally is more often used as chemically prestressed concrete using chemical prestressing concrete of greater expansive force rather than shrinkage compensating concrete.

9.2 Quality of Expansive Concrete

9.2.1 General

Concrete used for factory products shall have the required strength, expansive capacity, durability, watertightness, and capacity to protect steel, while having little scatter in quality.

9.2.2 Strength

(1)The strength of concrete used for factory products shall be based on one of the following giving consideration to such matters as curing:

(a) Test values of compressive strength at 14-day age for factory products subjected to accelerated curing.

(b) For factory products subjected to special accelerated curing such as autoclave curing, test values of compressive strength at an appropriate age earlier than14days.

(c) For factory products not subjected to accelerated curing or of comparatively large member thickness, test values of compressive strength at 28-day age.

(2) Compressive strength tests of concrete shall as a rule adapt Reference 2 of JIS A 6202. Specimens as a rule shall be made with a consolidation method and curing conditions equal as much as possible to those of factory products.

9.2.3 Expansion Rate

(l) The expansion rate of chemical prestressing concrete used for factory products shall be not less than 200×10^{-6} and not more than 1000×10^{-6}.

(2) The expansion rate of concrete shall generally be used on test values at 7-day age.

(3) Expansion rate tests of concrete shall be in accordance with Method A specified in Reference 1 of JIS A 6202.

9.3 Materials

9.3,1 Cement

Cement shall conform to one out of JIS R 5210,JIS R 5211,JIS R5212, and JIS R 5213 and, in addition, be capable of providing the required performances as expansive concrete.

[Commentary]

Generally speaking, factory products are often subjected to accelerated curing, and in selection of the cement, it is important for selection to be made of a cement which can adequately demonstrate effects with the curing method used.

9.3.2 Expansive Admixture

The expansive admixture shall conform to JIS A 6202 and, in addition, be capable of providing the required performance as expansive concrete used for factory products.

[Commentary]

Generally speaking, factory products are often subjected to accelerated curing, and it is important to select and use an expansive admixture which will amply demonstrate its effect with the curing method employed. Storage of expansive admixture should be done adapting 3.4.

9.3.3 Steel

(1) Steel shall conform to one out of JIS G 3109, JIS G 3112, JIS G 3506, JIS G 3521, JIS G 3532, JIS G 3536, JIS G3538, and JIS G 3551.

(2) When using a steel not indicated in (1) above, tests shall be performed and it shall be confirmed that the mechanical properties of that steel conforms to the purpose of use.

9.4 Mix Proportions

The mix proportions of concrete shall be selected for the factory product to possess the required strength, expansive performance, durability, watertightness, and capacity to protect steel giving consideration to methods of casting and curing.

[Commentary]

The quality of a factory product will differ greatly depending on the mix proportions, casting method, curing method, and restraint conditions of the expansive concrete, and mix proportions must be selected based on the results of direct tests of the factory product.

9.5 Manufacturing Facilities

(1) The batching plant shall be equipped with a silo, storage bin, weighing apparatus, etc. especially for the expansive admixture.

(2) Conveying of expansive admixture from silo to storage bin shall be by a separate line from cement.

9.6 Curing

9.6.1 General

(1) Concrete, after casting, shall be thoroughly cured in order not to be subjected to the deleterious effects of low temperature, drying, sudden temperature variations, loads, impact, etc.

(2) The method and period of curing shall be selected for the required quality to be obtained giving consideration to the variety, manufacturing method, handling method, etc. of the factory product.

[Commentary]

Regarding (1) and (2) With factory products using expansive concrete, it is extremely important to select not only suitable methods and periods of curing to allow hydration reaction of cement itself to occur, but also adequate expansion due to hydration of expansive admixture.

9.6.2 Accelerated Curing

(1) When performing accelerated curing in order to shorten curing time until stripping mold, to increase strength at early age, or to accelerate expansion, the method used shall not be one to cause cracking, spal1ing, deformation, etc, of concrete, or to inflict injurious effects to long-term strength and durability.
(2) After removal of molds, moist curing shall be thoroughly performed as a rule until the required strength and expansion rate are obtained.

[Commentary]

Regarding (2) Even when accelerated curing has been done, there will generally be unhydrated cement and expansive admixture remaining, and continuing with moist curing can increase strength and expansion rate. Therefore, after performing accelerated curing, the rule is to be for underwater curing or curing close to this (for example, curing by water sprinkling), However, when adequate strength and expansion rate are obtained, and when it can be confirmed that long-term damage due to expansion will not occur, the moist curing after removal of forms can be omitted.

9.7 Formwork

9.7.1 Construction of Formwork

Formwork shall be of sound construction, with accurate configurations and dimensions, and shall be easy to assemble and disassemble.

[Commentary]

Forms when using expansive concrete for factory products must be of constructions to withstand vibrations and pressures during casting and be sound enough to withstand expansive force of concrete produced during accelerated curing.

9.7.2 Timing of Stripping Forms

The timing of stripping forms shall be determined giving consideration to strength of the concrete and effects of expansion.

[Commentary]

Expansion occurring in factory products using expansive concrete is influenced by rigidity of forms and the time of stripping, Therefore, the time of stripping must be selected giving consideration to strength gain and at the same time studying how to obtain ample expansion effect.

9.8 Fabrication of Steel

When employing plain round bars, they shall be used welded into mesh form, providing anchorage plates at ends, or fabricating into closed configuration

.

[Commentary]

In order to restrain expansion of concrete in a sure manner, the rule is for deformed steel bars to be used, but bars of smaller diameter than D10 are often used for factory products. In such cases plain round bars or plain steel wires are generally used, but because of low bond strength with concrete, they must be used on fabricating into forms for amply restraining expansion of concrete such as welding into mesh form, providing anchorage plates at ends, or making into closed forms.

9.9 Quality Control and Inspection

9.9.1 General

Materials, mechanical equipment, and tools shall be properly controlled in order to economically make uniform factory products possessing the required quality. Manufacturing operations shall also be controlled in accordance with specified standards.

9.9.2 Tests of Expansive Concrete

For controlling manufacturing processes and judging qualities of factory products, compressive strength tests of concrete as stipulated in 9.2.2 and expansion rate tests of concrete as stipulated in 9.2.3 shall be, performed as a rule.

[Commentary]

It is important to grasp the quality of the expansive concrete to be used for controlling the manufacturing process of a factory product. Therefore, it was made the rule to perform the compressive strength tests and expansion rate tests stipulated in 9.2.2 and 9.2.3. Everyday control of the quality of expansive concrete can be achieved by compressive strength tests the same as factory products in general. In case of expansive concrete, the expansion rate will affect the quality of the product, so that it was made rule for confirmation to be made by testing, but when ultimately judging the performance of a factory product, batching records indicating the dosages of expansive admixture may be substituted, These tests are not only effective for control of materials, mix proportions, and manufacturing processes such as mixing and curing, but also for providing data to judge the quality of the factory product.

9.9.3 Tests and Inspection of Factory Products

(1) Tests of Factory Products
Crack loads, failure loads, and other necessary properties of factory products shall be as ascertained as a rule by direct tests of the actual products.

When direct tests cannot readily be performed on factory products, tests shall be carried out using specimens allowing the required qualities of the factory products to be judged.

(2) Inspection of Configuration and Dimensions
Factory products shall not have deleterious cracking, chipped parts, twisting, warping, etc. Errors in the Dimensions of factory products shall be not more than specified values.

[Commentary]

Regarding (1) The performance of factory product will vary not only depending on the quality of the expansive concrete used, but also greatly depending on conditions in the manufacturing process such as casting and curing, and the degree of restraint of concrete by reinforcing bars and other objects, and it is necessary for confirmation to be made by testing. Crack load and failure load of a factory product can be inspected with the actual product, and safety can be ascertained by performing these tests. Hence, inspection of the actual project was made the rule concerning these capacities. When not based on tests of the actual product, tests must be carried out using specimens allowing the required quality to be judged according to the variety of the factory product.

Regarding (2) In case reinforcing bars are arranged concentrated at one part of a cross section, it is liable that deformation such as warping and twisting will occur. And when precision of dimensions of a factory product is especially required, it will be necessary for considerations to be given so that the specified values will be attained when expansion has ceased.

CHAPTER 10 GENERAL MATTERS CONCERNING DESIGN CALCULATIONS

10.1General

In design of concrete structures or members using expansive concrete, the effects of expansion shall be Included in design calculations as a rule. Matters not indicated in this chapter shall be in accordance with the "Design Volume" of the Standard Specifications.

[Commentary]

When expansion of expansive concrete is restrained by restraining objects such as reinforcing bars, chemical prestress as compressive stress will be induced in the concrete and chemical prestrain as initial tensile strain in the reinforcing bars. Therefore, when expansive concrete is used in an ordinary reinforced concrete structure or member, it becomes a kind of prestressed concrete structure or member even when special implements or apparatus are not used, and improvement in crack strength of the member and improvement in displacement and deformation properties may be anticipated. In this case, the mechanical properties of members, fundamentally, can be evaluated using analytical techniques of prestressed concrete However, when the chemical prestress induced is made large, the expansion of concrete a also become large, and it will be necessary to give consideration in design to the facts that the material characteristics of concrete itself will vary, that a large chemical prestrain will occur in reinforcing bars also, and that the load action as chemical prestressing force will become so large that it cannot be ignored.
When shrinkage compensating concrete with uniaxial restraint expansion rate of concrete specified at not less and than 150×10^{-6} and not more than 250×10^{-6} is used for a reinforced concrete member having an ordinary reinforcing bar arrangement, the chemical influence of expansion need not especially be considered in the load action. Further, in the mechanical properties of members also, other than effects on flexural crack widths, the influence of expansion need not especially be considered. Still further, it has been found according to past research that the member characteristics of expansive concrete indicating an expansive rate of this degree are practically the same as for ordinary concrete.

10.2 Design Values of Materials

10.2.1 Design Strength

(1) The specified design strengths of concrete for compression, tension, flexure, bond, and pressure bearing may be determined in accordance with 2.3 herein and 3.2.1,"Design Volume," Standard

Specifications.

(2) The design strength for compression of chemical prestressing concrete shall be determined in accordance with2.3. The design strengths for tension, flexure, bond, and pressure bearing shall be determined based on test strengths obtained by appropriate tests.

[Commentary]

Regarding (1) and (2) According past research results and performance records, shrinkage compensating concrete of unit expansive admixture content about 30kg/m3 may be considered to exhibit more or less the same strength characteristics as ordinary concrete with the quantity of expansive admixture replaced with an equal amount of cement, On the other hand, with chemical prestressing concrete of high unit expansive admixture content, the various strengths are greatly influenced by the mix proportions and restraint conditions of expansion. Under conditions of ample restraint, there are cases when strength characteristics equal to or better than ordinary concrete are exhibited, but in the event restraint is insufficient, there will be cases when strength characteristics are lowered greatly. Consequently, it is necessary to select design strengths based on test strengths determined by appropriate test methods reflecting the restraint conditions of the actual structure.

10.2.2 Drying Shrinkage Strain

(1) The drying shrinkage strain of shrinkage compensating concrete may be the values given in Table 3.2.2 of 3.2.7, "Design Volume," Standard Specifications. Further, when ca1culating indeterminate forces by elastic theory 150×10^{-6} may generally be used.

(2) The drying shrinkage strain of chemical prestressing concrete shall as a rule be selected giving consideration to the humidity in the surroundings of the structure, the configurations and dimensions of member cross sections and, in addition, the mix proportions and restraint conditions of concrete.

10.2.3 Creep

(1) The creep coefficient of shrinkage compensating concrete maybe made the value given in Table 3,2.3 in 3.2.8, "Design Volume," Standard Specifications.

(2) The creep coefficient of chemical prestressing concrete shall as a rule be selected giving consideration to the temperature and humidity in the surroundings of the structure, the configurations and dimensions of the member cross section, the loading age, and in addition, the mix proportions and restraint conditions of the concrete.

10.3 Load

10.3.1 Chemical Prestressing Force

(1) Chemical prestressing force generally need not be considered for shrinkage compensated concrete.

(2) With chemically prestressed concrete, chemical prestressing force shall be selected by an appropriate method giving consideration to the variety of structure, mix proportions, curing method, restraint conditions, and method of execution.

[Commentary]

Regarding (1) Because of the fact that expansive concrete has expansive energy, a member in which it has been used will expand in the axial direction and the lateral direction. Therefore, in an indeterminate structure, a secondary stress occurs due to elongation of members, especially, elongation in the axial direction. However, shrinkage compensating concrete, basically, has the purpose of offsetting tensile force due to contraction of concrete from drying shrinkage, and chemical prestress more than that is not induced. Therefore, even if chemical prestress were to be remaining after drying shrinkage, it will be very small, and the secondary stress due to expansion will be of a size that it an be ignored. Accordingly, the effect of chemical prestressing force generally need not be considered.

Regarding (2) Chemically prestressed concrete is a material planned to be effective for controlling cracking of concrete through a certain degree of chemical prestress remaining even when drying shrinkage of concrete occurs. Therefore, in an indeterminate structure, it is necessary to consider secondary stress due to the chemical prestress. The chemical prestressing force at such time will be subject to influences of structure type, mix proportions, curing method, restraint condition, and work execution method, and is to be selected by an appropriate method giving consideration to these factors.

10.4 Examination of Ultimate Limit State

10.4.1 Examination of Safety under Bending Moment and Axial Force

(1) When calculating design axial compressive strength and design flexural tensile strength of shrinkage compensated concrete member, the influence of expansion need not be taken into consideration.

(2) When calculating design axial compressive strength of a chemically prestressed concrete member, the chemical prestrain induced in longitudinal reinforcing bars shall be taken into consideration

(3) When calculating design flexural tensile strength of a chemically prestressed concrete member the influence of expansion need not be taken into consideration.

[Commentary]

Regarding (2) With chemically prestressed concrete, not only is the chemical prestress to be induced in concrete large, but the chemical prestrain induced in reinforcing bars is also large. Therefore, the fact that when members are subjected to axial compressive force, there will be cases when reinforcing bars have not yet reached compressive yield strength even though the concrete has attained maximum compressive strength is taken into consideration.

Regarding (3) With chemically prestressed concrete, the ultimate state of bending moment is brought about by yielding of tensile reinforcement and the effect on moment arm length due to the chemical prestress induced is very small. This has been confirmed in experiment, and it was deemed that the influence of expansion on design flexural tensile strength need not be considered.

10.4.2 Minimum Reinforcing Bar Quantity

The tension reinforcement ratio of rod members for which the influence of bending moment is dominant shall be not less than 0.25% as a rule. However in case of a T-shaped cross section, longitudinal reinforcing bars shall be arranged at a ratio not less than 0.35% of the effective cross-sectional area of concrete. The effective cross-sectional area of concrete mentioned here is the effective height d of the cross section multiplied by the width b_w of the web section.

[Commentary]

When expansive concrete is used, the flexural cracking moment will become large due to chemical prestress. Therefore, when flexural cracks have occurred, there is a greater possibility of brittle fracture properties being displayed due to yielding or rupturing of reinforcing bars compared with ordinary reinforced concrete members. Consequently, the minimum reinforcement quantity was made 0.25% for a rectangular cross section and 0.35% for a T-shaped cross section to make it possible to prevent such brittle failure even when chemical prestrain of reinforcement of about 700×10^{-6} has occurred.

10.5 Examination of Serviceability Limit State

10.5.1 Examination of Flexural Cracking

(1) In examination of flexural cracking of member using expansive concrete, generally, it shall be confirmed that the flexural crack width w determined by Eq. (10.1) is not more than the allowable crack

width w_a given in Table 7.3.2 in 7.3.2, "Design Volume," Standard Specifications.

$$w = k\{4c + 0.7(c_s - \phi)\}\left(\sigma_{se}/E_s + \varepsilon'_{cs} - \varepsilon_{sp}\right) \quad (10.1)$$

where, k: constant expressing the influence of bond properties of stee1, generally permissible to be set as 1.0 in case of deformed bars

c: cover(m)

c_s : center-to-center spacing of steel

ϕ : steel diameter(cm)

σ_{se} : increment of steel stress due to bending moment(kgf/cm^2,N/mm^2)

E_s : Young's modulus of steel (kgf/cm^2,N/mm^2)

ε'_{cs} : numerical value for considering increase in crack width due to drying shrinkage and creep of concrete, and generally may be taken as 150×10^{-6}

ε_{sp} : chemical prestrain induced in restraining steel

(2) The chemical prestrain ε_{sp} induced in restraining steel shall be calculated by an appropriate method. However, with a shrinkage compensating concrete member, calculation of chemical prestrain may be omitted, in which case the size of ε_{sp} is to be identical to ε'_{cs}

[Commentary]

With members using expansive concrete, the chemical prestrain induced in steel becomes large, and when the chemical prestress induced in concrete also becomes large, flexural cracking moment becomes large. However, in the range that the acting bending moment is larger than the flexural cracking moment, the absolute strain of steel is not dependent on the size of chemical prestress induced in steel, and indicates a more or less same value, and there is almost no difference from an ordinary reinforced concrete member. This fact indicates that in a member using expansive concrete the amount of strain increase of steel occurring from an unloaded condition to a load level not less than flexural cracking load becomes smaller than in an ordinary reinforced concrete member by roughly the value of chemical prestrain. Further, when the fact that flexural cracking strength has increased is also considered, it may be considered that the amount of strain increase of steel having an effect on crack width will become smaller. However, from the facts that flexural rigidity of the member is high before occurrence of flexural cracking, and that the increment of flexural cracking strength is not so large, it was decided that the effects of these are to be ignored, and the flexural cracking width of member using expansive concrete can be calculated by E_q . (10.1). Further, for the amount of increase σ_{se} in stress of steel due to bending moment the value calculated for an ordinary concrete member is to be used.

Regarding (2) Shrinkage compensated concrete has chemical prestress of a degree to offset or reduce drying shrinkage of concrete. This has been used often and the effect has been confirmed. Therefore, it was stipulated that with shrinkage compensated concrete chemical prestress or chemical prestrain need not be calculated in particular in the limited case of chemical prestrain ε_{sp} made identical to ε'_{es} .

10.5.2 Expansion of Displacement and Deformation

In calculation of short-term displacement and deformation, the influences of chemical prestress and chemical prestrain shall be considered.

[Commentary]

Regarding bending properties of chemically prestressed concrete, flexural cracking strength increases due to chemical prestress, and as a result, displacement and deformation become smaller under identical loads. Accordingly, when calculating short-term displacement and deformation, it is advisable to adapt 7.4.3 of the "Design Volume," Standard Specifications, giving consideration to the fact that flexural cracking moment is increased by chemical prestress, and that abrupt increase in strain of steel after occurrence of flexural cracking is suppressed by chemical prestrain.

10.6 Examination of Fatigue Limit State

The examination of the fatigue limit state of a member using expansive concrete shall be made adapting the provisions of Chapter8, Examination of Fatigue Limit State "Design Volume," Standard Specifications.

[Commentary]

In a member using expansive concrete, the stress amplitude of reinforcement due to variable load becomes small from the fact that chemical prestress is induced. Therefore, with regard to fatigue strength of reinforcing steel, it will become the same as or somewhat more advantageous than for an ordinary reinforced concrete member. However, when the chemical prestrain occurring in the reinforcing steel is not very large, the influence of expansion need not be considered since there is not so much difference from ordinary reinforced concrete.

10.7 General Structural Details

10.7.1 Quantity and Method of Arrangement of Reinforcing Bars

The quantity and method of arrangement of reinforcing bars when using chemical prestressing concrete shall be selected giving consideration to expansion rate of concrete, type of structure, nature of load, configuration and dimensions of member, and method of work execution.

[Commentary]

The expansion rate and quality of concrete in a chemically prestressed concrete will differ depending on the expansive force of the concrete used, the type of the structure, the kind of load, the configuration and dimensions of the member, and the method of executing work, but the influences of the quantity and method of arrangement of reinforcing bars are the greatest. Accordingly, in order to make a concrete structure having the required performance, it is of extreme importance to pay attention to selection of reinforcing bar quantity and to the arrangement of reinforcing bars. When the reinforcing bars are small in quantity or are arranged extremely to one side in the cross section of the member, a part where expansion rate is especially high is produced and the quality of the concrete at that part may be impaired. Generally, therefore, it is advisable to select the quantity and method of arrangement of reinforcing bars so that the maximum expansion rate occurring in the member cross section during work execution and after completion will be not more than 1000×10^{-6}

10.7.2 Anchoring of Reinforcing Bar

(1) Anchoring of reinforcing bars shall be in accordance with 10.5, "Design Volume," Standard Specifications.

(2) The end of a reinforcing bar in case of using chemical prestressing concrete shall be reinforced with lateral reinforcing bars.

10.7.3 Jointing of Reinforcing Bars

(1) The joint of reinforcing bars shall be in accordance with 10.6, "Design Volume, "Standard Specifications,

(2) A lapped joint of reinforcing bars when chemical prestressing concrete is used shall be reinforced with lateral reinforcing bars.

10.7.4 Construction Joint

(1)The locations and directions of a construction joints shall be selected giving consideration to the influence of expansion, together with which selection shall be done in a manner that strength and appearance of the structure will not be impaired.

(2) Construction joints shall be clearly indicated in design drawings.

10.7.5 Contraction Joints

The locations and directions of contraction joints shall be selected for maximum effect in suppressing occurrence of cracking in the structure and shall be clearly indicated in design drawings. In such case, the influence due to expansion will be advantageous and intervals of contraction joints may be made wider than in normal cases.

[Commentary]

A contraction joint is a joint provided with t purpose of controlling cracks which occur in a structure due to phenomena such as drying shrinkage. Therefore, since the effect of expansion will be advantageous, it was stipulated that spacing can be made wider than in ordinary cases.

CHAPTER 11 DESIGN BY THE ALLOWABLE STRESS METHOD

11.1 General

(1) When designing a concrete structure using expansive concrete by the allowable stress method, Chapter 14, "Design Volume," Standard Specifications, shall be followed in general.

(2) When designing a shrinkage compensated concrete structure, the influence of expansion shall not be considered in general.

(3) When designing a chemically prestressed concrete structure, the influence of expansion shall be considered in general.

(4) The influence of expansion shall be calculated considering the type of the structure, the mix proportions of the concrete, the curing method, the amount and method of arrangement of reinforcing bars, and the restraint conditions of the surrounding ground and structures.

[Commentary]

Regarding (2) With shrinkage compensated concrete, even if there were to be a residual chemical prestress, it would be very slight and the influence of expansion on strength of the member is generally ignored, and so it was stipulated that the same examination as for ordinary reinforced concrete would be satisfactory. Consequently, with the allowable stress design method it would not be advantageous even if shrinkage compensated concrete were to be used, but cracking caused by drying shrinkage can be reduced with expansion of concrete, while in general, cracking strength can generally be increased.

Regarding (3) and (4) A chemically prestressed concrete has the effects of increasing flexural cracking load and reduction in flexural crack width under identical loads. There are also cases when the influence of expansion must be considered as one of the loads acting on a structure. Such an influence of expansion generally must be examined for the point in time when expansion becomes maximum at early age, and when subjected to the influences of drying shrinkage and creep.

11.2 Allowable Stress of Expansion Concrete

The allowable stress of concrete shall be in accordance with 14.3.1, "Design Volume," of the Standard Specifications.

[Commentary]

Reinforcing bars used for expansive concrete are required to effectively restrain expansion of concrete so that only deformed bars are used as a rule, and it is natural that the provisions regarding allowable bond stress are not applied.

11.3 Allowable Stress of Reinforcing Steel

(1) The allowable stress of reinforcing bars conforming to JIS G 3112 and used for shrinkage compensated concrete shall be in accordance with 14.3.2,"DesignVolume, " Standard Specifications,

(2) The allowable stresses of reinforcing bars conforming to JIS G3112 and used for chemically prestressed concrete shall be not more than the respective applicable allowable stresses in Tablell.1 for the cases of (a), (b), and (c) below.

(a) In case of a structure in general considering the influence of cracking, the allowable stress of reinforcing bars shall be not more than the allowable tensile stress of the general case of (a) in Tablell.1. When cracking which has occurred in concrete is especially deleterious, the allowable tensile stress of reinforcing bars shall as a rule be suitab1y selected at not more than the value of allowable tensile stress of the general case of (a) in Table ll.1. In this case, the value of allowable tensile stress shall be selected giving consideration to the expansion rate of concrete, nature of load, environmental conditions, and quantity and arrangement of reinforcing bars.

(b) In case of a member where influence of repetitive loads is extreme, the allowable tensile stress of reinforcing bar shall not exceed the value of allowable tensile stress generally determined by (b) fatigue strength in Table 11.1. However, with deformed bar proven to be of especially high fatigue strength, the allowable tensile stress may be raised more upon carrying out a thorough study.

(c) In case the influence of cracking is not considered, the allowable tensile stress of the reinforcing bar shall be the value of allowable tensile stress determined from (c) fatigue strength in Table11.1.

Table 11.1 Allowable Tensile Stress of Reinforcing Bar σ_{sa} (kgf/cm^2)

Variety of Bar	SD 295A,B	SD345	SD390
(a) Allowable tensile stress in general case	1,800 {180}	2,000 {200}	2,200 {220}
(b) Allowable tensile determined from fatigue strength	1,600 {160}	1,800 {180}	1,800 {180}
(c) Allowable tensile stress determined from yield strength	1,800 {180}	2,000 {200}	2,200 {220}

{ }: SI unit (N/mm^2)

(3) When specified concrete strength f'_{ck} is less than 180kgf/cm^2 {18N/cm^2}, the allowable tensile stress of reinforcing bar shall be not more than 1600 kgf/cm^2 {160 N/cm^2} for deformed bars.

(4) The allowable tensile stress of a reinforcing bar conforming to JIS G 3112 may be made the value of allowable tensile stress determined from (c) yield strength in Table11.1.

(5) When using a reinforcing bar other than determined from Table11.1, tests shall be conducted and allowable stress determined based on the results of the tests.

[Commentary]

Regarding (2) When cracks occurring in concrete are especially harmful to serviceability or durability of a structure such as in case of members subject to especially severe meteorological actions, members to be in contact with corrosive gases, water, and other fluids, or members especially requiring watertightness, that the allowable tensile stress of reinforcing bars must be of a value less than the allowable tensile stress for the general case of (a) in Table11.1 is the same as in the Standard Specifications. In this case, there are occasions when in important structures using ordinary concrete the exposure and other conditions of members are considered, and for SD295A and B, allowable tensile stress is lowered to around 800kgf/cm^2 {80N/cm^2}. However, for chemically prestressed concrete members, along with flexural cracking load being increased, crack widths for identical loads are small, and allowable tensile stress need not be lowered as much as for cases of ordinary concrete. This allowable tensile stress will differ depending on the expansive capacity of the expansive concrete used, the type of load and the degree of its influence, the environmental conditions under which the structure is to be placed, the quantity of reinforcing bars and their arrangement, etc., and therefore, it is to be selected taking these factors into consideration.

The reason that the allowable tensile stress of SD390 in (a) of Table11.1 was set at 2200 kgf/cm^2 {220N/cm^2} is that with chemically prestressed concrete members it is possible to reduce crack width.