

SP 64-1

The Future of Expansive Cement

By Bryant Mather

Synopsis: The future of expansive cement depends on a realization by cement users that there are circumstances where the best cement to use is one that expands. If there is an awareness that it is the optimum product for certain uses then it will be made available and its future will be assured.

Keywords: cracking (fracturing); economics; expansive cement concretes; expansive cements; marketing; research.

Honorary ACI member Bryant Mather is Chief, Structures Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. He served as president of ACI in 1964, and received the Henry C. Turner Medal from ACI in 1973. He is currently chairman of ACI Committee 308, Curing Concrete.

INTRODUCTION

I had the honor of knowing--and to some extent at least--working with both Alex Klein and Cedric Willson--from as far back as before either one of them was involved with expansive cement. I was selected to prepare this paper because I previously prepared and presented a luncheon address at the Expansive Cement Symposium at Berkeley in 1972.(1) Anyone who has been bold enough--or fool enough--to stand up at a cement symposium and preach a sermon on expansive cement was presumably regarded as bold enough--or fool enough--to speak on "The Future of Expansive Cement".

On one previous occasion--the 1970 ASTM Marburg Lecture (2)--I made predictions about the future of cement; I said:

I believe that the next two major areas for development, innovation, and improvement in specifications for portland cement will be to provide assurance (1) of greater uniformity of behavior and (2) that the cement will perform more uniformly in concrete with the selected kinds of admixtures with which it is used.

That was 7 years ago. You can each judge for yourself the probability that any part of that prediction has been or will be realized and perhaps then weigh accordingly the rest of these remarks.

USES OF EXPANSIVE CEMENT

I submit that expansive cement is a product that should be used when it is an advantage to the user of the cement to have a cement that expands. The problem the maker and marketer of expansive cement faces is how to convince the cement user that it is to his advantage to have a cement that expands. He can read ACI SP-38 (3) or any of a lot of other literature--but will he?

This problem is compounded in two ways. First: For many years in the past, in the present, and in the future, one criterion of acceptability of cement and hence one basis of its rejection as unsuitable for use has been, is, and will be a test for expansion--

if, when so tested, it expands appreciably it is, by definition "unsound" and unfit for use. Second: The phenomena that make expansive cement expansive are phenomena that are well known to be evil--and have been so recognized for a long time. This is why in my 1972 remarks in Berkeley (1) I took as one of my texts the words of the prophet Isaiah in Chapter 5, verse 20, of his prophesy: "Woe unto them that call evil good and good evil".

However it has also been recognized that there is a problem of cracking of concrete after hardening and that this problem is contributed to by many different factors--cooling, drying, and bending, among them. Cooling causes contraction; drying causes shrinkage; contraction, shrinkage, and bending all cause tension, which if in excess of the tensile strength, causes cracking. If the contraction on cooling, the shrinkage on drying, and the tension on bending can be compensated for by a prior expansion then we have a potentially powerful tool to fight cracking. It is however not the only available tool. For many purposes for which concrete is used, the members are of such dimensions and produced in such ways, that problems of cooling contraction and drying shrinkage do not arise. In somewhat different situations only relatively simple and economical measures to maintain a satisfactory moisture and temperature regime (called curing) suffice to prevent problems of cracking due to cooling and drying. In still other cases mechanical prestressing provides a satisfactory and economical solution.

Thus the question of "uses of expansive cement" devolves not merely on what it can do but on when can it do what it can do more economically than alternative methods of achieving the same goals. This is where the engineering skills come into play. The bidder who, by using expansive cement, comes up with a more economical means of accomplishing a concrete construction, will be the low bidder and hence the contractor and reap such profit as results from the job.

The foregoing scenario assumes that there has been a realization of the primary facts. First that more is needed in construction than mere absence of failure, and second that success involves locating and using a solution that rather closely approaches optimum. To do this it is essential that the concrete to be provided for use in a construction be considered from the standpoint of the desired performance of the system of which the construction is a part, the performance of the construction of which the concrete is a *part and*, finally, the performance of the concrete itself in the environment of service. If concrete fails to give satisfactory service it is either because the specifications were defective or they were not complied with. (4)

The role of expansive cement is to provide under appropriate circumstances a concrete that has appropriate levels of relevant properties so that when it interacts with the environment of service the concrete performance contributes desirably to the performance of the system of which the concrete is a part (Fig. 1).

AVAILABILITY OF EXPANSIVE CEMENT

The forces that act upon a manufacturer of hydraulic cement that ultimately determine which products are produced at a given manufacturing plant are myriad in number, complex in nature, and ever-changing in importance. Air pollution, energy costs, raw material costs, market demands, are merely the more obvious. Few are the cement manufacturers who are prepared today to come to the market with a new or different product. Few indeed are the cement producers who are willing aggressively to promote a product even if they are convinced of its usefulness. In the USSR last fall, at each laboratory I visited I kept being asked about regulated-set cement, a product invented in the United States, which once was being produced by a number of companies, but which, so the Soviet scientists had heard, is not produced widely any longer. Why not, what is wrong with it? If, in reply, one speaks of market demand, they look blank. If it's a good product it should be made and used for those purposes for which it is good. But a producer will not make regulated-set cement available, nor will he make expansive cement available, unless he is satisfied there is a market for the product.

FUTURE OF EXPANSIVE CEMENT

Having spoken in a general way of uses and availability; I now turn to the future--and the conclusion is obvious. If the awareness of the uses permeates the users, the users will create the demand, which will, in turn, cause the producers to make the product available; or so the principles of capitalism say. But who is it that causes the awareness of the uses to permeate the users? Do designers get taught in engineering schools about the benefits of using expansive cements? Do the building codes provide for differences in design when it is used? If not, why not? If expansive cement is truly the better mousetrap why isn't the path to the cement plants that make it a path to every cement plant in the world? In the USSR I formed the opinion that expansive cement was not as widely used as one might expect in view of the longer period during which it has been under development there. It seemed to me that everybody else was sort of waiting for Professor Mikhailov to do it all. This is not, I believe, the sort of problem we have. I believe our problem is merely one of inertia. Not only are there few cement producers who are willing to promote a product other than the most ordinary, but there are few specifiers who are willing to permit use of products other than the most ordinary. I believe that this will change and it must change. As we move, throughout the world, to a period of materials and energy shortages we must learn to use energy and materials more efficiently. When we begin more aggressively to seek more efficient solutions to engineering design problems we will, of necessity, find that special products have their roles to play in specific situations where they can do the job that needs to be done with maximum efficiency--which means minimum cost. Then where the

user needs a cement that will expand, he'll know that's what he needs, he'll demand it, he'll get it, and he'll be happy--and the future of expansive cement will be assured.

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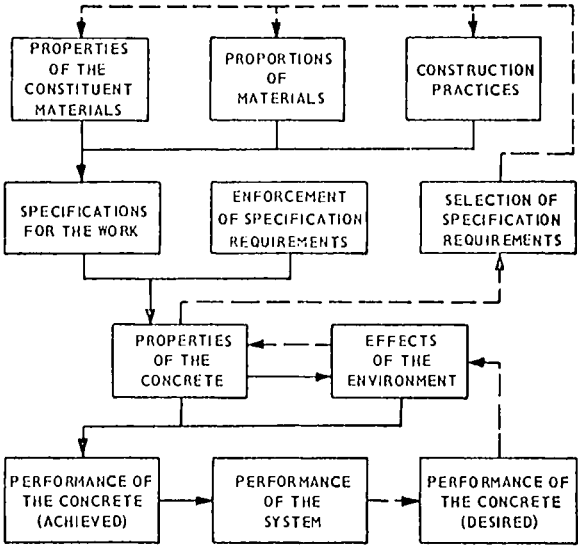


Fig. 1

SP 64-2

Hydraulic Structures Designed with Shrinkage-Compensating Concrete

By Joe V. Williams, Jr.

Synopsis: A brief description of the scope of shrinkage-compensating usage in various types of hydraulic structures is given. Effects of shrinkage-compensating concrete on reduction of drying shrinkage stresses, cracking, and water stops as potential points of leakage are discussed. Design considerations by some engineering firms with respect to shrinkage reduction, particularly in circular tanks, are outlined. Construction advantages, such as higher slumps, ease of placement, reduced honeycombing, and larger placement areas are covered. Durability factors such as freezing and thawing, deicer scaling, abrasion, and sulfate exposure are compared with portland cement concretes.

Keywords: concrete construction; cracking (fracturing); drying shrinkage; expansive cement concretes; freeze-thaw durability; hydraulic structures; seepage; shrinkage-compensating concretes; sulfate resistance.

ACI member Joe V. Williams, Jr. is presently Architectural Marketing Manager, Cement Division, Texas Industries, Inc., Arlington, Tex. He holds a BSCE degree from Southern Methodist University and is a member of ACI Committee 223, Expansive Cement Concretes and 350, Sanitary Structures. He is a registered engineer in Texas and a member of ASCE and ACI.

INTRODUCTION

The first known use of shrinkage-compensating concrete in hydraulic structures was an addition to a water treatment plant in Atlanta, Georgia in 1968, followed closely by a new water treatment plant in Midland, Tex. Since then several hundred similar structures have been completed with an ever-increasing number under construction or in the design stage.

Most all types of hydraulic structures have been constructed with shrinkage-compensating concrete. They include cooling tower basins, swimming pools, water storage tanks, walls and foundations for digesters, clarifiers, stilling basins, pump stations, outlet works, spillways, and some experimental work on a lock and dam by the U.S. Army Corps of Engineers.

LEAKAGE

Hydraulic structures are usually constructed to last for an indefinite period time, and as a result, a certain amount of conservation is exercised in the design. However, in addition to a long service life, the most important function of a hydraulic structure is its ability to contain the fluids for which they are intended without leaking.

Barring a structural failure, the primary sources of leaks are at waterstops, usually due to faulty construction, and from cracks caused when the tensile strength of the concrete is exceeded by excessive drying shrinkage in the concrete. Leakage at waterstops can be prevented by proper attention to detail in design and closer inspection during construction. Drying shrinkage cracks, however, are more difficult to control and add further cost to the structure when a more conservative design approach is used.

Some engineers are rather philosophical about cracks in concrete, believing that some will always occur no matter what precautions are taken. Others are more concerned and take extra care in their design in an effort to reduce cracking and subsequent leaking. In any case, leakage in hydraulic structures presents an unsightly appearance and tends to cast doubt on the structural integrity of the element where it occurs. The engineer must explain the cause of the leakage, and the contractor will usually have to bear the cost of repairs satisfactory to the owner.

EFFECT OF SHRINKAGE COMPENSATING CONCRETE

Research work at the Portland Cement Association laboratories on walls and slabs, the main components of hydraulic structures, demonstrate the advantage of shrinkage-compensating concrete over portland cement concrete. Pfeifer (1) concludes that "when companion walls were compared, the flexural cracking strength of the expansive cement specimen was always greater than the comparable Type I specimen. These flexural tests illustrate the advantageous effect of induced concrete compressive stresses caused by restrained expansion which minimize concrete tensile stresses caused by restrained drying shrinkage". Russell (2) states in his research on slabs that "some of the problems associated with the cracking or excessive deformation of reinforced concrete structures can be attributed to strains caused by shrinkage of concrete. Performance can be improved by either reducing shrinkage to a more acceptable level or eliminating its effects completely. A properly used shrinkage-compensating concrete achieves this. In this type of concrete, expansion takes place during the early hardening period and offsets subsequent shrinkage strains".

Thus the use of shrinkage-compensating concrete has enabled engineers to increase concrete placement sizes and thereby reduce the number of water stops as potential leakage sources. At the same time, the size and frequency of cracks have been reduced, or in many cases completely eliminated. The growing acceptance of shrinkage-compensating concrete in hydraulic structures in the United States would indicate that less leakage occurs when it is used.

DURABILITY

Still another consideration in hydraulic structures is the durability of the concrete. As stated before, length of service under extreme weather conditions and other outside influence is most important. Such durability can and is being obtained with shrinkage-compensating concrete. Recommendations of ACI Committee 223 (3) state that shrinkage-compensating concretes made with expansive cements are equally resistant to freezing and thawing, and deicer scaling and abrasion as portland cement concretes of the same water-cement ratio, when properly designed and adequately cured.

In many instances, hydraulic structures are subjected to sulfate exposure, and either Type II or Type V portland cement concrete is then used. When shrinkage-compensating concrete is used under sulfate exposure conditions, a check of the chemical properties should be determined. Some shrinkage-compensating cements made with Type I portland cement may be undersulfated with respect to the aluminate available. As a result, the concrete could be susceptible to further expansion and deterioration after hardening when exposed to

an external source of additional sulfates. Shrinkage-compensating cements made with a Type II or Type V portland cement clinker, however, when adequately sulfated, produce concretes having sulfate resistance equal to, or greater than, concrete made of the same type portland cement (4).

DESIGN CONSIDERATIONS

An increasing number of engineers are also utilizing the advantages of shrinkage-compensating concrete in their design procedure. For example, circular concrete tanks are most often designed by methods recommended by the Portland Cement Association. (5) The concrete stress due to ring tension is determined from the equation

$$f_c = \frac{CE_s A_s + T}{A_c + nA_s}$$

where C is the coefficient for shrinkage with an assumed value of 0.0003. When using shrinkage-compensating concrete, some engineers are reducing this coefficient in varying amounts to as much as zero. Depending on the configuration of the structure involved, a reduction in wall thickness can sometimes be achieved.

Other design advantages with shrinkage-compensating concrete are larger placement areas and fewer joints, as mentioned previously, and a possible reduction in reinforcement for drying shrinkage purposes.

A Dallas-based firm has another approach. When using portland cement concrete in circular structures, the allowable tensile stress due to ring tension is limited to 250 psi. When shrinkage-compensating concrete is used, the allowable tensile stress is increased to 350 psi.

CONSTRUCTION

This same firm currently has under construction a large waste water treatment facility near Dallas for the Trinity River Authority. When completed, the plant will have a capacity of 100 mgd with 96% removal of influent impurities. It will be capable of 250 mgd with a removal of 70% of the impurities, about the national average.

The project is actually an enlargement of an existing outmoded facility using open lagoons. Construction was scheduled in three phases: Interim, Phase I, and Phase II.

The largest part of the Interim Phase included construction of four equalization basins which were to be used as primary clarifiers until completion of the entire plant. The contractor was allowed a maximum placement dimension of 50 ft with portland cement concrete, but when shrinkage-compensating concrete was used, the placement limitation was a 3:1 ratio. On most of the work, the contractor kept within the 50 ft limitation; however, in several walls he elected to construct walls approximately 70 ft in length using shrinkage-compensating concrete.

An examination of the walls prior to use revealed numerous cracks in the portland cement concrete with occasional hairline cracks in the shrinkage-compensating concrete work. As a result, specifications for Phase I called for shrinkage-compensating concrete in all the water-holding basins and a 30 ft maximum placement length on the other structures where portland cement concrete was to be used. Because of this limitation, the contractor opted for the shrinkage-compensating concrete on most of the other work.

Phase II specifications required shrinkage-compensating concrete for all structures with the exception of pier work. Phase I and II are proceeding simultaneously, and when completed will have used about 100,000 cu yd of Type K shrinkage-compensating concrete.

Contractors, too, have found advantages in the use of shrinkage-compensating concrete in hydraulic structures. In addition to the larger placement areas and reduced construction joints and water stops, the higher recommended slump for shrinkage-compensating concrete increases the placement rate, requires less vibration, and results in less honeycombing.

CONCLUSION

As stated earlier, many hydraulic structures have been constructed with shrinkage-compensating concrete, and more are being planned. With the continuing growth in population and stricter requirements for water and sewage treatment by the Environmental Protection Agency, the prospects for increased use of shrinkage-compensating concrete for water and waste treatment facilities are quite good.

Many engineers have several years of experience with shrinkage-compensating concrete and have had an opportunity to compare its performance, sometimes on the same job, with portland cement concrete. As additional technical knowledge becomes available in the design field, the engineer will be able to gain further advantages from the use of this material. A prediction for the future is that shrinkage-compensating concrete may well become a standard product in all types of hydraulic structures.

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SP 64-3

Utilization of Shrinkage-Compensating Concrete—A Cold Storage Warehouse Application

By Charles A. Gaskill and Richard C. Jacobs

Synopsis: Expansive concrete has been used in a variety of warehouse applications but not under multiple temperature conditions. In addition, job data to support degrees of shrinkage compensation has been limited.

This project was used to compare slab design theory with on-site analysis of concrete expansion and shrinkage. Measurement pins were placed at 50 ft (15.24 m) and 100 ft (30.48 m) intervals and arranged to measure center and edge slab movement under a variety of restraint and temperature conditions.

Keywords: cold weather constructions; concrete construction; concrete slabs; construction costs; drying shrinkage; expansive cement concretes; flexural strength; low temperature; placing; punching shear; shrinkage-compensating concretes; thermal properties; warehouses.

ACI Member Charles A. Gaskill is the Vice President of Engineering and Principal of WBDC, Inc., Architects, Engineers, Planners, Grand Rapids, Mich. He is a Registered Professional Engineer in the state of Michigan, and for the past 19 years has specialized in structural design for buildings.

ACI Member Richard C. Jacobs was a technical service engineer with the Cement Division of Penn-Dixie Industries, Inc. A graduate in Concrete Technology at Alpena Community College and Civil Engineering at Lawrence Institute of Technology, Mr. Jacobs was also involved with local technical committees and a professional member of the Post-Tensioning Institute. Mr. Jacobs died in September 1977.

INTRODUCTION

The ability of shrinkage-compensating cement to induce sufficient compressive stress in properly reinforced concrete, which reduces the tensile strain produced through normal drying shrinkage, is generally understood by those concerned with the performance of reinforced concrete.

This paper deals with a cold storage application with working temperature from -10 F (-23.33 C) to +40 F (4.44 C). The building is located in the southwestern part of Michigan for the purpose of distributing prepackaged meat products and frozen foods from the manufacturer (supplier) to retail grocery outlets. This paper presents the results of project planning and on-site analysis of shrinkage-compensating concrete subjected to both the drying shrinkage and thermal contraction associated with a cold storage warehouse.

The design called for an area of 61,300 sq ft (5695 sq m) at a temperature of -10 F (-23.33 C) with an ancillary area of 34,600 sq ft (3214 sq m) to +40 F (4.44 C). Because of the one-building concept, special considerations were required for the separation of various temperature ranges (Fig. 1).

The structural support of the floor slab consists of engineered compacted sand fill; 8 in. (20.32 cm) precast concrete cellular plank (laid directly on sand); vapor barrier; 8 in. (20.32 cm) of high density insulation (foam sheets) applied in 2 in. (5.08 cm) layers; and a 6 in. (15.24 cm) thick concrete slab (shrinkage-compensating concrete), constructed with a monolithic high-abrasion floor hardener (Fig. 4).

DISCUSSION

While planning any warehouse floor, the structural engineer has three basic design considerations: (1) punching shear, (2) flexural stress under load, and (3) negative moments in unloaded areas. It is the engineer's responsibility to isolate and economically satisfy the requirements of the most critical condition.

The design considerations for the floor slab in a cold storage warehouse become more complicated through the limited ("k") factor offered in the subgrade insulation medium.

Shrinkage-compensating concrete can offer a benefit to each of the basic design considerations in the following manner:

Punching shear: Shrinkage-compensating concrete provides compressive strengths equal to or greater than normal portland cement concrete with the same constituents. (1)

Flexural stress under load: As indicated with compressive strength, both flexural and tensile strengths are improved with shrinkage-compensating concrete.

Negative moment: Negative moments are best illustrated by joint failure and slab settlement through nonuniform loading. Since shrinkage-compensating concrete allows larger placement areas which are undisturbed by control joints, the entire placement area can provide continuity for load support.

Because of the type of building and its high use factor, maintenance costs become a major consideration over the life expectancy of the facility. If failures do occur, it has a monumental impact on the operation. The economics of shrinkage-compensating concrete allow advantages in two ways: (1) larger placement areas allowed the location of construction joints under storage racks and an overall reduction in the joint footage exposed to traffic, and (2) a reduction in joint footage reflects a reduction in owner maintenance costs. This project required all joints (construction and control) to be filled with a low-temperature sealant. The total footage of joint reduction by substituting shrinkage-compensating concrete for conventional concrete, compared with the joint sealing costs for both systems, reflected a substantial savings in the use of shrinkage-compensating concrete.

Initial cost: Through the use of expansive concrete, the quantity of joints is reduced significantly. Fig. 2 illustrates the floor plan as it would have appeared using conventional concrete with total jointing as follows:

Construction joints: 2 @ 252 ft (76.8 m)

5 @ 380 ft (115.8 m)

Total construction joints: 2404 ft (732.7 m)

Control Joints: 9 @ 252 ft (76.8 m)

6 @ 380 ft (115.8 m)

Total control joints: 4548 ft (1386.2 m)

In addition, all column box-outs would have been formed prior to slab placement and filled at sometime following the placement. This procedure adds an empirical cost to construction.

The expansive concrete approach as illustrated by Fig. 3 offered versatility with the following total joints:

Construction joints: 2 @ 252 ft (76.8 m)

2 @ 210 ft (64.0 m)

Total construction joints: 924 ft (281.6 m)

As is typical of expansive concrete usage, all control joints were eliminated and all column isolations were cast with the slab placement. In general, the use of expansive concrete eliminated 87% of the joint cost and offered the owner a net savings on initial construction costs.

Maintenance cost: As in any warehouse facility, heavy hi-lo traffic exists creating high impact loads at floor joints. Joint repair cost per year (based on semi-annual maintenance) = \$2.00/linear ft (0.3048 m).

Since the longitudinal construction joints are concealed under storage racks, only the transverse construction joints which cross aisle ways are exposed to traffic loading and maintenance expense. Due to the building lay out, less than 100 ft (30.5 m) of joint are subject to maintenance expense.

In arranging the floor plan to utilize shrinkage-compensating concrete, it must be realized that thermal properties of shrinkage-compensating concrete are similar to those of conventional concrete (2). As illustrated in Fig. 3, there were several predetermined breaks between slabs. The 2 in. insulation strip was provided to minimize temperature transfer between adjacent storage areas with different room temperatures. The location of construction joints in the freezer portion of the building (designated as -10 F) (-23 C) required careful planning. The insulation medium offered very little subgrade friction, therefore allowing uninhibited slab movement for

both expansion and thermal contraction. The total placement area was based on two considerations: first, the tensile stress on interior columns could not exceed the tensile strength of the concrete; secondly, it was difficult to predict the effects of concrete temperature, slump variations, maximum size of coarse aggregate, cement content, mixing time, restraint, curing, and building temperature on total concrete shrinkage. In predicting the construction joint locations, a value for drying shrinkage was considered to be 0.03% (3) and thermal contraction as 5.5 (4) millionths per degree Fahrenheit (0.776×10^{-5} cm per 1 C). If the shrinkage-compensating concrete fully compensated for the 0.03% drying shrinkage, thermal contraction could be expected to reach $\frac{1}{2}$ in. (1.27 cm) in 100 ft (30.48 m) for an 80 F (26.67 C) change in temperature. With the possibility of encouraging concrete chippage when the joint opening exceeded $\frac{1}{2}$ in. (1.27 cm) and the elastic limit of the joint sealer was somewhat limited to $\frac{1}{2}$ in. (1.27 cm), placement areas were held to 105 ft (32 m) x 84 ft (25.6 m).

CONCRETE

The physical properties and other details of the concrete used during the tests are given in Tables 3 through 8.

SCOPE OF TEST PROCEDURE

Measurement pins were placed in the concrete at locations noted on the floor plan. The measurement set consisted of a brass plug and a 4 in. (10.16 cm) machinist scale attached to a $\frac{1}{4}$ in. (0.635 cm) x 2 in. (5.08 cm) x $3\frac{1}{2}$ in. (8.89 cm) piece of flat stock. The measurement pins were placed at approximate intervals of 50 ft (15.24 m) and 100 ft (30.48 m) with a surveyor's tape while the concrete was in an initial set condition. Initial and subsequent measurements as listed in the Slab Expansion Chart given in Tables 1 and 2 were made with an Invar tape, which is exclusive of any temperature corrections.

TEST DATA

SET A 100 ft (30.48 m)--Typical of the first concrete placement. This slab was free from external restraint for 14 days and reflected the most expansion at 28 days. Measurement was taken at this location to compare unrestrained (external) expansion under field conditions with the values obtained under laboratory conditions. As noted in Table 1, the 7-day expansion of 0.039% offered 100% efficiency when compared with the 0.038% value for laboratory controlled 7-day expansion (5).

SETS B and C 100 ft (30.48 m) and 50 ft (15.24 m), respectively-- These sets were established to measure midslab movement with external restraint on three sides. Expansion dropped considerably from that of Set A, but the slab did remain in compression at 28 days.

SETS D and E 100 ft (30.48 m) and 50 ft (15.24 m), respectively-- These sets were established to measure slab edge movement providing full restraint within seven days. Slab expansion was rather low with the concrete reaching a tensile range within 28 days.

SET F 50 ft (15.24 m)--Set F was established to measure larger slab movement with full restraint from date of placement. Measurement did show some expansion even though completely restrained. Some of this movement could be explained as compressing the 2 in. insulation strip.

CONCLUSIONS

Set A--Set A was intended to reflect maximum field expansion to compensate for drying shrinkage on a specific project. Since the approximate expansion potential of the concrete used on this project was 0.038% at 7 days, we can reflect a maximum field efficiency of 100%.

As indicated by the extended measurements in the 20 F range, a small degree of expansion was present. By retaining expansion up to this date, complete shrinkage compensation was made.

Sets B-C and D-E--In both Sets B-C and D-E, the slabs were subject to some external restraint with both being restrained on three sides within 7 days. Sets B-C reflected much higher measurement readings with pin placements in midslab. Since Sets D-E were placed directly over the construction joint dowels, the increased restraint tended to produce slab warpage in a horizontal dimension. In both cases, however, near complete shrinkage compensation was available at 28 days.

Set F--Set F was virtually subjected to full external restraining. Set F had some expansion. Since the slab dimensions were larger than the previous slabs, we feel a portion of the expansion was reflected through the elastic limits of the concrete and a portion reflected through compression of the insulation strip.

Visual Inspection: Up to the date of initial cool down (approximately 120 days), all slabs remained crack-free. At approximately the same time, while the building temperature was in excess of 35 F (1.67 C), the crack pattern illustrated on the floor slab plan (Fig. 3) around columns appeared. Even though the structural steel flange was boxed-out with fiberboard to prevent interlock, the bulkheads were placed against the columns. The procedure enabled the column to be

encircled by a narrow section of concrete. Consequently, the effective concrete fiber was too small to resist the maximum tensile strain at slab perimeter. These cracks are approximately $\frac{1}{4}$ ft (1.22 m) long from end to end and are protected by storage rack location. Crack prevention could be provided by column isolation to the construction joint as noticed in the 30 F (-1 C) and 34 F (1 C) areas. Construction joints in these areas were located at column edge since the insulated panels are supported by the columns.

Circular interior column isolation was provided as illustrated in Fig. 4. The circular isolations minimized stress buildup and remain crack-free.

Various cracks have appeared in the deck area which is not subject to extreme thermal change. These cracks have appeared even though stress bars were provided at re-entrant corners. We would recommend the use of construction joints or complete slab isolation as a method of prevention.

In general, all slabs provided compensation for drying shrinkage. The degree of joint opening after thermal contraction was directly related to the sequence of placement.

In areas using consecutive placements, the joint openings were limited to $\frac{3}{8}$ in. (0.95 cm). In areas which allowed peak expansion at 5 to 7 days between slab placements, the reflected joint opening was $\frac{1}{2}$ in. (1.27 cm) to $\frac{5}{8}$ in. (1.59 cm).

Based on slab performance up to this time, shrinkage-compensating concrete can be considered an economic asset to cold storage warehousing.

As in all construction, the lines of communication between Architect, Owner, Engineer, Contractors, and Concrete Supplier are most important. These lines were provided on this project and were obviously successful.

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SLAB EXPANSION IN %										
REFERENCE NO.	AGE IN DAYS					TEMPERATURE - °F - (°C)				
	12 HR	3	5	7	28	30° (-1°)	20° (-6.7°)	10° (-12°)	-10° (-23°)	HOLD
SET B	.013	.031	.036	.039	.016	.014	.008	-.009	-.019	-.029
	.010	.029	.036	.039	.016	.016	.007	-.010	-.020	-.030
	.013	.031	.034	.039	.010	.017	.009	-.010	-.021	-.029
	.010	.031	.036	.034	.013	.014	.008	-.009	-.020	-.028
	.013	.031	.036	.039	.016	.014	.008	-.009	-.020	-.030
	.012	.031	.036	.039	.014	.015	.008	-.009	-.020	-.029
SET C	.010	.023	.026	.026	.008	-.090	-.011	-.019	-.026	-.031
	.013	.023	.026	.025	.006	.011	.010	-.018	-.027	-.033
	.013	.023	.023	.026	.006	-.010	.010	-.018	-.027	-.032
	.008	.021	.026	.026	.007	-.010	.011	-.016	-.025	-.033
	.013	.021	.023	.025	.008	-.010	-.010	-.018	-.026	-.032
	.011	.022	.025	.026	.007	-.010	-.010	-.018	-.026	-.032
SET C 50 FT. (15.24 M)	.011	.021	.023	.023	.010	-.006	.011	-.017	-.024	-.031
	.011	.020	.023	.022	.009	-.005	-.010	-.017	-.025	-.033
	.010	.019	.026	.024	.010	-.006	.010	-.018	-.025	-.031
	.010	.020	.024	.025	.010	-.006	.009	-.019	-.026	-.031
	.010	.021	.023	.025	.008	-.006	-.011	-.018	-.026	-.031
	AVG	.010	.020	.024	.009	-.006	-.010	-.018	-.025	-.031

Table 1--Slab expansion (in percent)--Sets A, B, and C

SLAB EXPANSION IN %										
REFERENCE NO.	AGE IN DAYS					TEMPERATURE - °F - (°C)				
	12 HR.	3	5	7	28	30° (-1°)	20° (-6.7°)	10° (-12°)	-10° (-23°)	HOLD
SET "D" 100 FT. (30.48 M)	.004	.010	.011	.013	.003	-.006	-.009	-.016	-.022	-.032
	.006	.011	.012	.013	.000	-.006	-.008	-.015	-.025	-.030
	.004	.011	.011	.014	.001	-.007	-.009	-.015	-.025	-.030
	.005	.011	.011	.012	.001	-.006	-.009	-.017	-.024	-.029
	.005	.011	.012	.014	-.001	-.006	-.009	-.015	-.022	-.030
	AVG.	.005	.011	.011	.013	-.006	-.009	-.015	-.024	-.030
SET "E" 50 FT. (15.24 M)	.007	.011	.013	.015	.003	-.004	.010	-.017	-.021	-.028
	.005	.013	.013	.015	.001	-.004	.012	-.016	-.022	-.027
	.006	.010	.011	.015	.001	-.005	.011	-.016	-.022	-.027
	.006	.013	.013	.015	.000	-.004	.010	-.017	-.022	-.029
	.006	.013	.013	.015	.000	-.005	.010	-.016	-.021	-.028
	AVG.	.006	.012	.013	.015	-.004	.011	-.016	-.022	-.028
SET "F" 50 FT. (15.24 M)	.011	.022	.039	.037	.020	.016	.012	.000	-.009	-.022
	.009	.021	.036	.037	.019	.017	.011	.001	-.010	-.020
	.010	.021	.038	.040	.020	.017	.012	.001	-.011	-.021
	.010	.022	.037	.037	.021	.016	.011	.001	-.009	-.020
	.009	.021	.038	.038	.021	.017	.012	.001	-.010	-.020
	AVG.	.010	.021	.037	.038	.017	.012	.001	-.010	-.020

Table 2--Slab expansion (in percent)--Sets D, E, and F

Table 3--Mix Design Criteria

Minimum strength	3750 psi (263.66 kg/cm ²)
Cement content	517 lb (234.5 kg)/cu m
Slump	4 to 6 in. (10.16 to 15.24 cm)
Air Content	3 to 5 percent
Method of placement*	Pump ~ 300 ft (91.44 m) (horizontal)

*"Cold Weather Concreting", ACI 306-66

Table 4--Mix Design

Cement	517 lb (234.51 kg)
Fine aggregate*	1120 lb (508.43 kg)
Coarse aggregate*†	2190 lb (993.37 kg)
Water	305 lb (138.35 kg)
A.E.A.	$\frac{1}{2}$ oz/100 lb (14.78 cm ³ /45.36 kg)

*ASTM C 33

† $\frac{1}{2}$ in. maximum

Table 5--Physical Properties
(Laboratory)

Slump--initial	5.25 in. (13.34 cm)	Unit Weight	151.8 lb/cu ft (0.43 g/cm ³)
Slump--final	4.50 in. (11.43 cm)	Yield	27.22 cu ft/cu yd (1,008,148 cm ³ /m)
Air content	4.2%	Extended Cycle	6.3%
		7-Day Strength	3420 psi (240.46 kg/cm ³) 3480 psi (244.68 kg/cm ³)

Table 6--Concrete Expansion at 73 F (22.2 C)

Day	Percent
1	0.026
2	0.037
3	0.037
6	0.035
7	0.038

Table 7--Physical Properties (Field)

Test	Date	Slump, in. (cm)	Air content, percent	Unit weight, lb (kg)	28-Day Strength, psi (kg/sq cm)	
1	1/09/75	4.5 (11.43)	4.4	150.9 (68.45)	4,863 (341.92)	4,845 (340.65)
2	1/10/75	4.0 (10.16)	4.0	151.6 (68.76)	5,040 (354.36)	4,951 (348.10)
3	1/14/75	4.0 (10.16)	4.3	150.7 (68.41)	4,669 (328.28)	4,669 (328.28)
4	1/15/75	4.2 (10.67)	4.2	151.0 (68.49)	4,792 (336.92)	4,800 (337.49)
5	1/16/75	4.5 (11.43)	4.4	150.9 (68.45)	5,111 (359.35)	5,005 (351.90)
6	1/17/75	5.0 (12.7)	4.2	150.8 (68.40)	4,315 (303.39)	4,460 (313.58)
7	1/21/75	4.2 (10.67)	4.5	151.0 (68.49)	4,828 (339.46)	4,845 (340.65)

Table 8--Averages

Average concrete temperature:

64 F (17.8 C)

Average building temperature:

54 F (12.2 C)

Curing - 7 days

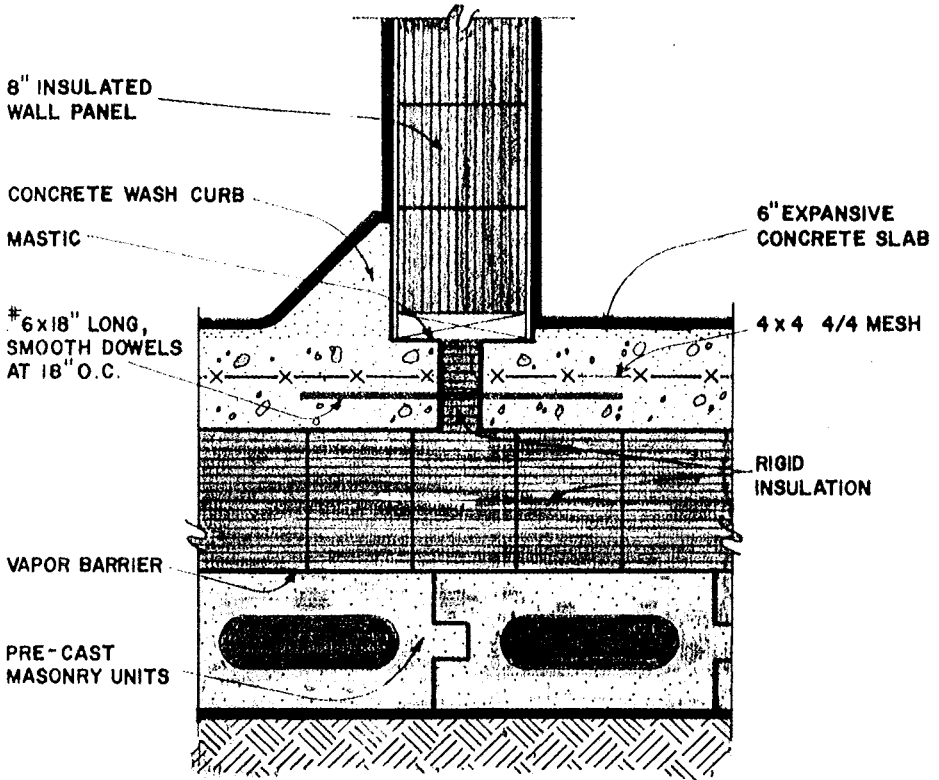
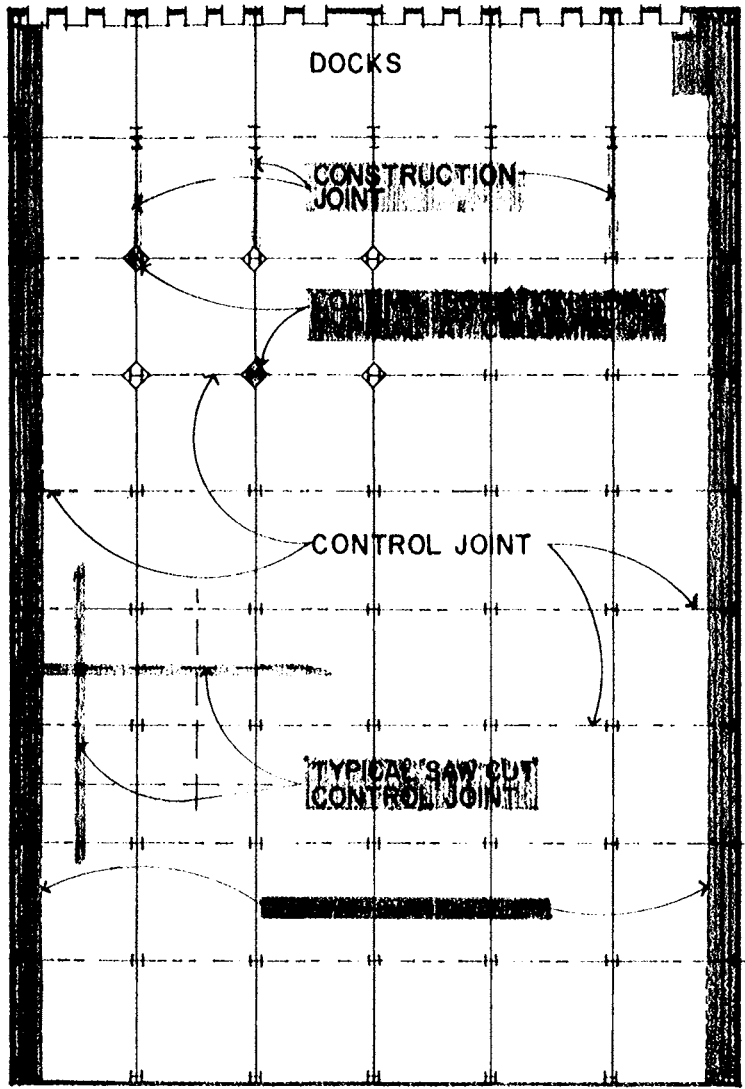


Fig. 1--Typical slab isolation between temperature ranges

**FROZEN FOODS WAREHOUSE
FLOOR SLAB PLAN (STANDARD CONCRETE)**
LINEAR FEET (METERS) OF JOINT = 3916'-0" (1193_m)



TEMPERATURES AND DIMENSIONS ARE IDENTICAL TO THOSE SHOWN ON FIG. 3

Fig. 2--Frozen foods warehouse floor slab plan (standard concrete)

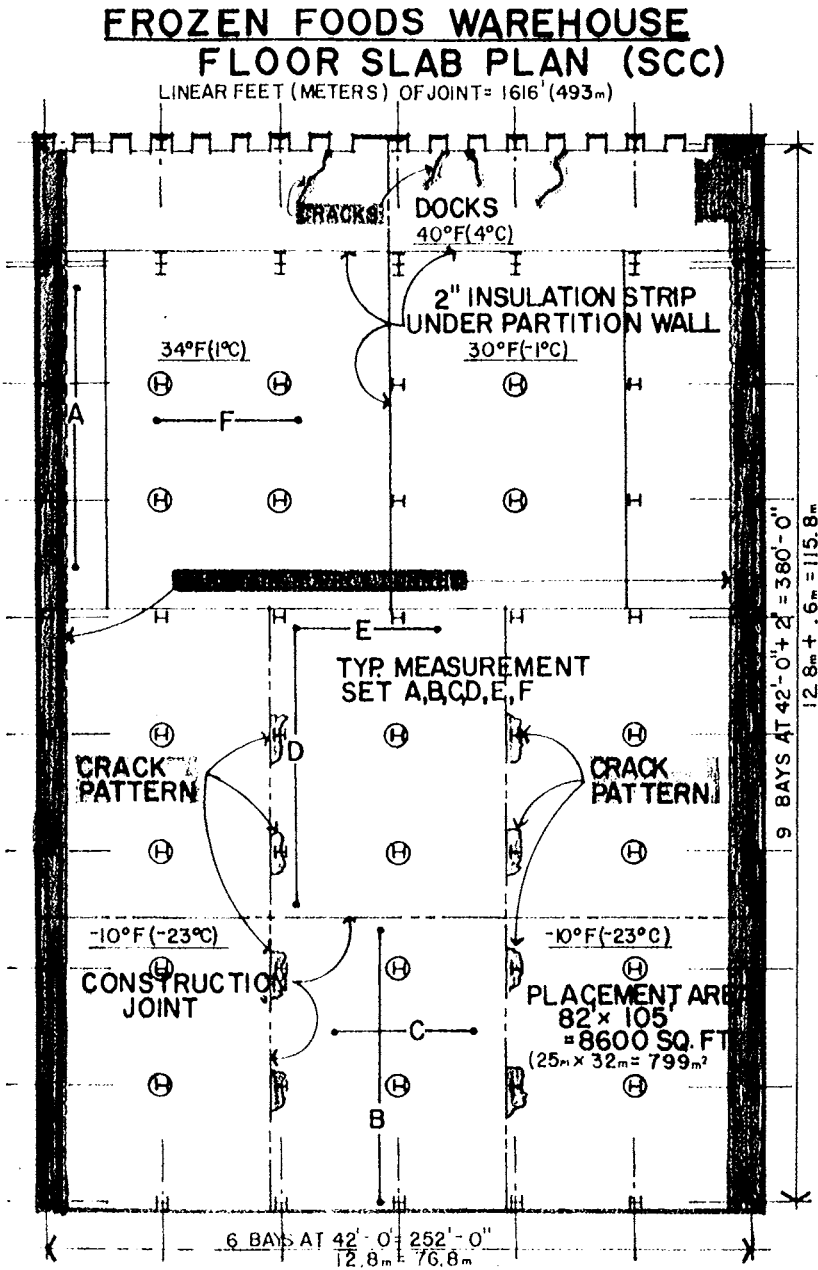
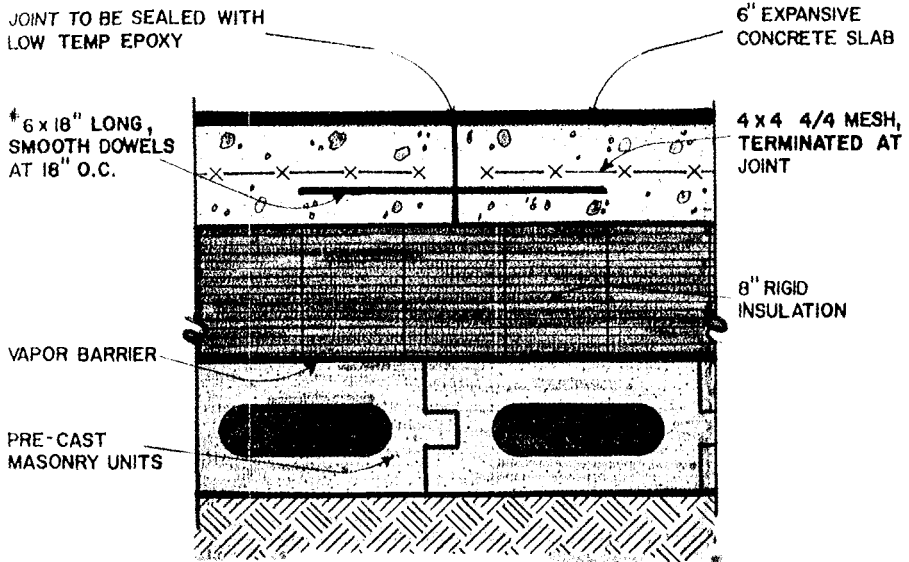
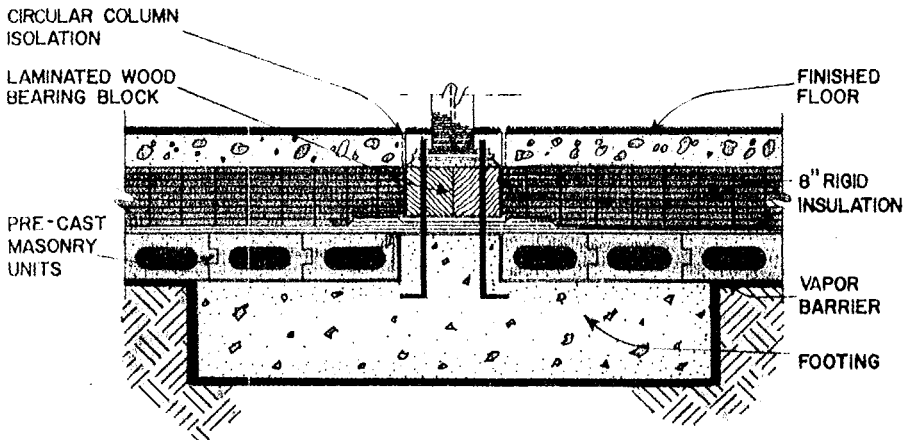


Fig. 3--Frozen foods warehouse floors slab plan (shrinkage-compensating concrete)



TYPICAL CONSTRUCTION JOINT



SECTION THRU FOOTINGS

Fig. 4--Typical construction joint; section through footings

SP 64-4

Use of Shrinkage-Compensating Cement Concrete in the Dallas Municipal Center

By Jack E. Rosenlund

Synopsis: A description of the role of the architect, engineer, laboratory, and contractor in the design and construction of this all cast-in-place concrete structure is given. Discusses shrinkage control to reduce cracking, and the dual role played by shrinkage-compensating concrete and post-tensioning in achieving this. Explains field, as well as laboratory, testing of concrete to determine effect and amount of expansion experienced.

Keywords: concrete finishes (hardened concrete); cracking (fracturing); drying shrinkage; field tests; laboratories; post-tensioning; public buildings; shrinkage-compensating concretes.

ACI member Jack E. Rosenlund is president of Rosenlund & Company, Consulting Engineers, Dallas, Tex. He has a BSCE from Southern Methodist University and a MSCE from the University of Minnesota. He is a registered engineer in Texas, as well as several other states. He received the ACI Construction Practice Award in 1958, for his paper "The Design and Construction of the Dallas Memorial Auditorium".

INTRODUCTION

As early as 1965, the City of Dallas saw the need for a new building to house the city government of one of the fastest growing cities in the United States. Under the guidance of a progressive mayor and city council they sought not only to satisfy this need functionally, but also architecturally and environmentally.

Located directly across from the Convention Center which hosts many thousands of visitors annually, the Dallas Municipal Center needed to be a structure that was pleasing to any viewer and one which would express the welcome and hospitality of its citizens. Internationally known architect, I. M. Pei and Partners, and Harper & Kemp were charged with this dual task, and I believe the result speaks for itself.

DESCRIPTION

The Dallas Municipal Center can best be described as an inverted half pyramid housing seven levels of office space, one level for mechanical equipment and two lower levels. The entire building is 560 feet in length but varies at every level in width. The basement areas are 230 feet wide, the first level is 126 feet wide, and each succeeding floor increases by 9'-4" in width to a final dimension of 200 feet at the top.

In front of the building's center is a plaza/park of 2 city blocks in area which covers a 2-level underground parking garage with a capacity of over 1300 cars. The floor to floor height of the building proper is 14 feet. Mechanical and electrical services are in 14'-0" wide cores serving 65'-4" wide office spaces in an 8" high false floor. The striking and unique feature about the building is that it is an all cast-in-place structure with exposed concrete bearing walls as main support elements carrying floors of a 3'-0" deep coffer or waffle system. This waffle system also serves as an exposed ceiling.

The building is designed on a 4'-8" grid module in both directions. There are 520,000 sq ft of space above grade and 250,000 sq ft below grade. The cost was approximately \$32,000,000.

There are some 84,000 cu yd of concrete in the project, of which 60,000 cu yd were cast with a buff colored, Type K, shrinkage-compensating concrete. Some 6,000 tons of mild steel, predominantly 60 ksi grade, and 450 tons of 270 ksi grade post-tensioning cables were used.

STRUCTURAL ASPECTS

Our firm started working on the project in early 1967 doing some preliminary designs, establishing structural depths, wall thicknesses, etc. However, construction did not commence until 1972 due to a delay in the city bond program. Shortly thereafter, the architect, contractor, and engineer made a tour of several projects of cast-in-place exposed architectural concrete. These were of different finishes varying from board form, plastic coated form, bush-hammered, and sand blasted. We saw structures with cracks, some small, some not so small, but on the whole, structures which were pleasing, attractive, and accomplished what the architect intended in regard to architectural appearance and load bearing frame. None of these structures contained shrinkage-compensating concrete.

It became apparent from this tour, and also from the shape of the bearing walls, the openings through them, and the fact that concrete has been known to crack from temperature changes and shrinkage, that a concerted effort was required on our part to eliminate or reduce whatever causes that result in cracks in concrete. As can be seen, the main bearing walls cantilever to the outside creating giant brackets (Fig. 1) on which floors spanning 65'-4" (Fig. 2) for office space and 14'-0" for service space are supported. In our estimation, the change in shape where the bracket becomes the least dimension appeared to be a potential crack location, not only from a structural shear aspect, but also from a shrinkage point of view.

These giant load bearing brackets were designed to be post-tensioned both horizontally and vertically for strength and stability. In order to post-tension, of course, the concrete must be strong enough to take the compression due to tensioning. On this project, generally all concrete was specified as 4000 psi at 28 days (some concrete reached 5000 and 6000 psi) with tensioning strength set at 3500 psi. Tensioning usually was accomplished at 5 to 6 days and in some cases at 4 days. Since shrinkage begins almost immediately after placing concrete, it was important to use whatever means we could to overcome shrinkage strains. Therefore, the 4 or 5-day strength gain time for tensioning was not as important in controlling shrinkage stress as it was to assist the contractor in expediting the construction.

We had had some experience with shrinkage-compensating concrete on a very large warehouse a year or two before. This was a four story building of some 1,000,000 sq ft with 250 psf live load. On the whole the shrinkage-compensating concrete was successful in reducing shrinkage cracking, although some cracking was experienced in topping over structural slabs.

If a graph is plotted of time versus shrinkage for Portland cement concrete and for shrinkage-compensating cement concrete, it can be seen there is an increase in volume for the shrinkage-compensating cement concrete compared with a decrease in volume of the Portland cement concrete. Naturally, the manufacturer's claims were checked in the lab for verification. Generally there was increase in volume, but generally not quite as much as the manufacturer claimed. It was learned that expansion was greater when a 6-inch slump at the pump discharge end of the line was maintained in comparison to lower slumps.

ARCHITECTURAL CONSIDERATIONS

Architecturally the building has the overpowering shape of being larger at the top and smaller at the bottom. During space studies with the City of Dallas it was found that larger floor areas were required on the upper floors to serve the mode of operation of the city government. The ordinary citizen's business could be taken care of on the lower levels which required less space. The architect also felt the sloping north face had the effect of welcoming anyone to the city government center. The site is located on the south section of the central business district on property that was cleared of old two and three story buildings, parking lots, and low tax revenue producing land. The building effectively upgrades the area. The buff color of the shrinkage-compensating concrete has a very pleasing appearance and is a harmonious blend of architectural finish concrete and structural load bearing concrete. Originally designed for board form finish, the form work was changed to Finn Form to expedite construction. Careful consideration was given to structural and architectural features in locating construction joints. All joints in the walls were located at form panel joints and no farther apart than 70 feet. In my estimation, the contractor did a commendable job in obtaining the designed architectural finish.

ROLE OF TESTING LABORATORY

All concrete work was finished by mid-September 1977. However, the testing laboratory started almost as early as the design team. In 1969 the lab started gathering aggregates, cement samples, form materials, etc., and cast more than fifty sample panels. The panels were 18" x 24" x 3" and each one of a different mixture of aggregates, aggregate proportions; slumps, etc. They were all of normal Portland Type I cement and some blends. Then, when Type K shrinkage-compensating cement became available in a buff color, all these tests were repeated. Originally, the minimum cement content was six sacks per yard. However, in order to effect an economy, the cement was reduced to 5 3/4 sacks. Later, the mixture was revised by increasing the coarse aggregate factor in order to help reduce shrinkage, which in turn reduced the sand. Finally, to maintain

constant cement/sand ratio, the cement was reduced to 5 1/2 sacks. With this reduced cement content, the contractor was still able to maintain the specified 28-day strength of 4000 psi without an effect on color or texture. There were times during good weather that 5000 psi concrete was obtained. It was also learned that increasing the slump to six inches was necessary to activate all the expansive components in the cement. The high slump, or more than normal water, also brought about a problem of slight bleeding on the vertical surfaces, resulting in some undesirable surface defects which became prevalent after sand blasting. It became a precise operation for the laboratory to control the concrete so as to have enough water to fully utilize the shrinkage-compensation of the concrete without having too much water to cause surface defects. A maximum concrete placing temperature of 85 F was specified, which in hot weather, required cold water or ice to be used frequently. This was deemed necessary to help control slump loss and reduce the amount of water added at the job site. The temperature control was also maintained to help disburse the heat build-up by hydration and outside temperature. Specifications required that the concrete in the walls be placed in 12" to 18" lifts to control bleeding, but field forces have a tendency to overlook some recommendations, and some times the concrete was placed in 3 to 5 foot lifts.

Before construction began on the building, a mock-up was constructed on the site at a cost of some \$100,000. The mock-up was 14'-0" wide 23'-4" long and one-story in height. The roof of the mock-up building was the typical 4'-8" square coffer ceiling. Not only was the mock-up used to "get a feel" for the architecture, it provided the laboratory an opportunity to test the concrete for shrinkage-compensating characteristics, time-of-set and rate of temperature gain. For example, strain gauges were placed in selected areas to determine if tension developed in the reinforcement due to expansion in the concrete. In all cases there was some strain in the concrete and the reinforcement.

The manufacturer's literature claims a range of expansion of 0.03 to 0.1 percent expansion of concrete. The lab and field tests showed expansion more in the range near 0.03 percent of the mortar. However, there was more interest in obtaining a residual increase in volume of the concrete rather than just percent expansion.

CRACK REDUCTION

In the early construction stages, occasional hair-line cracks in walls created some anxiety on the part of the architects. Since work was still in the lower levels, every effort was made to keep the cracks to a minimum. All phases of construction were reviewed, and some changes were made in the mix design, placing techniques and curing procedures.

It was known from the test work on the mock-up that job concrete was producing expansion, but what was not known was how much it was helping in crack reduction.

From previous field tests, it was determined by thermocouples placed in a particular wall section during a very hot day, that the temperature on the exterior of the wall was 100 F and in the center of the wall 150 F. With this temperature differential, the stress in the concrete was computed to be 175 psi by Professor Polivka, an independent consultant from the University of California. This stress was much higher than could be counteracted by the shrinkage-compensating concrete regardless of its expansive capability.

The total sum of widths of cracks in the wall under investigation was measured by Professor Polivka and found to be 0.07 inches. Then the width of cracks which could be normally expected under the same conditions with standard Portland cement concrete was computed and found to be twice what actually occurred. Professor Polivka's conclusion, and one in which we all concurred, was that shrinkage-compensating concrete was in fact obtaining crack reduction.

CONCLUSION

On the whole, I believe the shrinkage-compensating concrete performed very satisfactorily. Even though there were some cracks, they were minimum in size. Architecturally, the building is unique and outstanding. The finishes are excellent, and the shape, size, and design is most impressive to the viewer and the occupant.

CREDITS

Acknowledgement is made to: The Associated Architects, I. M. Pei & Partners, and Harper & Kemp; Texas Testing Laboratories; Robert E. McKee, General Contractor; and Texas Industries, Inc. (who supplied all concrete for the project) for their part in the design and construction of this magnificent structure, and for the assistance provided in preparation of this paper.

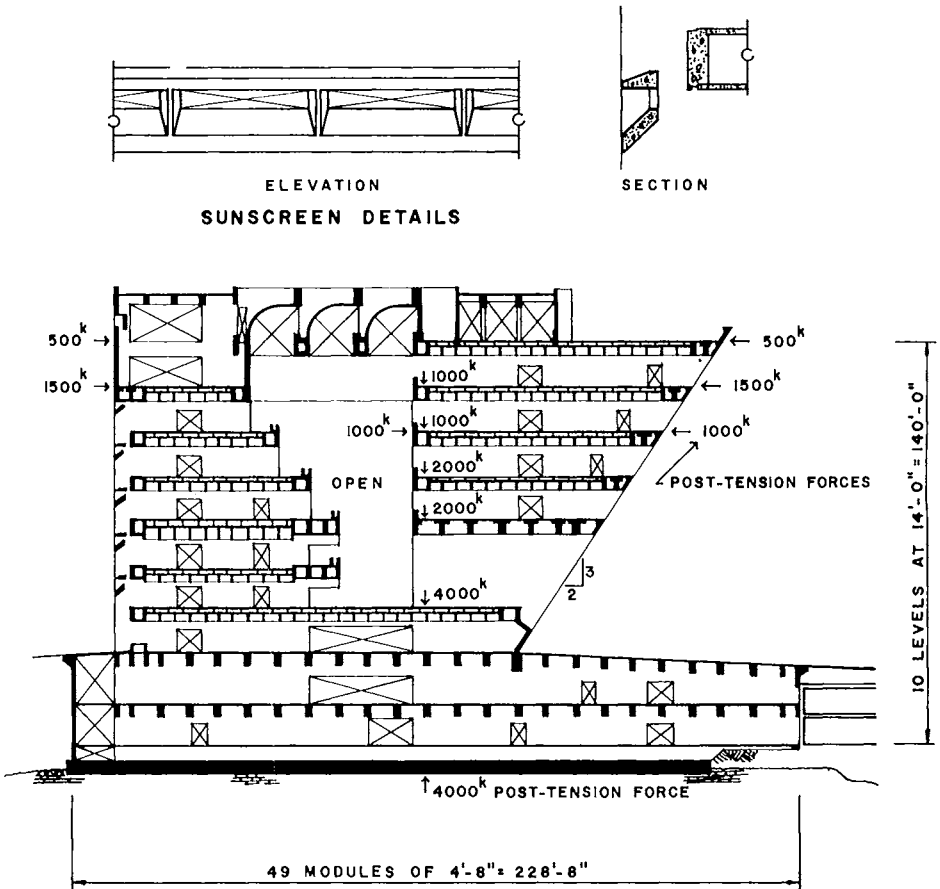


Fig. 1--Building wall elevation showing cantilever construction

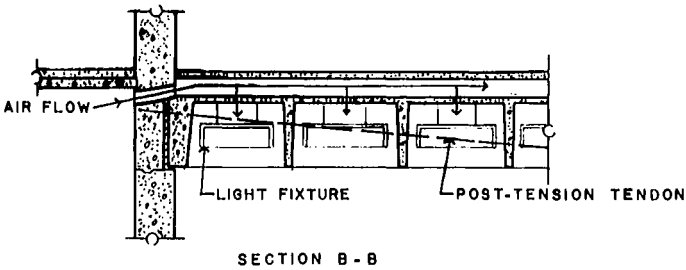
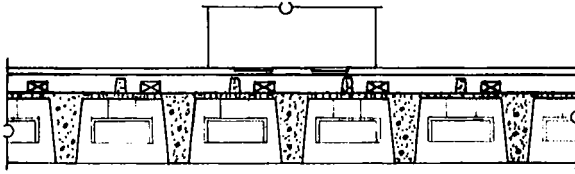
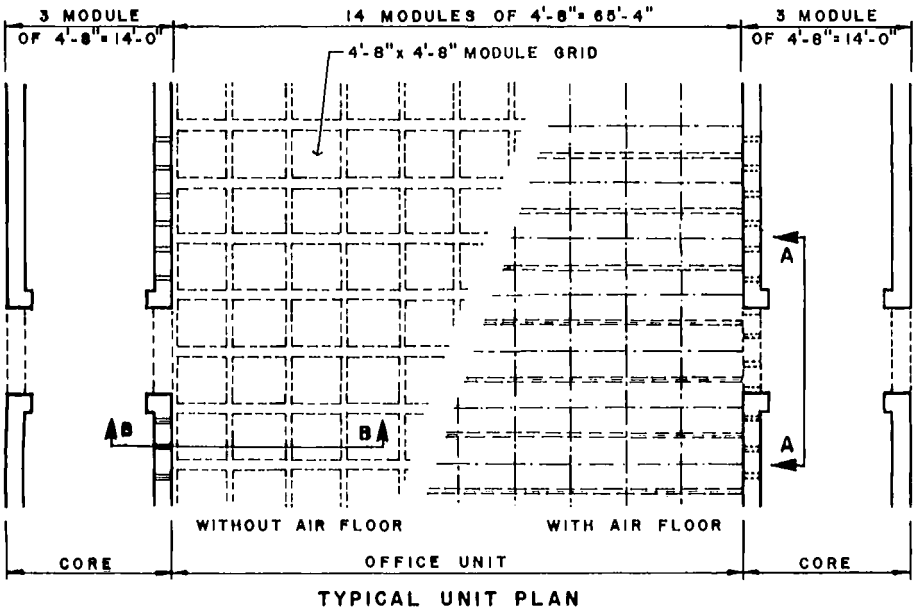
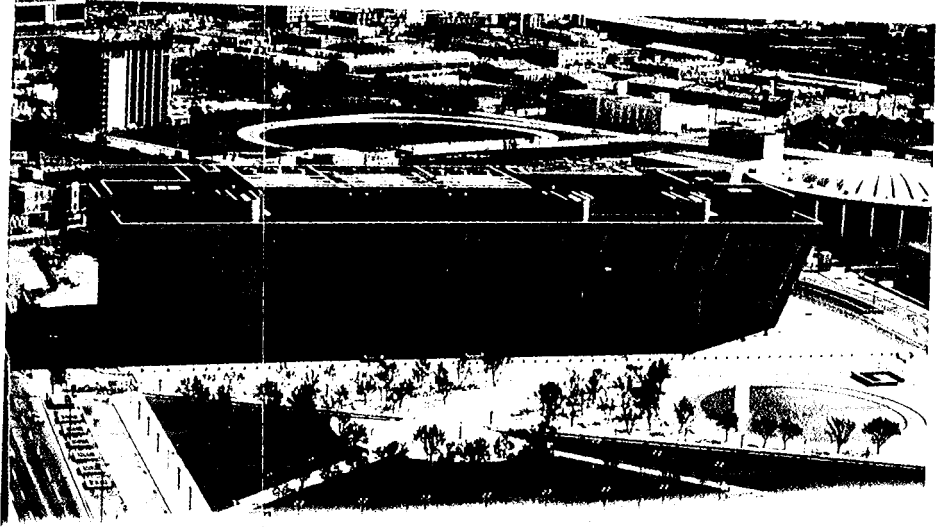
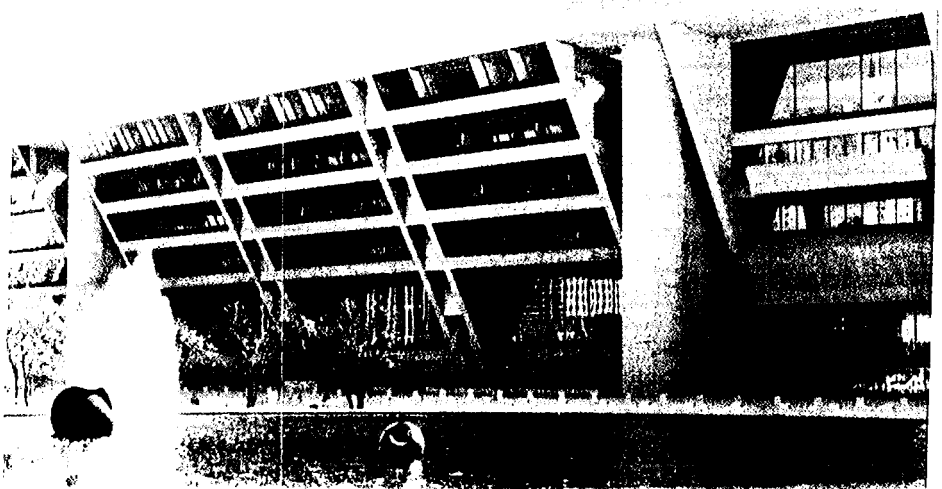


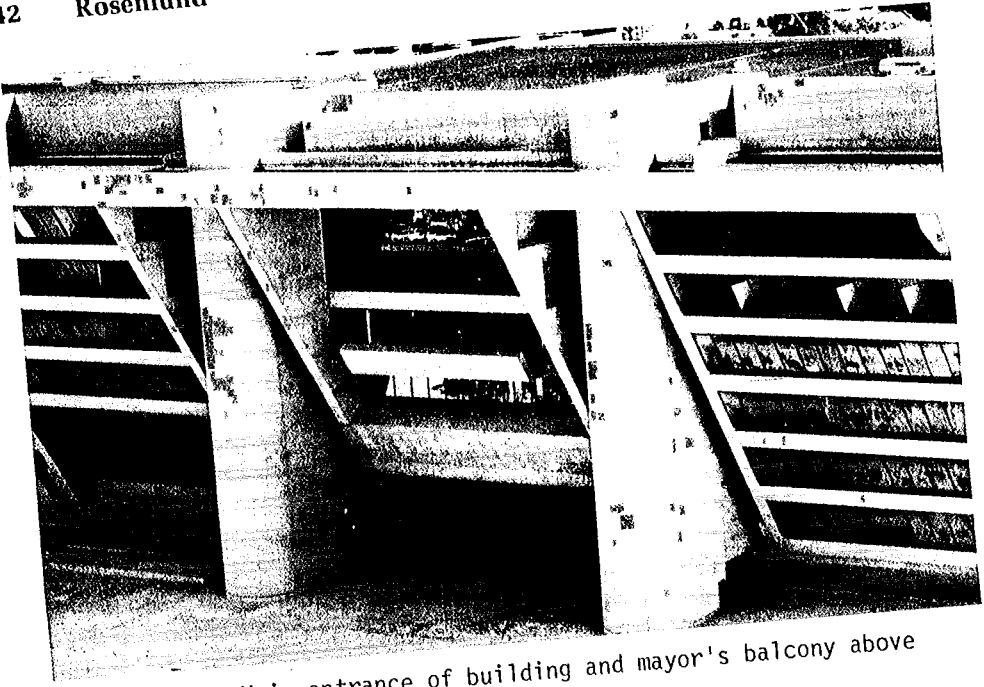
Fig. 2--Floor space diagrams showing support structure



View 1--North face of building



View 2--North face of building across fountain



View 3--Main entrance of building and mayor's balcony above at 5th level



View 4--Southwest corner of building

SP 64-5

Expansive Cement Concretes in Japan

By Shigeyoshi Nagataki

Synopsis: In Japan, expansive cement concretes are made by the addition of expansive components at the time of mixing in the field. According to the quantity involved these expansive components can be used in shrinkage-compensating concretes, or self-stressing concretes. This paper describes the present state of expansive cement concretes in Japan, some information on principal research reports, standard test methods, recommended practices, and examples of the use of expansive cement concretes for various types of structure.

Keywords: buildings; concrete pavements; concrete slabs; cracking (fracturing); expansive cement concretes; expansive cements; field tests; grouting; precast concrete; research; self-stressing concretes; shrinkage-compensating concretes; standards; subsurface structures; tests; water tanks.

ACI member Shigeyoshi Nagataki, Dr. Eng., Associate Professor, Tokyo Institute of Technology, is Chairman of the Japan Society of Civil Engineers' Subcommittee on Expansive Cement Concrete. In recent years much of his research work has been on expansive cement concretes, and he has written some 20 papers on this subject.

INTRODUCTION

As stated in the paper by Kokubu (1), expansive cement concretes have been applied to various types of construction in Japan since 1965. However, up to now only expansive components instead of expansive cements have been used commercially, and the consumers have used these materials as mixtures in concrete to produce expansive cement concretes. At present, there are in Japan four manufacturers selling expansive components, with an estimated production of about 50,000 tons in 1976. These quantities, when converted into amounts of expansive cements for shrinkage-compensating use, equal about 500,000 to 550,000 tons or about 1 percent of total cement production.

The amount of expansive components production in use for buildings site concrete, for other types of structures besides building site concrete, and for precast concrete are 40, 30 and 30 percent, respectively. Furthermore, most of the site concretes are in shrinkage-compensating concretes, and self-stressing concretes have found application in almost all precast concretes. Although expansive cement concretes have been used in great quantities up to now, it is obvious that it is quite inconvenient to use them without standard methods of testing for choice of expansive components, for quality control of expansive cement concretes. Furthermore there are no recommendations for practical application. Therefore in applying expansive cement concretes to various types of construction, it is necessary to standardize methods of testing, and specifications for each type of field performance.

In view of this, in 1976 the Japan Society of Civil Engineers and the Architectural Institute of Japan each organized a committee for drawing up their own recommendations. At the same time, a working group for drafting standard methods of testing expansive cement concrete was established by representatives of both institutes' committees. At present, recommendations by JSCE and AIJ have been published (27) (28), and a tentative standard for expansive components with standard testing methods will be authorized as a Japanese Industrial Standard (JIS A 6202) in March 1980 (29).

Being a report on the present state of expansive cement concretes in Japan, this paper introduces testing methods, recommendations by the Japan Society of Civil Engineers and the Architectural Institute of Japan, and typical examples of the use of expansive cement concretes for various types of structures.

CHARACTERISTICS AND METHODS OF USE OF EXPANSIVE COMPONENTS

At present there are four manufacturers selling expansive components in Japan. There are some difference in the chemical composition and mechanism of expansion of their products. Table 1 shows the physical and chemical properties of these four types of expansive components. Expansive Component A, which had been used commercially in the earlier periods, is the material closest to the components used in Type K expansive cement. Expansive Components B and C were placed on the market later. Expansive Component C has compounds completely different from Expansive Component A, and the mechanism of expansion in this case is due the formation of calcium hydroxide. Expansive Component B can be considered something in between Expansive Components A and C. Expansive Component D was available in 1976 and is the type closest to Expansive Component C, having a formation of calcium hydroxide with the addition of gypsum.

The scanning electronic microscope pictures of Fig. 1 and 2 show the elements of expansion due to the formations of ettringite and calcium hydroxide, respectively. Table 2 shows other special types of expansive components for steam cured concretes.

Fig. 4 is a comparison (3) of the rate of expansion for Expansive Components A, B, and C. As shown, the rate of expansion is fastest in the calcium hydroxide type, and slowest in the ettringite type.

As mentioned previously, in field performance in Japan, the expansive components are weighed separately from the cements and placed in the mixer. Consequently, it is required to select the type of cements required by the construction work and the expansive components in the field.

In earlier stages of the use of expansive cement concretes, it was common to represent the amount of expansive component used in terms of percentage of the amount of cement (or cement plus expansive component) used. However, later research (4) revealed a linear relationship between the amount of expansion in expansive cement concrete and the unit expansive component content (refer to Fig. 5). Thus, at present, the amount of expansive components used are mostly expressed in terms of unit expansive component content.

In the case where special curing is not used, expansive cement concrete is generally used as shrinkage-compensating concrete, if unit expansive component content is about 25 to 30 kg/m³ in concrete, and as self-stressing concrete if it is about 40 to 60 kg/m³.

For the prevention of cracking it is effective to use expansive cement concrete as a shrinkage-compensating concrete, because the drying shrinkage of expansive cement concrete is less than that of normal concrete, and the extensiveness of expansive concrete is large. According to recent investigations (5) in which the expansive

components of the ettringite type is used as this mechanism, small free shrinkage can be explained by the formation of needle-like or lath-like large crystal of ettringite, by the through solution reaction in the capillary pores of the hardened expansive cement concrete. Also, the extensiveness of expansive cement concrete is large because the capillary pores of the expansive cement concrete are increased by the initial expansion due to the formation of needle-like smaller crystals of ettringite due to topochemical reaction and the crystal growth of calcium hydroxide gel.

When the scale of construction in which expansive cement concrete is used becomes large, the use of two types of expansive components can be considered. In this case, there is the possibility of mixing and using the ettringite type and the calcium hydroxide type of expansive components together by mistake. Thus, tests on a combined use of two types of expansive components are performed (6). Fig. 3, 6, and 7 show the results of such tests. The results of the experiments on x-ray diffraction and on the amount of expansion illustrate no danger in the combined use of two different expansive components.

Needless to say, batching operation is important in field where expansive components are used.

The weight of expansive components per batch is far less than that of cement and the influence is extremely dominant especially when the value of weight is inaccurate. For this reason it is necessary to be concerned with the capacity and the sensitivity of the meters.

Fig. 8 illustrates the results of control tests in a field performance (7) where expansive cement concretes have been used for long periods. In this construction, because of the employment of self-stressing concrete and the large amount of expansive components used, one realizes that very careful construction process-control is required.

STANDARD FOR EXPANSIVE COMPONENTS AND TESTING METHODS OF EXPANSIVE CEMENT CONCRETES

As mentioned previously, due to the need for performance standards for expansive components and for quality control of expansive cement concretes, a Working Group was set up in Japan in 1976 to determine a standard for expansive components and for testing methods. The following is an outline of the standard and test method which will be authorized as JIS A 6202.

Standard for Expansive Component

Table 3 shows the tentative standard for expansive components specified by the Japanese Industrial Standard. In this table, chemical

composition is shown. Ig. loss will be measured by JIS R 5202 (Method for chemical analysis of portland cement) which is similar to the ASTM method. Physical properties of an expansive component such as fineness by the Blaine method, setting time, and compressive strength will be tested by JIS R 5201 (Physical testing methods of cement). However, in the test of setting time and compressive strength, 5 percent of cement by weight must be replaced by an expansive component because specified values of setting time and of compressive strength are given with and without an expansive component.

A brief outline of this test method is as follows. As shown in Fig. 9 and 10, the restrained instrument consists of two restrained plates with dimensions 39.5 x 39.5 x 5 mm, a restraining rod made of 4 mm diameter high-tensile strength steel wire with its whole length is threaded, and two ends processed into spherical shapes of radius 2.5 mm, and 4 nuts used to fasten the two restrained plates and restraining rod together. Before the placing of mortar, the length between the two ends of this restrained instrument is measured in comparison to that of the reference bar. The measured length is called the basic length.

Subsequently, this restrained instrument is set inside a mold with dimensions 40 x 40 x 160 mm, and mortar composed of 468 g of cement (ordinary portland cement, type 1), 52 g of expansive component, 1040 g of standard sand, and 312 g of water, i.e., [(cement + expansive component) : sand = 1 : 2, (cement + expansive component) : water = 1 : 0.6, expansive component/(cement + expansive component) = 10 percent] is placed. After removal from the mold at the age of 1 day and curing in water at 20 ± 1 °C until the age of 7 days, all specimens are put into a thermostatic constant humidity chamber of 20 ± 2 °C and relative humidity of 58 ± 1 percent. During this period the change in length is measured at the time of removal from the mold, at the age of 2 days, at 7 days, then at the end of 1 week, 4 weeks and at other ages as necessary during the drying period are measured too.

The length change is given by the following equation:

$$\text{Length change} = \frac{(x_{01} - x_{02}) - (x_{i2} - x_{i2})}{L_0} \quad (1)$$

where L_0 : Effective length (135mm)

x_{01} : Reading of dial gauge on reference bar when the basic length is measured (mm)

x_{02} : Reading of dial gauge on the restrained instrument when the basic length is measured (mm)

x_{i1} : Reading of dial gauge on reference bar at time i (mm)

x_{i2} : Reading of dial gauge on the specimen at time i (mm)

The tests for mixing, placing, compaction and curing of mortar are performed in accordance with the physical testing methods of cement.

Method of Test for Restrained Expansion and Contraction of Expansive Cement Concrete

This procedure is designed and standardized for testing expansion and contraction of expansive cement concretes under uniaxial restrained conditions in the appendix of JIS R 6202 (Expansive additives for concrete). For convenience of application, two methods are authorized as A and B. Method A is applied to measure restrained expansion only and Method B is applied in the measuring of restrained expansion and contraction.

Method A is used mainly in the field, to determine whether the placed concrete possesses the prescribed amount of expansion. This method is similar in principle to the length change test for expansive components and employs the measurement of restrained expansion of expansive cement concretes. This test is restricted to the case that the maximum size of the coarse aggregate is less than 25 mm. However, for convenient and rapid measurements in the field, the restrained instrument is designed to rotate easily, and the test specimen is cured in water after removal from the mold.

Fig. 11 illustrates the restrained instruments where a high-tensile strength steel rod of diameter 11 mm is being welded with the restrained plates, and the gage plugs are being inserted in the plates. This is to prevent the errors in the measured values that may result from striking the plugs, due to carelessness, when many test specimens are to be cured under water.

The basic length of the restrained rod ($L_0 = 360$ mm) is measured before the placing of concrete. The test specimen is measured at the time of removal from the mold, after which it is in principle stored in water at 20 ± 1 °C until the age of 7 days, and the amount of expansion during this period is measured.

Method B will be applied chiefly in the choice of mix proportions in field conditions. The method is similar in principle to length change test of expansive components and employs the measurement of the change in the length of expansive cement concretes restrained by restraining rod. This test also is restricted to the case that the maximum size of the coarse aggregate is less than 25 mm. Moreover, concerning the method of curing, although the test indicates, as a standard, curing in water after removal from the mold until the age of 7 days, and then dry curing carried out under 20 ± 2 °C, 60 ± 5 percent relative humidity in reality, when expansive cement concretes are exposed to conditions of special curing, the test shall be so designed to perform under these conditions.

As shown in Fig. 12, the instruments are two restrained plates

with dimensions 99.5 mm x 99.5 mm x 19 mm, a high-tensile strength steel rod of diameter 11 mm and length 484 mm, threaded through its length, four nuts and two other nuts with gage plugs. Prior to the placing of concrete the basic length between the two ends of the restrained instrument is measured.

Subsequently, this restrained instrument is set in the mold. As a standard procedure, the concrete is placed and then cured preferably in a constant temperature room at 20 ± 2 C. The specimen is removed from the mold at the age of 24 hr. After that, the test specimen is stored under the prescribed conditions. Measurement is taken if necessary and the change in the length can be calculated from equation (1) and L_0 as specified in 385 mm.

Method of Test for the Strength of Expansive Cement Concrete Cured Within the Mold

This standard test is for the testing of the compressive strength of expansive cement concrete cured under condition where expansion is restrained. The restraint imposed here is similar to the case of a triaxial restraint. Consequently, to determine the compressive strength of expansive cement concrete cured under unrestrained conditions on expansion, it is sufficient to test the specimens in accordance with the procedure described in JIS A 1132, JIS A 1108.

Except that the test specimen is cured within the mold from the time of placing the concrete until the strength is to be tested, this standard test is the same as in the usual method concerning the size of the test specimen (the height of concrete compression test cylinders which is twice its diameter), placing, finishing, curing and so on.

The usual method of test is applicable to shrinkage-compensating concrete while the test considered here is applicable to self-stressing concrete used under restrained conditions, even if in this case the combination of use with the usual method (so-called free expansion) is desirable. Fig. 13 shows an example of the experimental results. The causes of variation in the strength of expansive cement concrete are not only the changes in water cement ratio generally, but also due to the influences of changes in the amount of expansive components used and variations in the performance of the expansive components.

The experimental value in the specimen of free expansion reflects the influence due to the above factors, whereas in the restrained expansive specimen, the experimental value mainly reflects the influence of the water-cement ratio. Consequently, only after tests on the two kinds of specimens have been performed, it can be concluded whether the variations in strength are due to the water-cement ratio or to expansion.

RECOMMENDED PRACTICE FOR THE USE OF EXPANSIVE CEMENT CONCRETES

Although expansive cement concretes have been used in great quantities up to now, recommendations for practical application of expansive cement concretes were not enacted. The Japan Society of Civil Engineers and the Architectural Institute of Japan each organized a committee for drawing up their own recommendations in 1976. Tentative recommendations by these two societies were published in February 1978 (by AIJ) and November 1979 (by JSCE). In both recommendations, the subjects were stated for the use of shrinkage-compensating concretes in the same way as the proposed ACI standard (8). However, applications of expansive components not only in factory products but also to grout mortar which is poured to the space under shoes of the bridge, are very popular in Japan. Recommended practice for the use of expansive components in factory products and recommended practice for the use of grout mortar mixed with expansive components were proposed in the appendix of the recommendation by JSCE. Furthermore, recommended practice for the design of chemical prestressed concrete members (the term of chemical prestressed concrete is used in place of self-stressing concrete) were mentioned in the appendix. The following table shows the scope of performance of expansive cement concretes treated in each recommendation.

Proposed Specification by AIJ	Length change of expansive cement concrete shall be measured by Method B under the condition of $20 \pm 2^\circ\text{C}$ 60 ± 5 percent relative humidity after 7 days water curing at $20 \pm 1^\circ\text{C}$ (i) Expansion at the age of 7 days is more than 15×10^{-5} (ii) Contraction at the age of 6 months is less than 45×10^{-5}
Tentative recommendation by JSCE -subject-	(i) Strength of concrete at the age of 28 days (nonrestrained) and expansion at the age of 7 days (Method A) will be based in design (ii) Strength of concretes with expansive components due to nonrestrained specimen must not be less than that without expansive components
Recommendation (JSCE) -appendix- (1) Factory product	Strength of concrete at the age of 14 days by restrained specimen and expansion at the age of 14 days (Method A) will be based in the design
(2) Grout mortar	(i) Expansion of grout mortar shall be measured by special method similar to Corps of Engineers test (ii) Grout mortar must not indicate contraction at all
(3) Chemical prestressed concrete	(i) Strength of concrete at the age of 28 days (nonrestrained) and expansion at the age of 14 days (Method A) will be based in the design (ii) Expansion of concrete must be more than 25×10^{-5} and less than 50×10^{-5}

USE OF EXPANSIVE CEMENT CONCRETES IN VARIOUS TYPES OF CONCRETE STRUCTURES

As there are extremely numerous examples on the applicability of expansive cement concrete in concrete structures, it would be quite impossible to introduce all of them here. Consequently, in this report where the various concrete structures are classified accordingly, only those applied examples which are relatively new, those where a large amount of expansive cement concrete is being used, or those which are relatively rare shall be selected and introduced.

Concrete for Water Tanks, Filter Plants, Pools, and Silos

Water tanks may be cited as typical of structures in which cracking of concrete is most undesirable. The expansive cement concrete is the most highly suited for the use in water tanks and their use had thus been contemplated from the beginning.

Table 4 shows some examples of the application of expansive cement concrete in water tanks. From the same idea, those examples of application to other hydraulic structures like filter plants and pools are also increasing. Due to conditions of locations, filter tanks for waterworks and sewerage facilities in Japan are sometimes constructed in a multistoried pattern (12). In such cases, expansive cement concretes have come into use for the whole facilities so as to ensure the watertightness.

Table 4 shows examples of the application of expansive cement concrete in filter tanks, pools, together with the use of it in silos where airtightness is required.

Slab Concrete

Since the beginning of the development of expansive cement concretes, there has been quite a number of field applications of expansive cement concretes in slab; no waterproofing membranes to prevent cracking are required, to reduce costs. Table 5 shows some of the more extraordinary applications of expansive cement concrete used in slab like those used with vacuum processing (13), those where lightweight aggregates are being used (14), large sized slabs, etc. However, recent examples have shown that the use of expansive cement concretes in slab does not bring about good results in the prevention of cracking because of the increment in unit water content caused by the pumped-field performance. In such cases, as shall be discussed later, expansive cement concretes are either used in the structural floors or they are used for the highly-restrained first and second floor from the ground and the method of placing concrete