TITLE NO. 74-8

Expansive Cement Jacks

By JOHN TIMUSK and SHAMIM SHEIKH

An attempt to develop a jack which uses expansive cement to generate the jacking force is described. Combinations of portland cement and other raw materials were first tested for free expansion potential. Of these the cement which produced a large expansion after an adequate delay time was selected for further testing where the cement was allowed to expand against predetermined uniaxially applied loads while lateral restraint was provided by the jack bodies. The tests suggest that expansive cement jacks could, under certain circumstances, provide an inexpensive alternative for the stressing of concrete structures.

Keywords: expanding agents; expansion; expansive cements; jacking; portland cements; prestressing; research; self-stressing cements.

■ THIS PAPER DESCRIBES AN ATTEMPT to develop a jack which uses expansive cement to generate the jacking force and displacement. While stressing of concrete by this approach shares many of the limitations and shortcomings of self-stressing concretes, there are certain advantages to be derived from the concentration of the expansive material in one location. Of these, the psychological ones are perhaps the most important. Materials at predictable prices and with known properties and design, detailing, and construction procedures which are familiar can be used throughout the bulk of the structure, while all details pertaining to expansive cements can be left to a few experts. Further, by separating the expansive and structural concretes, the materials for each can be proportioned independently and the need to make compromises is largely eliminated. Losses in strength associated with large expansions in inadequately restrained self-stressing concretes can be eliminated as it is a simple matter to provide adequate lateral restraint in the jacks.

Chemically-stressing jacks could also, in some instances, replace conventional hydraulic, mechanical, or flat jacks. As such jacks would be relatively inexpensive, they could be cast into concrete members where they would, without the need for vulnerable grout tubes or leads, apply the load after the surrounding concrete has gained adequate strength.

Although the jacking force is applied over several days, whereby creep losses in the stressed member are reduced, the maximum strain attainable in it is limited by the permissible stress. In above-ground applications stresses remaining after creep losses will be wiped out by shrinkage. At the other extreme numerous applications exist where shrinkage strains are very small, or where stressing is against flexible elastic abutments. The latter resembles stressing by means of high-strength steel cables where shrinkage and creep losses become relatively unimportant. The investigation described here was undertaken for an application which called for the stressing of a large number of inaccessible structural members against flexible abutments.

PROPORTIONING OF THE EXPANSIVE CEMENT

Since commercially available expansive cements do not produce significant expansion with adequate delay time to satisfy jacking requirements, a cement had first to be formulated from commercially available materials. The compositions of the materials used are given in Table 1.

Seven different cements were formulated by the combination of the normal portland cement and the expansive component. Three different percentages (35, 36, 40) of the expansive component were used. The mix proportions of all the cement

TABLE 1—COMPOSITION OF MATERIALS USED IN THE FORMULATIONS OF EXPANSIVE CEMENT, PERCENT

Compounds	Normal cement*	High alumina cement	Gypsum	Molding plaster	Quick lime	Hydrated lime
SiO_2	21	8.60				
Al_2O_3	6.15	43.20				
Fe_2O_3	2.02	4.05				
FeO		5.30				
TiO_2		2.05				
CaO	63.11	33.70			94	
$Ca(OH)_2$						94
$Ca(SO_4), 2H_2O$			95.0			
$Ca(SO_4), \frac{1}{2}H_2O$				95		
SO_3	2.69	0.10				
MgO	2.57	0.85			0.9	
K_2O	1.35	0.12				
Na_2O	0.18	0.40				
Loss on ignition		1.40				
Free lime	0.52					

*Blaine fineness, sq cm/g, = 3300

TABLE 2—EXPANSIVE CEMENT FORMULATIONS

Constituent	Cement 1	Cement 2	Cement 3	Cement 4	Cement 5	Cement 6	Cement 7
	Percent						
Normal cement	60	60	60	60	65	64	64
High alumina cement	25	25	25	25	23	24	24
$Ca(SO_4), 2H_2O$	12	12			10	12	
$Ca(SO_4), \frac{1}{2}H_2O$			12	12			12
$Ca(OH)_2$		3	3				
CaO	3			3	2		
$C:A:C\overline{S}$	1.89:1:0.63	1.78:1:0.63	1.78:1:0.745	1.89:1:0.745	1.76:1:0.57	1.418:1:0.655	1.418:1:0.776
$C:\overline{S}:A$	4.0:1:1.59	3.83:1:1.59	3.38:1:1.34	3.54:1:1.34	4.09:1:1.754	3.165:1:1.53	2.827:1:1.288

formulations with corresponding $C:A:C\overline{S}$ and $C:\overline{S}:A$ ratios are given in Table 2.

FREE EXPANSION TESTS

The free expansion characteristics of 4 x 12 in. (10.2 x 30.5 cm) expansive cement grout cylinders were used to evaluate useful expansive potential and delay in expansion.

By taking advantage of the false set of the cements it was possible to prepare the specimens for testing within 2 hr after casting. Specimen preparation included demolding, attachment of gage points, and waxing of the ends. Sealing of the specimen ends limited ingress of water to the sides, and thereby facilitated comparison with other tests where specimen diameters were varied. After taking the first reference readings the specimens were stored in water baths at 73 F (23 C). Availability of water was representative of the actual jacking conditions and felt to be essential for the expansion of the cement.

In the first free expansion series, grouts from seven cement formulations with a water-cement ratio of 0.35 were tested.

While a detailed discussion of the results from these tests is beyond the scope of this paper and can be found in Reference 1, a few points warrant mention here. The observed linear expansions do not necessarily represent actual volumetric expansions because in some tests much of the expan-

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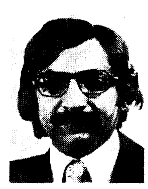

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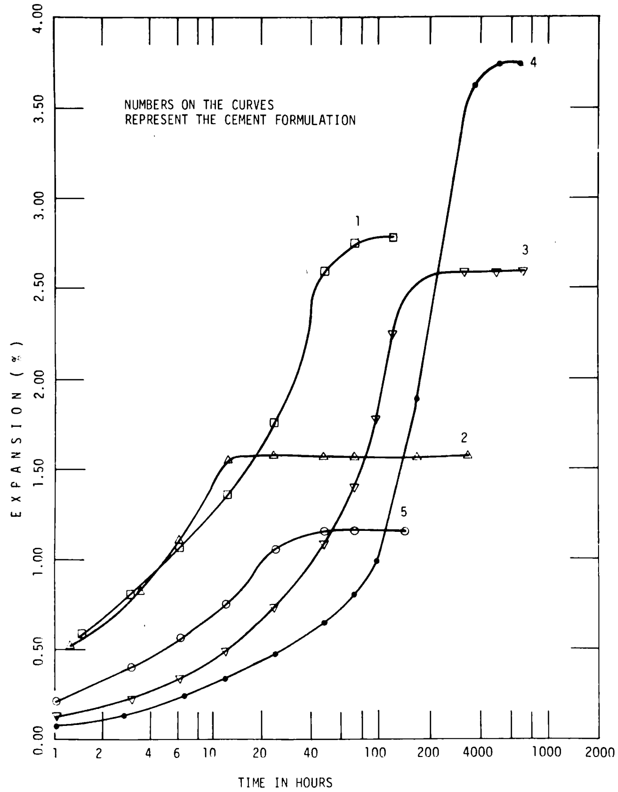

Fig. 1—Free expansion characteristics of different cement formulations

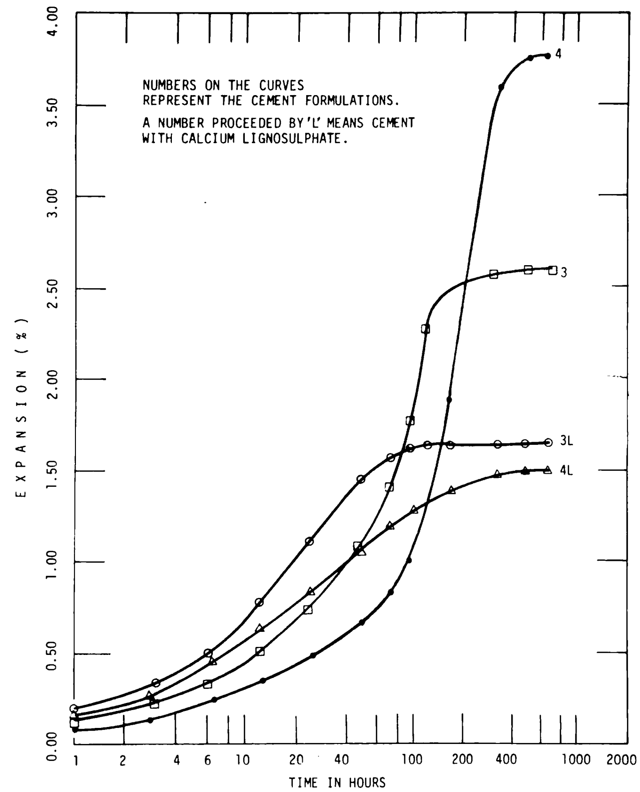

Fig. 2—Effect of calcium lignosulfate on the free expansion characteristics

sion could have occurred before the first readings could be taken. In others, cracking at advanced stages of expansion produced strains which were too large and resulted in large variations in expansion from one series to the other.

As shown in Fig. 1, an increase in the expansive component from 35 percent (Cement 5) to 40 percent (Cement 1) increased expansion. The total lack of expansion with Cements 6 and 7 was more difficult to explain but it indicated the importance of free lime in the mix. From Tests 1 to 4 where the total volume of expansive component was fixed (40 percent), it is apparent that the onset of rapid expansion can be delayed by replacing $CaSO_4,2H_2O$ with $CaSO_4,½H_2O$ and $Ca(OH)_2$ with CaO.

Cement 4 was considered adequate for the jacking requirements as it combined the longest delay with the largest amount of free expansion. Further free expansion tests were carried out for this cement to evaluate the effects of parameters such as water-reducing admixtures, specimen size, and water-cement ratio on the expansion characteristics.

An attempt to increase workability through the introduction of calcium lignosulfate in Cements 2, 3, and 4 resulted in a significant loss of measured expansion. The development of large amounts of heat soon after mixing suggests that much of the expansion may have taken place before measurements could be taken. The results showing this effect are shown in Fig. 2 for Cements 3 and 4. Cement 2 with lignosulfate did not show any expansion. False set, mentioned earlier, would be of some nuisance in practice, but after remixing, the grout could be placed without any difficulties. Remixing did not appear to have any deleterious effects on subsequent expansion.

In one series, specimens with diameters of 3, 5, and 6 in. were tested for free expansion. It was found that the surface-volume ratio did not have any effect on the rate or amount of expansion, which suggests that either enough water was present in the paste itself or that enough water could be imbibed through the specimen sides to satisfy the water demand.

In the last free expansion series, water-cement ratios of 0.4, 0.45, and 0.5 were used. All that can be concluded from these tests and others for the same cement with a water-cement ratio of 0.35 is that the onset of rapid expansion is delayed by about 2 days if the lowest water-cement ratio is used. The effect is illustrated in Fig. 3 where various degrees of expansion are plotted against water-cement ratio and age. The results from the above series suggest that decreasing the water-cement ratio increased the total expansion moderately, but the test series-to-test series variation was too large for any significance to be attached to this result. A water-cement ratio of 0.35 was finally selected as it was expected to behave better once expansion was restrained.

RESTRAINED EXPANSION TESTS

Model jacks were made by filling steel tubes, 5 in. (12.7 cm) high, 0.245 in. (6.2 mm) wall thickness, 4 in. (10.2 cm) inside diameter, with Expanding Cement 4 grout with 0.35 water-cement ratio. Here lateral expansion could, for all practical purposes, be considered as fully restrained. At the same time internal restraint to axial expansion caused by friction between the tube walls and the expanding grout was minimized by cutting a series of horizontal slits at about 0.6 in. (15 mm) intervals into the tube walls, which made the tube walls behave like springs. Gaps of ⅛ in. (3.2 mm) were left between the tube ends and covering steel plates to maintain a controlled area through which water could enter the jacks and to prevent direct loading of the steel tubes (see Fig. 4). All steel surfaces in contact with the expanding grout were lined with porous paper to facilitate water movement into the specimens. A layer of polyethylene sheet placed against the inside surface of the tube was introduced to prevent entry of water through the horizontal slits. This detail would be omitted in practice, but was used in the test only to minimize the specimen-to-specimen variation caused by different rates of water ingress through the tube wall. The relative movement of the end plates, determined with a demountable mechanical gage, was used as a measure of the axial movement.

The specimens were stored 2 hr after casting in water at 73 F (23 C) temperature for about 20 hr at which age they were surrounded by water jackets and placed in testing machines and loaded to produce a stress of 300 psi (2068 kN/m^2) and 530 psi (3654 kN/m^2) respectively for two of the test series. In the third, a nominal stress of 4 psi (28 kN/m^2) was applied by means of dead weights to eliminate the cracking observed in the free expansion tests. It was later found that this load was inadequate; some cracking still took place at advanced stages of expansion.

To keep the applied stresses close to the predetermined values, the testing machine loads were frequently adjusted while the specimens were expanding. The water jackets were removed when deformation readings were taken.

Fig. 5 shows the expansion for the various restrained specimens. It can be seen that for the specimens loaded to the stresses of 300 and 530 psi (2068 and 3654 kN/m^2), creep deflections initially dominated over expansion, the maximum negative strain of 0.07 percent being reached by about 20 hr

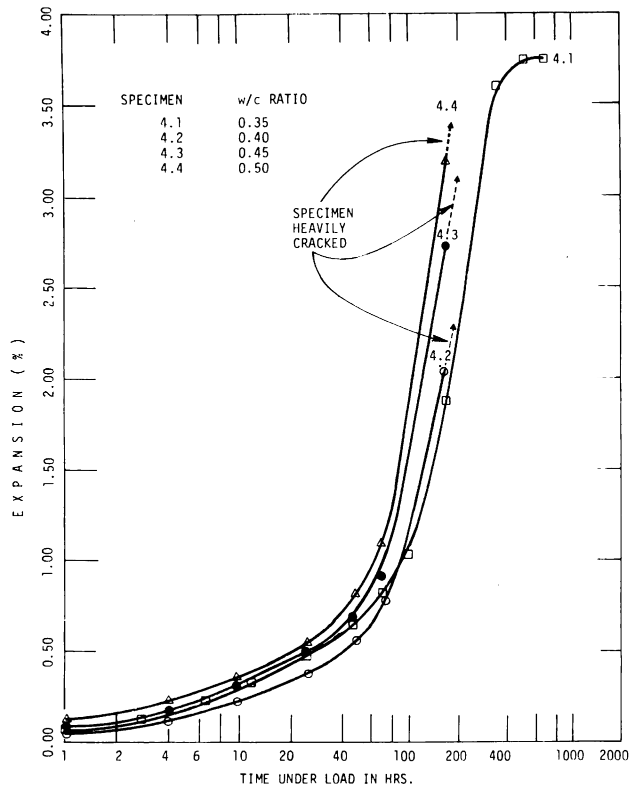

Fig. 3—Effect of water-cement ratio on the free expansion characteristics

after loading. By 60 hr the creep losses had been completely balanced by expansion.

While expansion for the specimen with the nominal stress of 4 psi (28 kN/m^2) corresponded in all respects to that of the free expansion specimens, a significant delay in the expansion as well as a reduction in the total expansion was observed for the specimens which were expanding against the applied loads.

Where expansion is plotted against restraining load (see Fig. 6), it can be shown that the delay during expansion is not clearly related to the

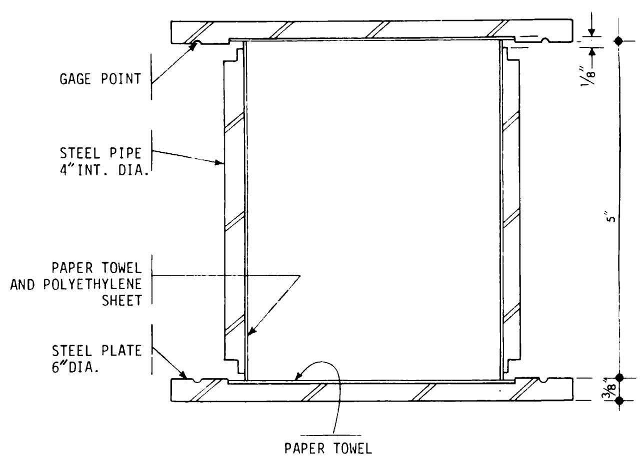

Fig. 4—Restrained expansion specimen

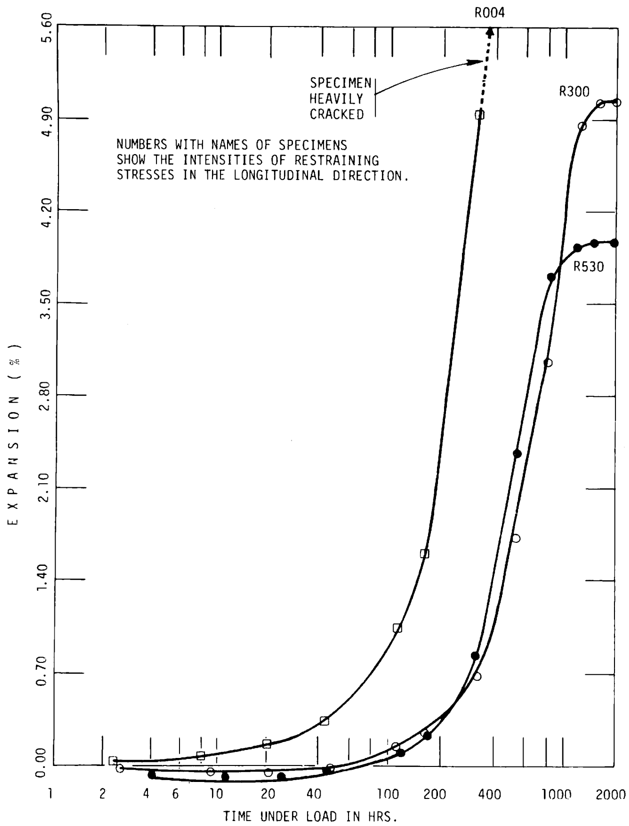

Fig. 5—Restrained expansion characteristics of Cement 4

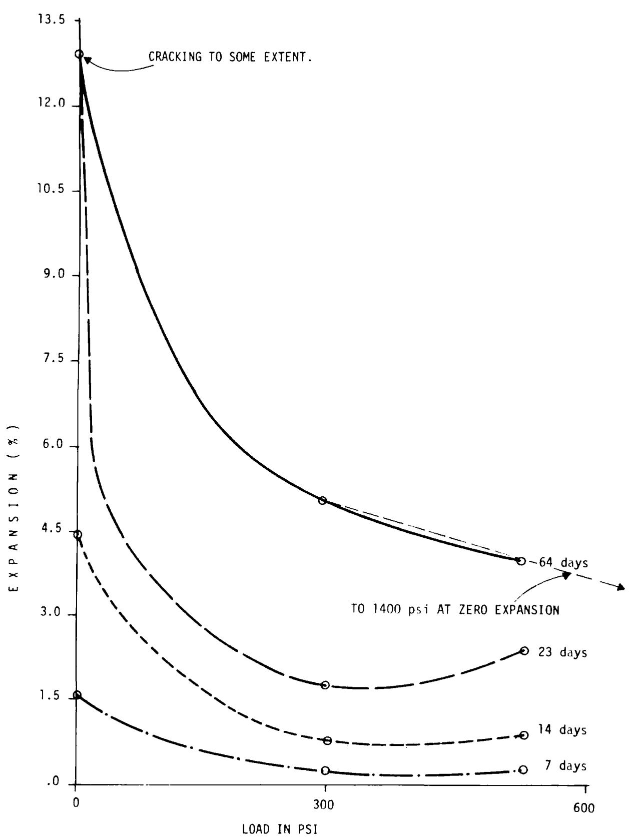

Fig. 6—Effect of axial load on the expansion of Cement 4 for various ages of specimens

stress level. The final expansion is, however, stress dependent, decreasing with increasing applied stress. If the 4 psi (28 kN/m^2) test result where cracking did take place is ignored, then a linear extrapolation of the remaining two terminal expansion values, which is good approximation of the curve between the two points, suggests that about 1400 psi (9650 kN/m^2) stress is required to prevent the expansion from taking place. This value is considerably lower than 35,000 psi (241,000 kN/m^2) indicated by tests by Mehta and Klein,[2] suggesting that expansion is not very sensitive to restraining stress at higher levels of stress. Thus if the length and stiffness of the member to be stressed is known, the stress level desired can be obtained fairly accurately by selecting an appropriate jack length.

The loading history in this series was not quite realistic. In practice, the restraining force would increase parallel to the expansion rather than be applied all at once at an early age. This would not only decrease creep losses which have been shown to be high for early age loading[3] but would also allow the expanding grout to reach a higher strength whereby the amount of useful expansion generated would increase.

CONCLUSIONS

An expansive cement has been developed in this investigation as a source of energy to be used in a jack. It is suggested that the expansive cement jack could be used under certain circumstances to prestress the concrete structures, thus providing an economical alternative to the conventional jacks and at the same time eliminating the need for grout tubes or leads. A number of expensive cements prepared from commercially available materials were tested both for free and restrained expansion characteristics. The following conclusions regarding the expansive cement emerge from this research:

Free expansion characteristics of expansive cements are related to the amount of expansive component present in the cement but are not proportionally related. The limited data of this research[4,5] support the hypothesis that the rate of expansion is proportional to the amount of readily hydratable aluminate present as long as $CaSO_4$ is available, and that for a given aluminate content the amount of expansion depends upon the amount of calcium sulfate present.

Hemihydrated calcium sulfate and calcium oxide suppress expansion at an early stage which results in larger useful expansion at a stage when concrete has attained sufficient strength.

Addition of calcium lignosulfate accelerates the formation of ettringite initially; then the reaction slows down which results in a smaller and useful expansion.

The specimen size has no significant effect on the free expansion characteristics of the expansive cement if the specimens are stored in water after initial readings.

Lower water-cement ratios delay the expansion and the ultimate expansion may be somewhat larger.

In the restrained expansion test where the specimens are completely restrained in lateral direction and a constant axial force is applied the following points can be evaluated:

The restraint delays the expansion but the delay is not clearly related to the stress level. The final expansion decreases with the increase in applied stress, but expansion is not very sensitive to the restraining stress particularly at higher levels of stress.

Clearly more work needs to be done to establish a reliable jacking system. Some specific areas needing further research are:

1. The effect of temperature on the expansion characteristics of the cement.
2. The need for free water from external sources required to complete the expansion.
3. The effects of specimen size and water-cement ratio on the restrained expansion characteristics.
4. The age of the specimen at which the restraint in the axial direction is applied which may also have a significant effect on the total expansion.
5. The effects of different types and degrees of lateral restraint on the expansion characteristics of the cement.

ACKNOWLEDGMENT

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STANDARDIZATION

Announcements, Revisions, Reaffirmations, Withdrawals

PENDING ACTIONS

The Standards Board has approved, according to Part II (Expedited Procedure) of the Standardization Procedure (see July 1976 Journal, p. N7), the following Standardization Actions. Notice of these pending actions is hereby given to voting members of the Institute.

REVISION—ACI 211.2-69

"Recommended Practice for Selecting Proportions for Structural Lightweight Concrete (ACI 211.2-69) (Reaffirmed with revisions 1976)."

Synopsis: "Describes, with examples, a method for proportioning and adjusting structural grade concrete containing lightweight aggregates. The method described uses a "specific gravity factor," determined by pycnometer test on the aggregates, which accounts for variations in moisture content of the aggregates. A tabular form is suggested for systematic calculation of batch weight and "effective displaced volumes." Examples are given for adjustments for change in aggregate moisture content, aggregate proportions, cement factor, slump, and air content."

PROPOSED REVISION

Delete the present Table 3.3 and replace it with Fig. 3.3 as shown.

Reason: The conversion of the table to graphic form permits greater accuracy in anticipating the relationships between compressive strengths and cement contents for "all-lightweight" and "sand-lightweight" aggregate.