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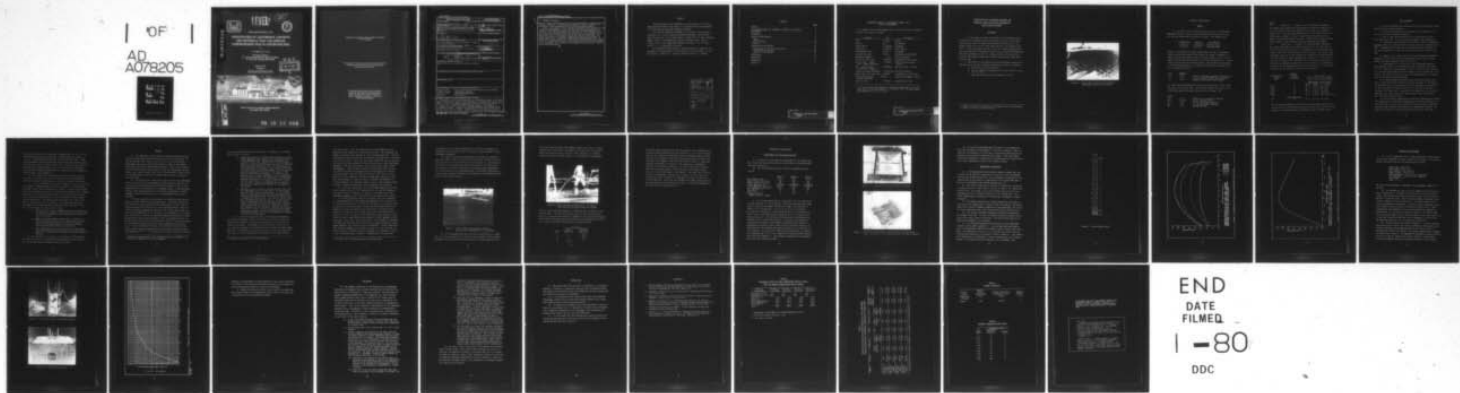
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INVESTIGATION OF LIGHTWEIGHT CONCRETE AND MATERIALS, EAST LOS ANGELES COMPREHENSIVE HEALTH CENTER BUILDING

by

A. D. Buck and T. C. Liu

Structures Laboratory

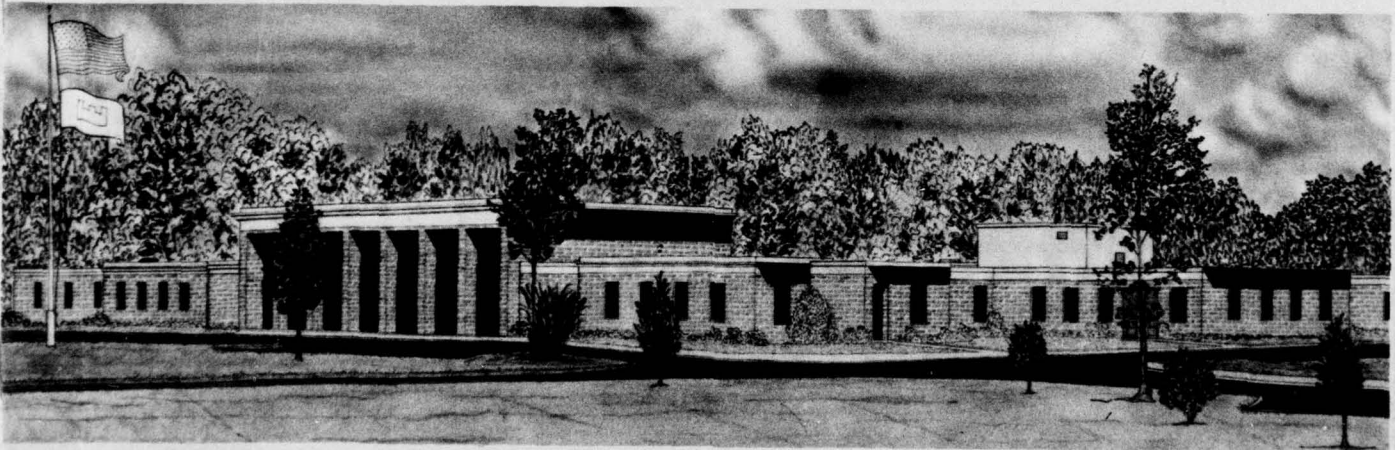
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

November 1979

Final Report

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The objective of this investigation was to determine the causes of the undulation problem (waffle pattern) that developed in the lightweight concrete floor slabs at the East Los Angeles Comprehensive Health Center and to determine the effect, if any, on the serviceability and the safety of the structure. Samples of portland cement and lightweight aggregate were examined using petrographic methods. Concrete cores obtained from the structure were tested for air content and unit weight. Simplified model tests and study of early (continued)		

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20. ABSTRACT (Continued).

concrete volume changes were carried out in the laboratory to simulate the construction conditions. In addition, two-dimensional thermal calculation for predicting concrete temperatures during construction was performed.

Based on the results of these laboratory examinations and inspection of the construction photographs, it can be concluded that the undulations were not caused by a materials problem and should not have structural implications. It is believed that the waffle pattern was developed due to the movement of the upper reinforcing steel bars while the concrete was still unhardened. The waffle effect seen on the hardened lightweight concrete floor surfaces was largely residual due to incomplete removal during finishing operations. If indeed there was any movement after finishing of these surfaces, it was probably due to a combination of factors such as expansion due to aluminum contamination of aggregates, form settlement, and perhaps, other factors that could not be positively identified.

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PREFACE

This investigation was requested by a letter dated 12 April 1978 and attachments thereto from County of Los Angeles Facilities Department to US Army Engineer Waterways Experiment Station.

The work was conducted by members of the staff of the Structures Laboratory (SL), US Army Engineer Waterways Experiment Station (WES), under the direction of Mr. Bryant Mather, Acting Chief, SL, Mrs. Katharine Mather, Chief of the Engineering Sciences Division, and Mr. John M. Scanlon, Chief of the Engineering Mechanics Division. Mr. A. D. Buck and Dr. T. C. Liu prepared this report.

The Commanders and Directors of the WES during this study and the preparation and publication of this report were COL John Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, US CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	by	To Obtain
feet	0.3048	metres
inches	25.4	millimetres
pounds (mass)	0.4535924	kilograms
cubic feet	0.2831685	cubic metres
hundredweight (cwt)	45.359	kilograms
calories per gram	4.184	kilojoules per kilogram
Fahrenheit degrees	5/9	Celsius degrees*
pounds per cubic yard	0.5932764	kilograms per cubic metre
Btu per hour · square foot · degree Fahrenheit	5.678263	watts per square metre · Kelvin
Btu · inch per hour · square inch · degree F	20.7688176	watts per metre · Kelvin
inches per degree Fahrenheit	0.014111111	metres per Kelvin
pounds (mass per cubic foot	16.01846	kilograms per cubic metre
Btu per pound (mass) · degree Fahrenheit	4186.8	Joules per kilogram · Kelvin
miles per hour	1.609344	kilometres per hour

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = C + 273.15$.

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INVESTIGATION OF LIGHTWEIGHT CONCRETE AND
MATERIALS, EAST LOS ANGELES COMPREHENSIVE
HEALTH CENTER BUILDING

BACKGROUND

1. It was observed during construction of the building that an unusual effect developed on the upper surfaces of four of the floors. The effect was that of a square grid pattern with the sides of the squares being 1/4 to 1/2 in. lower than the rest of the squares (Figure 1). Since each square was about 8 in.* on a side, it was apparent that the pattern was outlining the upper layer of reinforcing steel bars which were intended to be 3/4 in. below the surface of the concrete. Visually this surface looked like a waffle with the ribs being low instead of high.

2. The County of Los Angeles Facilities Department requested inspection of the partially completed structure and tests to determine:

- a. What caused the waffle pattern?
- b. Was the causative mechanism still active or had it ceased to be at work?
- c. What were the structural consequences, if any?

* A table of factors for converting US customary units of measurement to metric (SI) units is given on page 4.

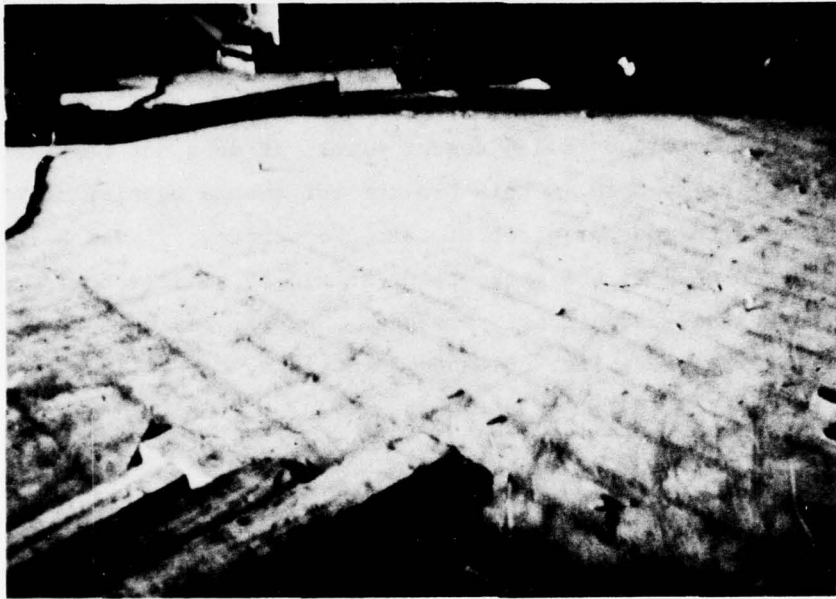


Figure 1. Typical grid pattern in the hardened lightweight concrete floor slabs.

MATERIAL INVESTIGATION

Samples

3. The floors and the production facilities of the lightweight aggregate producer and the concrete producer were inspected in January 1978 and samples were selected for testing. The samples were:

<u>SL Serial No.</u>	<u>Amount</u>	<u>Description</u>
CL-23 C-1	4-oz bottle	Portland cement
CL-23 C-2	5-lb bag	Portland cement

Sample C-1 was from one portland cement plant; it does not represent material specifically used in this project but should be similar to it. Sample C-2 was from another plant of the same company; it was a later sample than that used in the project but should be similar to it. Cement from both plants was used in this project. The samples were furnished by Osborne Laboratories, Inc. of Santa Fe Springs, CA, in January 1978 (C-1) and March 1978 (C-2).

<u>CL-23</u>	<u>Amounts</u>	
G-1	2 lb	1/2-in. lightweight aggregate from stockpile
G-2	2 lb	1-1/2-in. natural gravel from stockpile
S-1	2 lb	Washed concrete sand from stockpile

The three aggregate samples were obtained from stockpiles of the ready-mix plant on 12 January 1978. The following samples were taken at the lightweight aggregate manufacturing plant on 12 January 1978.

<u>CL-23</u>		
Ss-1	2 lb	Plastic bag of crushed raw material
Ss-2	1 piece	Unfired extruded sample
G-3	2 lb	1/2-in. lightweight aggregate
G-4	2 lb	No. 400 lightweight aggregate
MS-1	2 lb	Lightweight sand

CL-23

G-5 About 10 lb 5 bags of No. 400 lightweight aggregate
This sample was obtained by a representative of Osborne Laboratories on 6 July 1978 after it had been hauled about 70 miles in an aluminum-bodied truck. The bags were numbered with 1 and 2, taken from an end-dump truck, and bags 3, 4, and 5 taken from a bottom-dump truck. Sample 2 was residue from the truck bed. Sample 4 was scraped from the bottom surface of the container before the aggregate was dumped.

G-6 About 20 lb 3 bags of No. 400 lightweight aggregate
This sample was taken by the same individual on 19 July 1978 after it had been hauled about 65 miles in an aluminum-bodied bottom-dump truck. Sample 6 was split into two bags as A and B; sample 7 was residue after discharge; one piece in this bag had been deliberately scraped against the metal surface to cause contamination. Samples G-5 and G-6 were received on 18 August 1978. The intent was to examine this aggregate to determine if aluminum contamination could be detected. The assumption would be that the aluminum would come from the surfaces of the aluminum containers due to abrasive contact with the aggregate.

<u>SL Serial No.</u>	<u>Material</u> <u>Cores</u>	<u>Description</u>
<u>CL-23</u>	<u>6-in.-diam.</u>	No. 1, 0.6-ft-long, normal weight concrete from basement
DC-1	X	
		<u>Lightweight concrete cores</u>
		<u>LA No.</u> <u>Length</u> <u>Floor</u>
DC-2	X	No. 2 1.05 ft 1st floor
DC-3	X	No. 3 1.01 ft 2nd floor
DC-5	X	No. 5 1.01 ft 3rd floor
DC-7	X	No. 7 1.02 ft 3rd floor
DC-8	X	No. 8 1.00 ft 3rd floor
DC-6	X	No. 6 0.96 ft 4th floor (roof)
	<u>4-in.-diam. core</u>	
DC-4	X	No. 4 1.01 ft 3rd floor

All of the cores except No. 8 were from the high areas between intersecting valleys of the waffle pattern; core 8 was from a low area of the pattern; core 4 was from one of the "mushy" slower to harden areas.

Test Procedure

4. All X-ray patterns were made with an X-ray diffractometer using nickel-filtered copper radiation.

5. An X-ray diffraction pattern was made of the cements (CL-23 C-1, C-2) in their as-received condition.

6. Part of the concrete sand (CL-23 S-1) was ground to pass a 45- μ m sieve (No. 325). An X-ray pattern was made of the ground sand.

7. Portions of the raw material (CL-23 Ss-1) from the lightweight aggregate plant were ground as above and X-ray diffraction patterns were made. Sedimented clay slides were also prepared and were X-rayed air dry, after application of glycerol, and after heating to 350°C for one hour.

8. Samples of the 1/2-in. and No. 400 size processed lightweight aggregate (CL-23 G-3 and G-4) were ground and sized as before; these powders were then examined by X-ray diffraction.

9. Approximately 25 to 30 pieces of the lightweight aggregate were removed from the top and bottom portions of concrete floor cores 2, 5, 8. These were ground together to pass a 45- μ m sieve and X-rayed as a tightly packed powder and after drying on a glass slide from a water slurry. The intent of the slurry was to provide opportunity for hydration of any clay that might be present.

10. A concentration of hydrated cement paste was prepared from cores 7 and 8 and an X-ray diffraction pattern was made of each sample. The procedure was to obtain sample as free of aggregate as possible and to pass this material through a 150- μ m sieve (No. 100) using gentle crushing. The intent was to concentrate the cement paste in the finer material; this finer material was then ground to pass a 45- μ m sieve (No. 325) before being X-rayed.

11. The cores were inspected for significant differences or features that might relate to the waffle phenomenon that had been observed on the floor surfaces. They were then sawed vertically along their long axes and these sawed surfaces were inspected for significant features. The depth of the top mat of steel was measured for the five cores that

intersected one or more of these bars. Approximately 1 to 3 in. of concrete was sawed from the top and from the lower surface of cores 2, 4, 7, and 8. These pieces were selected to be free of steel bars. These cores represented floors one and three and also high and low areas from the floors and a slow to harden "mushy" area. The pieces were tested in accordance with ASTM Designation C 642-75. This series of weighings after suitable treatments provided data on specific gravity, absorption, and void space of the specimens.

12. Air contents were determined on a vertical surface from the top halves of the same four cores in accordance with ASTM Designation C 457-71 to develop information on the air void system of the concrete.

13. The No. 400 lightweight aggregate samples (CL-23 G-5,6) that had been hauled in aluminum-bodied trucks were considered as three samples with bags 1 and 2 from an end-dump truck; bags 3, 4, and 5 from a bottom-dump truck; and bags 6A, 6B, and 7 from another bottom-dump truck. Samples from each of these groupings were tested in 1 M NaOH solution to determine if metallic aluminum particles could be detected by their generation of hydrogen gas. The NaOH solution would have a pH of about 12.8, which is similar to the pH of a mixture of portland cement and water. The samples were usually washed to remove the finest material. One or all of three things were then done as follows:

- a. Search was made using a stereomicroscope for single pieces of aluminum in a sample. When one was found, it was placed in a drop of NaOH solution and observed with the microscope for reaction.
- b. Washed or unwashed samples were placed in a beaker of NaOH solution and the side of the beaker near the liquid to air interface was observed for aluminum particles. They will characteristically rise and fall repeatedly, emitting hydrogen gas bubbles as they travel.
- c. Place washed finer or coarser material in a petri dish, cover with NaOH solution, and observe with a stereomicroscope for the characteristic bubbles that signify metallic aluminum.

14. Ms. Inge Rose of the County of Los Angeles Facilities Department furnished a set of 81 photographs showing details of the construction of the Health Center building; these were studied.

Results

15. The inspection of the building in January showed some areas of floor surface where the waffle pattern could still be detected. It was the opinion of Ms. Rose, Mr. Buck, and Dr. Liu of the Waterways Experiment Station that this effect had not occurred in the basement floor which was made of normal weight concrete. Thus, it was concluded that the waffle pattern was restricted to the four lightweight concrete floors, and it had occurred on all four of those surfaces. While it was or had been present on all four of these floor surfaces, its presence was not uniform.

16. The fact that the construction period for the four lightweight floors covered a period of approximately eight months and that two concrete batch plants furnished the concrete was assumed to rule out such explanations as the accidental use of expansive cement or malfunctioning concrete plant batching devices. Such expansive mechanisms as cement-aggregate reaction, sulfate attack, or freezing damage were also not indicated.

17. Hence, some factor was needed to be identified that would be present over the variables of time and plants. The initial belief was that the waffle pattern appeared between completion of a day's work of placing concrete and inspection of it the following morning. Since all of the lightweight aggregate was hauled to the concrete batch plants in trucks with aluminum beds,^{*} the possibility of contamination of the aggregate with metallic aluminum and subsequent expansive generation of hydrogen gas in the fresh concrete seemed to offer an explanation of the observed waffle effect that was broad enough to cover the variables involved. It was known from previous work that such contamination can and does occur.¹ Such contamination produces a subtle effect whereas the pumping of concrete through aluminum pipe has been known to produce perceptible expansion.^(2,3,4) In the present case a subtle effect was indicated

* Information supplied by Mr. Karl Blaufuss and later confirmed by the County of Los Angeles Facilities Department.

since the waffle pattern was not excessive. Accordingly, the original test plan was as follows:

- a. Verify the presence of contaminating aluminum in a lightweight aggregate sample known to have been transported in an aluminum truck bed. Examination of aggregate from bags 2, 3, and 6A from samples CL-23 G-5 and 6 showed the presence of small amounts of small gray metallic particles that emitted gas in NaOH solution. It is believed that these particles were aluminum. These samples represented all three trucks that had been sampled. No such particles were found during a brief search in the bag 4 or bag 7 material, and material from bags 1, 5, and 6B was not examined since it seemed unnecessary as the contamination had already been found. The single piece of lightweight aggregate from bag 7 that had been deliberately contaminated by hand scraping it along the side of the truck was not visibly coated with aluminum, but the amount of gas emitted in NaOH solution showed that contamination was present.
- b. Determine the air content of several concrete cores from the lightweight floors to show that it was consistently above the four percent intended value. It was believed that the combined evidence of finding contamination and demonstrating slightly higher air contents would be ample to explain the waffle effect. The four air contents that were determined are shown in Table 1. In order for such data to be meaningful the air contents of the freshly placed concrete must be known for comparison. Since air content tests were not made at the construction site,** this comparison was not possible. However, the values in Table 1 of 3.3, 3.6, 4.3, and 5.1 percent do not suggest consistently higher air due to gas generation from contaminating aluminum. Neither is the possibility completely ruled out by these data.

18. It was also planned that some of the cement and aggregates used in the lightweight concrete or materials like those that had been used would be examined to preclude the possibility of their being the cause of the problem. The samples of portland cement, CL-23 C-1 and C-2, that were examined by X-ray diffraction were normal portland cements. While it is not possible to be sure that they were like the cements that were used, it is not believed that any property of the cements caused

** Information furnished by Mr. Karl Blaufuss.

the waffle effect. The X-ray examination of the aggregates and raw material did not indicate any problem there either. The lightweight aggregate raw material was composed of clays including smectite,^{*} chlorite, clay-mica, and kaolinite and non-clay minerals including quartz, feldspars, and a little calcite. The X-ray examination showed that the clay minerals and the calcite were destroyed by the burning process to make lightweight aggregate. They were converted to spinel, glass, and perhaps olivine and maghemite. This alteration removed the possibility that swelling clay could be involved by taking up water and enlarging in the fresh concrete mixture. The sand that was used (CL-23 S-1) did not contain smectite; it was composed of chlorite, perhaps some vermiculite, clay-mica, and kaolinite as clays and quartz, feldspars, and amphibole as non-clay minerals. The hydrated cement in cores 7 and 8 appeared normal in that it contained crystalline calcium hydroxide and ettringite.

19. The X-ray examination of the lightweight aggregate from three of the concrete cores (2, 5, 8) showed that it was like the aggregate that had not been in concrete. No change in the composition of the lightweight aggregate after incorporation in the concrete was detected.

20. Another possible cause of the waffle effect was considered to be upward movement of the lightweight aggregate in the concrete due to its low specific gravity. If this had occurred, it was believed that the position of the upper layer of steel bars would have blocked this movement just above the bars and would have led to the waffle effect. Inspection of concrete cores in some of Ms. Rose's photographs and inspection of cores 1 through 8 in the laboratory before and after sawing failed to reveal a perceptible concentration of coarse aggregate in the upper part of the cores. The data in Table 2 were obtained to determine if weight data would indicate an effect due to upward movement of lightweight aggregate that was not visually recognizable. Table 2 shows that there was more absorption in the tops of cores 2, 4, and 8 and less in the top of core 7; specific gravity was higher in the bottoms of cores 4, 7, and 8 and about equal in core 2. Examination of these data and

* Swelling clay of the montmorillonite-saponite group.

consideration of the visual examinations of cores do not support the hypothesis that the waffle effect was caused by upward movement of the lightweight aggregate.

21. Study of the jobsite photographs showed that the waffle effect was clearly visible soon after the initial bull floating operation and long before the final finishing was done (Figure 2). This meant the effect was occurring somewhere between 30 minutes to 75 minutes after the concrete was batched. The short elapsed time between smoothing of the freshly placed concrete and appearance of the waffle effect made it unlikely that pronounced effects of gas generation from aluminum contamination would be seen so soon.

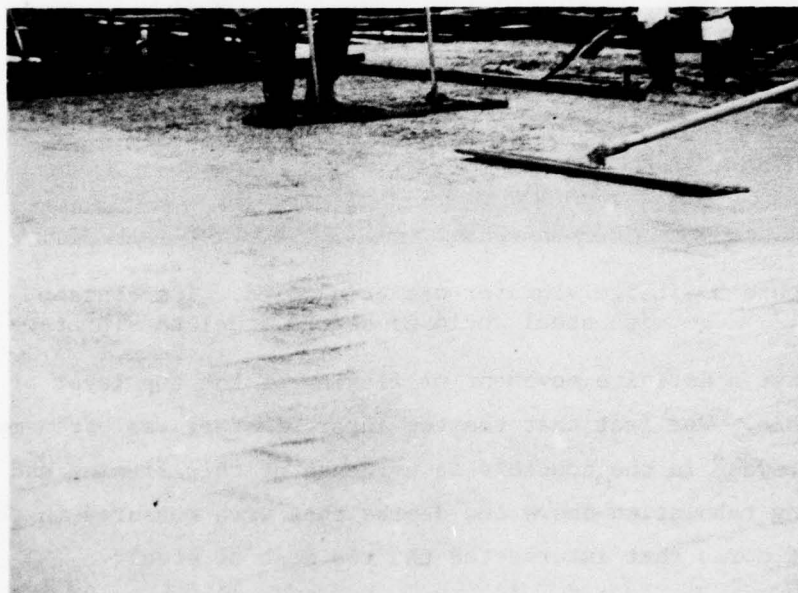


Figure 2. Waffle effect was visible on concrete surface almost immediately after placement.

22. The photographs show that the early waffle effect or a large part of it was probably due to flexing of the top layer of steel during placement and strike-off activities adjacent to freshly smoothed areas.

One slide shows individual bars sagging beneath each foot of a worker. Another slide shows that it was almost a certainty that the vibrator being used would hit some of the top steel, causing it to transmit vibrations along its length (Figure 3). The sequence of photographs



Figure 3. Large vibrator was being used. Its contact with steel would cause the steel to vibrate.

indicates that a definite movement or flexing of the top layer of steel was inevitable. The fact that the top layer of steel was often more than 3/4 in. deep in the concrete is evidence of this flexing and sagging. The following tabulation shows the depths that were measured in the five of the eight cores that intersected the top mesh of steel:

<u>Core</u>	<u>Bar Depths</u>	
	<u>Actual depth, in.</u>	<u>Estimated depth, in.</u>
2	--	1-1/4
3	--	1-3/4
5	--	3/4
7	--	1
8	1-5/8	--

The actual depth indicates both bars were visible. The estimated values represent measured depths which were reduced by 1 in. for the overlying bar that the core did not intersect; these are minimum estimated values, because if the missing bar was the bottom instead of the top one or was less than 1-in. diameter, then the depths would be greater. Additional evidence of movement of the steel is the presence of an aggregate-deficient zone of mortar, perhaps 1/2 in. wide around some of the top steel bars on sawed surfaces. This indicates an infilling of empty space by the more fluid phase of the mixture. This same effect can also be seen in conventional concrete when a vibrator is left in one place too long and leaves a mortar-rich, aggregate-deficient zone where the vibrator had been. All of the cores examined had tight contact of steel bars and concrete which indicates there was no significant movement of the steel after the concrete had set.

STRUCTURAL INVESTIGATION

Displacement of Top Reinforcing Bars

23. In order to verify that the displacement of top reinforcing bars in the slab could have caused the waffle pattern, simplified model tests were carried out.

24. The concrete mixtures used in the test specimens were as follows:

	<u>Batch 1</u>	<u>Batch 2</u>	<u>Batch 3</u>
Water-Cement Ratio	0.52	0.52	0.52
Water Content (lb/cu yd)	325	325	325
Cement Content (lb/cu yd)	630	630	630
Coarse Aggregate Type	Limestone	Lightweight	Lightweight
Coarse Aggregate (lb/cu yd)	1607	934	934
Fine Aggregate (lb/cu yd)	1355	1355	1355
Air Content (%)	2	5	4
Slump (in.)	6	3-1/2	5
Atomized Aluminum Powder (g/cwt of cement)	0	0	4

25. The concrete was mixed in a laboratory 7.5-cu ft rocking and tilting drum mixer in 3-cu ft batches. Each batch was tested for slump and air content in accordance with CRD-C 5 (ASTM C 143) and CRD-C 8 (ASTM C 173),⁵ respectively. Two 12- by 12- by 12-in. specimens were made from each batch. The specimen was cast in the steel mold in which a No. 6 reinforcing bar was positioned at 3/4 in. below the top surface (Figure 4). The concrete was hand placed in the mold and consolidated with a conventional vibrator. The surface was finished by screeding and floating in approximately 30 minutes after vibration. Approximately 30 minutes later, (when concrete was still plastic), the reinforcing bar was vibrated and lowered by about 3/4 in. from the initial position. As soon as the reinforcing bar was lowered, an indentation (approximately 3/8 in.) was formed on the concrete surface directly above the rebar (Figure 5). This phenomenon appeared on all specimens made from three different batches.

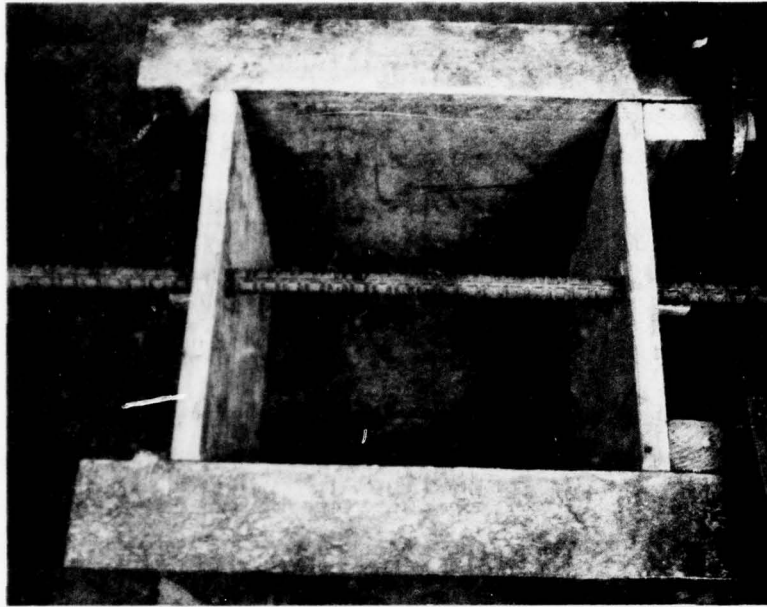


Figure 4. Location of reinforcing steel in the form.



Figure 5. Typical concrete surface condition after the reinforcing steel was lowered. The indentation above the bar is visible.

26. In one of the specimens made from Batch 1, the reinforcing bar was forced down at approximately 1 hour after finishing. (Some concrete set has occurred.) In this case, a void space around the bar was developed, but no surface indentation was formed. These tests demonstrated that movement of a near-surface reinforcing bar in fresh concrete will cause a depression to form on the concrete surface.

Temperature Calculation

27. A two-dimensional finite-element computer program⁶ was used to calculate the concrete temperatures in the 12-in.-thick lightweight concrete slab during construction. This information is required for the investigation of the effects of temperatures on the lightweight aggregates to be performed by the Osborne Laboratories, Inc.

28. The finite-element model selected for temperature calculation is representative of a unit width of interior section of the lightweight concrete slab. The height of the finite-element model was 12-3/4 in., representing 12 in. of concrete slab and 3/4 in. plywood form. The finite-element model, consisting of 36 nodes and 17 elements, is shown in Figure 6.

29. The thermal properties of concrete required by the temperature calculation program are (a) specific heat, (b) density, (c) thermal conductivity, and (d) adiabatic temperature rise versus age. The values of thermal properties used in the analysis are given in Tables 3 and 4.

30. The concrete placement temperature and ambient temperature are assumed to be 70°F. In order to compute convection transfer coefficient, wind velocity data are required. The wind velocity used in the analysis was assumed to be 4 miles/hr.

31. The calculated temperature distribution in the lightweight concrete slab is shown in Figure 7. It can be seen that peak temperatures of approximately 108°F were attained at about 19 hours after placement. The temperature history at 7 in. from the top surface (position at which peak temperature is reached) is shown in Figure 8. This temperature information was transmitted to Osborne Laboratories, Inc. through County of Los Angeles Facilities Department on 13 September 1978.

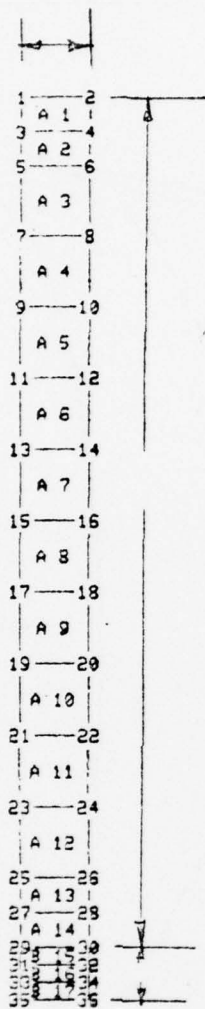


Figure 6. Finite-Element Model.

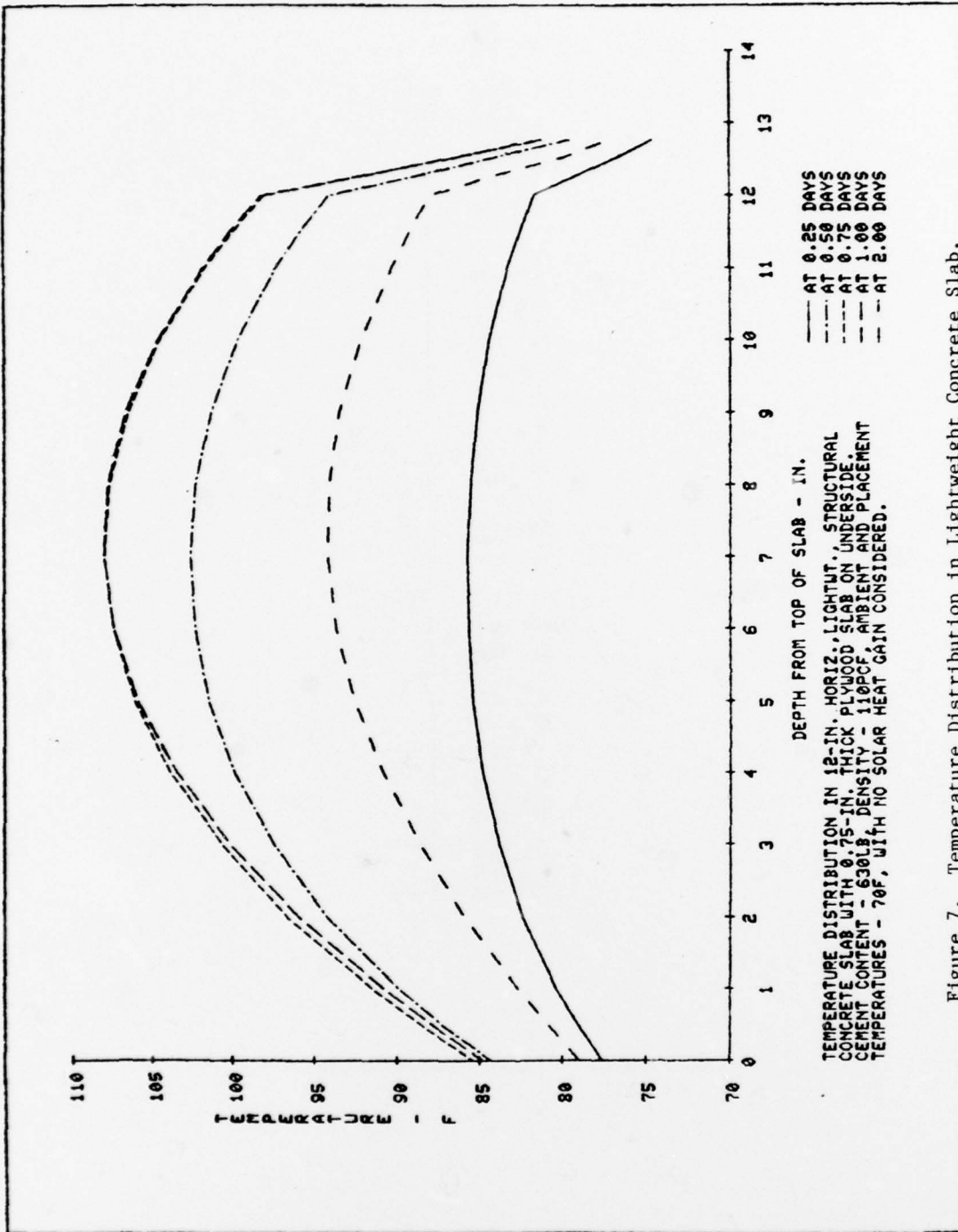


Figure 7. Temperature Distribution in Lightweight Concrete Slab.

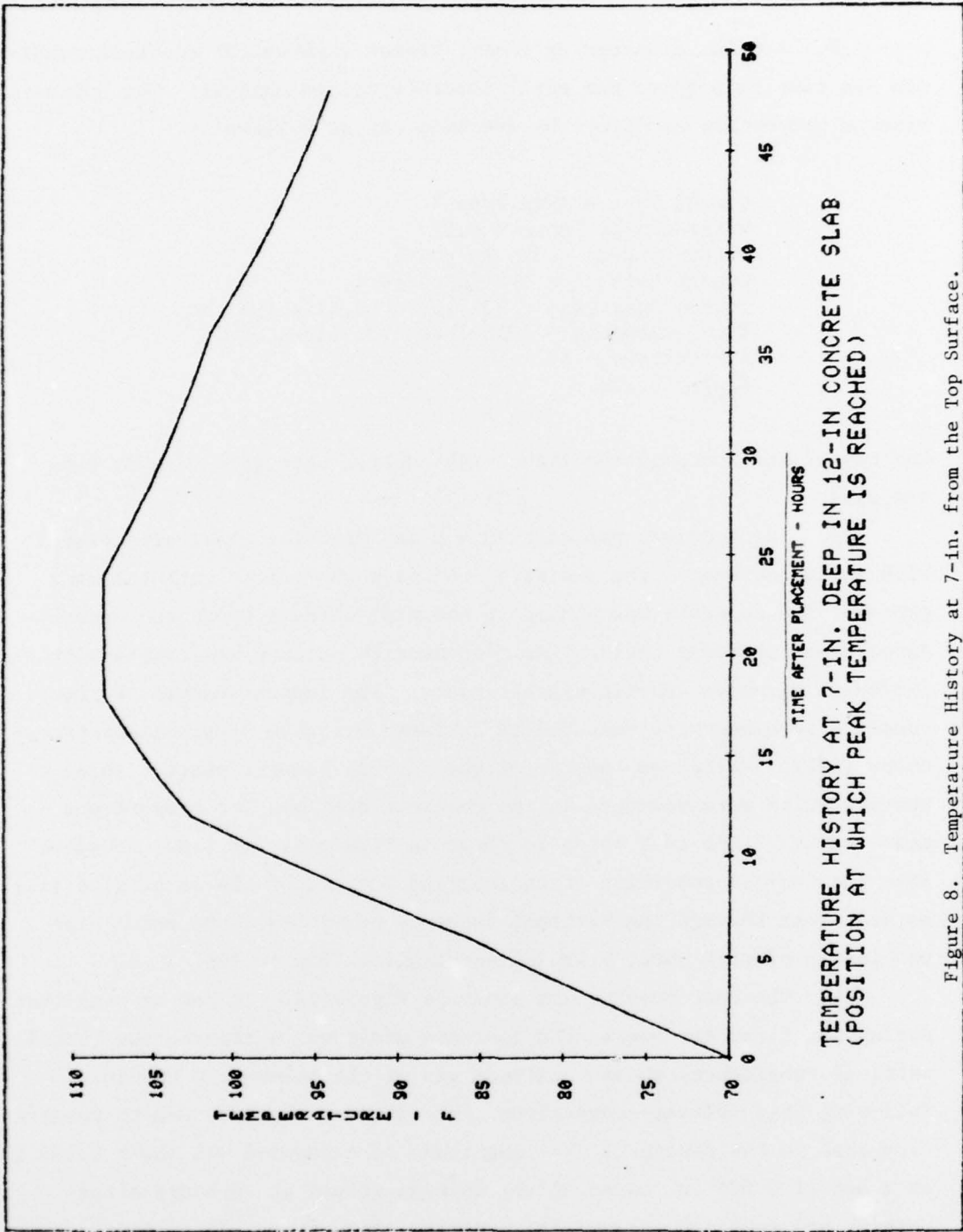


Figure 8. Temperature History at 7-in. from the Top Surface.

Concrete Volume Changes

32. A 6-in. diameter by 12-in. height lightweight concrete specimen was cast to measure the early concrete volume changes. The concrete mixture proportion used for the specimen was as follows.

Cement Type - ASTM Type I
Water-Cement Ratio - 0.52
Water Content - 325 lb/cu yd
Cement Content - 630 lb/cu yd
Coarse Aggregate - 934 lb/cu yd, lightweight
Fine Aggregate - 1355 lb/cu yd, limestone
Air Content - 6%
Slump - 5 in.

One bag of the contaminated lightweight coarse aggregate (Sample G-6) was used.

33. The specimen was cast in a 6-in. diameter steel pipe fitted with a plywood base. The inside of the pipe was coated with silicone grease. The concrete was placed in the pipe using a scoop and consolidated on a vibrating table. The top concrete surface was capped with a 5-3/4-in. diameter acrylic plastic plate. The length changes of the concrete specimen were measured by a linear variable displacement transducer (LVDT) located on the top of the acrylic plastic plate. Three thermocouples were embedded in the concrete specimen for temperature measurements. The test setup is shown in Figure 9. In order to simulate the thermal condition of an interior portion of the large slab (i.e., no heat loss through the vertical faces is permitted), the steel pipe was insulated with about 8 in. of vermiculite (Figure 10).

34. The test results are shown in Figure 11. It can be seen that during the first two hours, the concrete underwent a contraction (total vertical subsidence) whose magnitude was of the order of 0.005 in. Following this initial contraction, the concrete expanded due to temperature rise in the concrete. The magnitude of expansion was about 0.009 in. or a net of 0.004 in. based on the initial volume at 70 hours after casting and remained essentially constant thereafter. This recorded

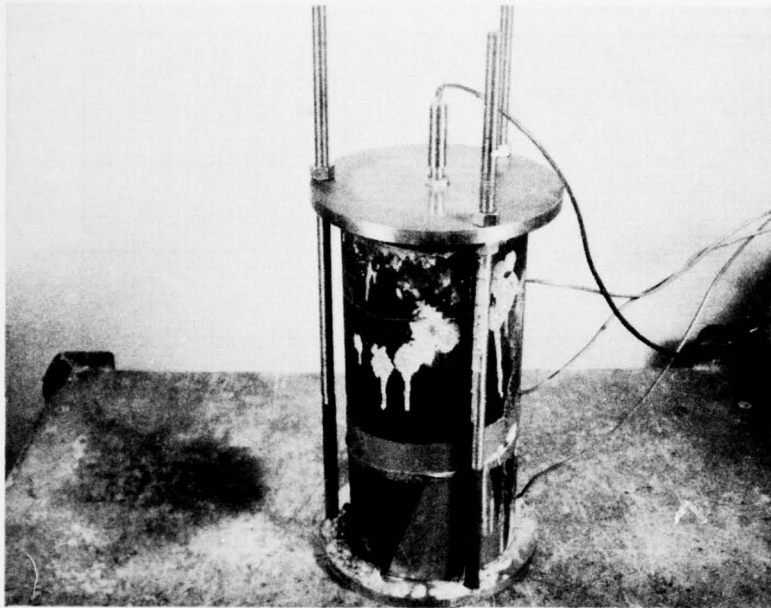


Figure 9. Test Setup for Early Volume Change Study.

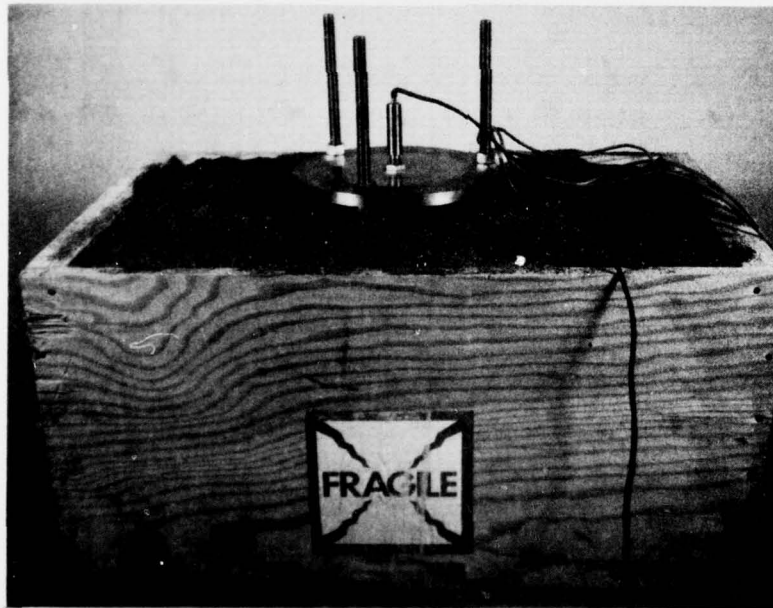


Figure 10. Insulated Test Setup.

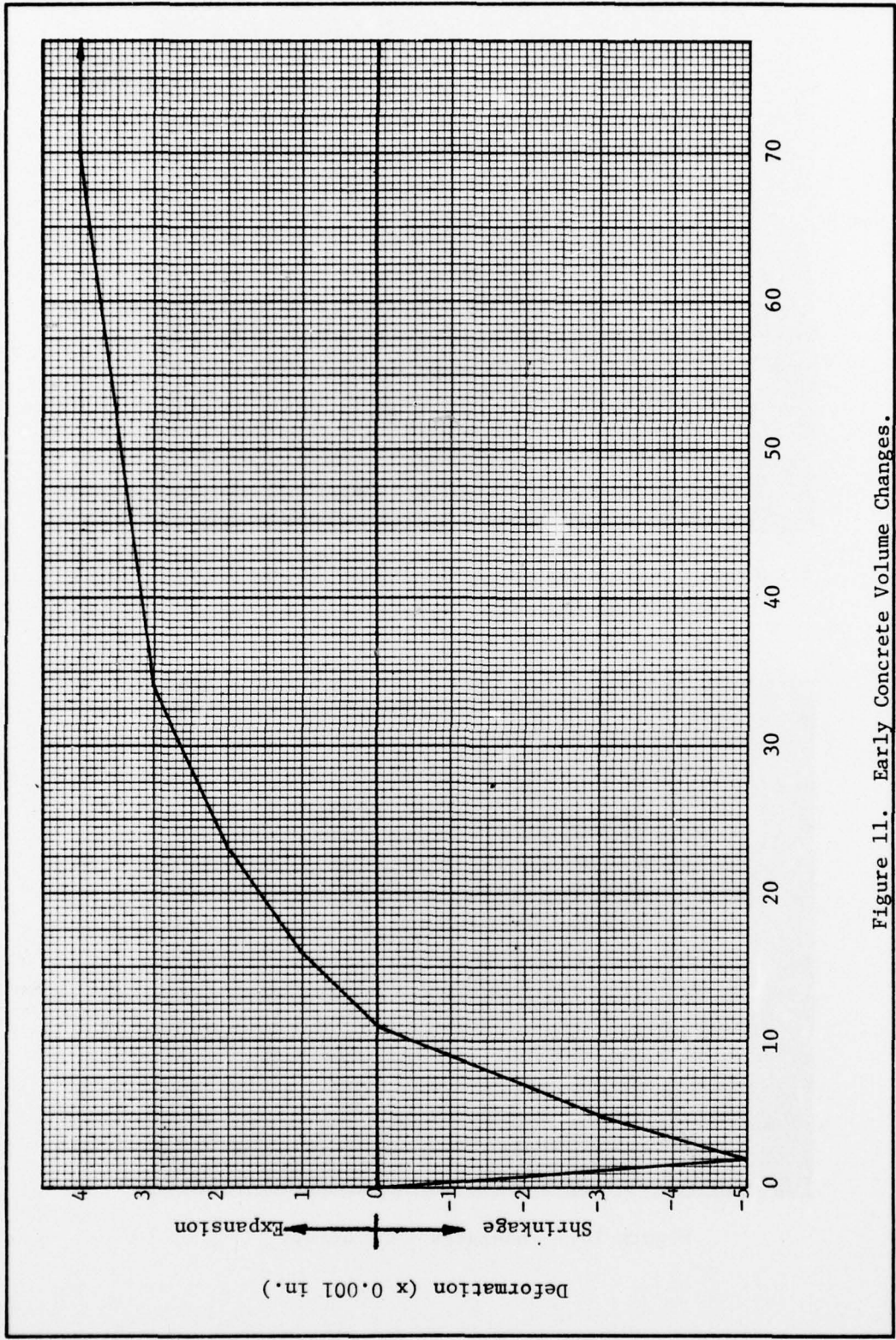


Figure 11. Early Concrete Volume Changes.

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expansion is approximately one one-hundredth of the relative difference in elevation of the high and low places as observed in the waffle pattern in the structure where it is most fully developed.

35. Based on the results of this test, it may be concluded that early volume growth of the lightweight concrete was not the main contributing factor for the undulation problem.

DISCUSSION

36. The original inspection of the building and the subsequent laboratory investigation that was made indicated that the waffle effect was not due to a structural or a materials problem. The involvement of metallic aluminum contamination of the aggregate as a major causative factor seemed unlikely since the air content of the concrete was not excessively high and the strength of the concrete not excessively low, as would be the case if there were substantial amounts of hydrogen gas voids present. Proof of its presence as contamination of the lightweight aggregate due to the aggregate being transported in aluminum-bodied trucks was shown. Therefore, it must be considered as a probable minor contributing factor. The following is offered as a probable explanation of the origin of the waffle pattern:

- a. A layer of reinforcing steel bars was present near the upper surface of the concrete. Had the steel been lower, the grid effect probably would not have been recognizable or as easily seen.
- b. The intended slump of the concrete was 4 in., not a stiff mixture.
- c. Flexing, sagging, and vibration of the upper steel mat during placing and finishing operations adjacent to areas of already partially finished unhardened concrete caused the waffle effect to develop. The photographs (Figures 1 and 2) show this early development of the pattern and the probability that construction activities were the cause of its appearance. The question then is, was this early grid pattern removed during the final finishing operations only to reappear by the day following placement or was removal during finishing not always complete. Nothing in this investigation has provided a definite answer to this question. The logic for the later grid pattern being residual due to sometimes incomplete removal during the final finishing operations is as follows:
 - (1) Detection of the presence of the waffle effect is enhanced by the presence of water in the depressions. This was noted during inspection of the building in January and by examination of photographs. Its detection is also enhanced by observing it at a glancing angle.
 - (2) Since all of the free water should have been gone when the finishers started working the concrete, the

presence of the waffle effect would be less noticeable. Also making it less noticeable would be the fact that the finishers would be observing the surface from above rather than from an angle. Therefore, it is possible that the waffle pattern was present but not detected, or not always detected, and therefore, no efforts or no consistent efforts were specifically made to remove it because the finishers were not aware of its presence.

- (3) Since the start of finishing is based on appearance and minimal indentation of the concrete surface, there is room for latitude in starting final finishing. Therefore, it is likely that the stiffness of the concrete was not always uniform when final finishing began. In those cases when it was stiffer it would have offered more resistance to removal of the waffle effect. Some of Ms. Rose's photographs suggest that the waffle effect was not always completely removed by the finishing operation. On the other hand, there is some evidence in some of Ms. Rose's photographs and in statements of County of Los Angeles Facilities Department personnel that some overnight movement did occur as a general waviness that could be seen against a long straightedge.
- (4) It is believed, in view of the foregoing discussion, that any grid pattern seen the day after placement was due to incomplete removal during final finishing plus possible additional flexing of the steel from adjacent placing operations. Any overnight movement that resulted in an overall undulation was a combined effect of some expansion due to the aluminum contamination, some movement due to uneven form deflection under load, and an overall effect due to the fact that concrete finishing operations did not always produce plane surfaces free of undulations.

37. The way to avoid a repetition of this problem would probably involve several steps. These would include lowering the level of the steel mat, increasing the rigidity of the upper steel mat to eliminate or reduce its ability to sag or flex, reducing the slump of the concrete, and immediate finishing (smoothing) of concrete surfaces to remove any grid pattern that might develop. The elimination of aluminum contamination might also be desirable.

CONCLUSIONS

38. The waffle effect was not due to a materials or a structural problem. It was due to construction practice, and it developed during the construction activities because of movement of the upper reinforcing steel while the concrete was unhardened.

39. It is believed that the waffle effect seen on the hardened lightweight concrete floor surfaces was largely residual due to incomplete removal during final finishing operations.

40. If there was any movement after final finishing of these surfaces, it was probably due to a combination of factors such as expansion due to aluminum contamination of the aggregate, form settlement, and perhaps other factors that have not been identified.

41. It is believed that the mechanism that caused the pattern to develop was one that was at work only as the pattern developed, and no further movement should be expected.

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Table 1
Micrometric Data * for Four Lightweight Concrete Cores,
East Los Angeles Comprehensive Health Center

Concrete Constituents	Core No. 2, 1st Floor	Core No. 4, 3rd Floor	Core No. 7, 3rd Floor	Core No. 8, 3rd Floor
Entrained air, † %	2.5	2.8	1.7	1.8
Entrapped air, ** %	<u>1.8</u>	<u>2.3</u>	<u>1.9</u>	<u>1.5</u>
Total air, %	4.3	5.1	3.6	3.3
Paste, %	31.2	27.3	34.0	26.3
Coarse Aggregate, %	34.8	43.4	39.2	43.4
Fine Aggregate, %	29.7	24.2	23.2	25.0
Steel Bar, %	--	--	--	<u>2.0</u>
Total	<u>100.0</u>	<u>100.0</u>	<u>100.0</u>	<u>100.0</u>

* Determined in accordance with ASTM Designation C 457-71.

† Voids with circular section ≤ 1 mm.

** All other air voids.

Table 2
Data* on Portions from Tops and Bottoms of Four Lightweight
Concrete Cores, East Los Angeles Comprehensive Health Center

Sample	Portion	Absorption,		Bulk	Specific Gravity		Apparent Specific Gravity	Permeable Pore Space, %
		After Immersion and Boiling	After Immersion and Boiling		After Immersion and Boiling	After Immersion and Boiling		
Core No. 2 1st Floor (high)	Top	9.54	12.53	1.73	1.89	1.94	2.20	21.65
	Bottom	9.08	12.44	1.72	1.88	1.94	2.20	21.46
Core No. 4 3rd Floor (high)	Top	9.93	15.80	1.56	1.71	1.81	2.07	24.63
	Bottom	8.79	13.41	1.69	1.84	1.91	2.19	22.72
Core No. 7, 3rd Floor (high)	Top	8.36	11.67	1.71	1.85	1.91	2.14	19.94
	Bottom	9.57	11.99	1.73	1.90	1.94	2.19	20.78
Core No. 8 3rd Floor (low)	Top	8.82	12.19	1.70	1.85	1.90	2.14	20.70
	Bottom	8.40	11.22	1.72	1.87	1.91	2.13	19.30

* Calculations based on weights obtained in accordance with ASTM Designation C 642-75.

Table 3
Thermal Properties

<u>Material Type</u>	<u>Specific Heat (Btu/lb-°F)</u>	<u>Thermal Conductivity (Btu/hr-in.-°F)</u>	<u>Density (lb/ft³)</u>
Lightweight concrete	0.25	0.0306	110
Plywood	0.29	0.00557	34

Table 4
Adiabatic Temperature Rise Input

<u>Time (day)</u>	<u>Temperature (°F)</u>	
	<u>Lightweight Concrete</u>	<u>Plywood</u>
0	0	0
0.25	17	0
0.50	39	0
0.75	53	0
1.00	63	0
1.50	75	0
2.00	83	0
2.50	90	0
3.00	93	0
5.00	100	0

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

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Investigation of lightweight concrete and materials, East Los Angeles Comprehensive Health Center building / by A. D. Buck and T. C. Liu. Vicksburg, Miss. : U. S. Waterways Experiment Station : Springfield, Va. : available from National Technical Information Service, 1979.

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