CONCRETE NUCLEAR DENSITY STUDY

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INTRODUCTION

In early 1977, the Colorado Department of Highways began taking nuclear densities of bridge decks. Since the Department already had a procedure for taking densities of plastic concrete pavement, this procedure was used with no changes.

During the first year, several problems arose which could not be solved by patchwork methods: densities exceeding the maximum theoretical field density were frequently encountered; certain pieces of required equipment were not readily available; required calculations were often confusing to personnel. A study was obviously needed in order to devise a new procedure.

PHASE 1

Some questions had arisen concerning possible chemical activity effects on the nuclear gauge, so the first phase of the study was conducted in this area. A wooden box, 22" x 22" x 4" was filled with fresh concrete containing no ad-mixtures, vibrated, and struck off. A Troxler 2401 Nuclear Gauge was set on it in the two-inch transmission position within six minutes of mixing completion. Four quarter-minute counts were taken every five minutes the first hour, every fifteen minutes the next hour, and every half-hour for an additional four hours. No significant change in nuclear density was noticed, so this procedure was repeated with different amounts and types of ad-mixtures. Again, no significant changes were encountered.

Since hydration or admixtures had little or no effect on the nuclear readings, the next question investigated was whether the nuclear gauge is able to read plastic concrete the same as dried concrete, allowing for the difference in density due to evaporation.

PHASE 2

Because the wooden box was easily damaged when removing the dried blocks, and its volume could not be determined accurately, it was decided to construct a reusable water-tight steel mold. See Figure 1 for details. The sloping sides expedited removal of dried blocks. The size of the mold, 24" x 24" x 8" was considered sufficient to provide an infinite volume for the nuclear gauge. The actual volume was determined by filling with water at known temperature, and weighing.

The following equipment was also used: A three cubic foot drum mixer; type B air content meter; slump cone; a 1.5 inch pencil type vibrator; 500 kg platform scale; forklift; miscellaneous hand tools; Troxler 2401 Nuclear Gauge. The air meter base volume (nominal 0.25 cu ft) was also checked with water.

One mix was used for the remainder of the study. See Table 1 for details. Mixing time was eight minutes with a three minute rest period. Slump, unit weight (in air meter base) and air content were determined and recorded. Half way through this phase, it was decided to include a five-second vibrated unit weight as well as the rodded unit weight. The vibrated unit weight was determined by adding an additional amount of mix to the air meter base sample that was used for the rodded unit weight. The 1.5 inch pencil type vibrator was inserted into the center of the sample for five seconds. The vibrator was not allowed to touch the air meter bucket. The vibrated air content was also taken and recorded. The mold (Figure 1) was set on a solid base and swabbed with form release. The entire batch of concrete was placed in the mold and then vibrated in a set pattern - twelve equally spaced locations for five seconds each. The mold was then screeded with a rigid straightedge until all excess concrete was removed. The mold was cleaned and then moved to the scale with help of the forklift. The plastic concrete was weighed and the density calculated and recorded. A template and drive pin were used to form a hole for the source rod of the nuclear gauge. The template insured placement of the gauge in a predetermined location each time. Both two-inch transmission and backscatter densities were obtained and recorded. The drive pin was then reinserted and the block was left covered overnight. The next morning, backscatter and two-inch densities were taken and the block re-weighed. Calculations were made and information was recorded. It was then removed from the mold for storage.

Six concrete blocks were poured for this phase. The first three blocks were discarded because of flaws. These flaws were of two types: a tear in the concrete caused by the drive pin; a depression around the source rod hole which caused an air gap under the gauge. These flaws caused erroneous nuclear densities; they were corrected in later blocks by holding the vibrator alongside the drive pin, and by filling in with mortar around the source rod hole.

A summary of data obtained is shown in Table 2, which indicates that the nuclear gauge can accurately determine the density of wet or dry concrete in the transmission mode. The "light" backscatter densities on the dried block were probably caused by surface roughness, which affects transmission mode considerably less.

PHASE 3

The purpose of phase three was to investigate the effects of re-steel on nuclear readings.

A grid of #5 re-steel was assembled (see Figure 2), and wired together at the joints. Four eyebolts were wired to the steel to position it and also to prevent movement. Four holes were drilled in the bottom of the mold and the eyebolts were fastened by nuts on both sides of the bottom. By rotating both nuts, the depth of the steel could be adjusted. The density of the steel and eyebolts was determined for each block and this was used to adjust the mold volume and tare weight. In the next four blocks, the steel was placed at a depth of 2-1/2". These blocks were constructed in the same manner as the six previous (no steel) blocks.

During construction of block number eight, we began vibrating the air meter base for an additional ten seconds, after the rodded unit weight and the five-second vibrated unit weight had been obtained. Air content was also obtained and recorded. See Tables 2 and 3.

The nuclear gauge gave good results in the transmission mode, regardless of whether the blocks were wet or dry. Again the backscatter mode gave better results on the wet blocks than on the dry blocks. It was difficult to obtain a good gauge seating on the dry blocks. The re-steel appeared to have very little effect on the nuclear readings.

For the next four blocks, the steel was raised one-inch and its pattern was changed. See Figure 3. The new pattern was needed to avoid having the source rod hit the re-steel. Also the number of cross-members was increased in an effort to emphasize any effect of the steel on the nuclear readings. These blocks were constructed in the same manner as the first ten blocks.

In addition to the backscatter and two-inch transmission modes, a one-inch depth was used beginning with block number eleven in the dry state and block number twelve in the wet state. A steel strip fastened to the index rod of the gauge ensured that the source would be positioned one-inch below the surface of the block. For results see Table 2.

Again notice the tendency of the nuclear gauge to read the dried blocks much lighter than the wet blocks, even in the transmission mode. The one-inch transmission mode gave better results than either the backscatter or the two-inch mode on these last four blocks.

DISCUSSION

Overall, it appears that the backscatter mode is all right to use provided the steel has at least two-inches of cover. Gauges capable of one-inch transmission should be used when there is less than two-inches of cover. Also backscatter should not be used when concrete is too dry or deformed to obtain a good seating with the gauge.

The results of the air content, unit weight, and nuclear information (see Tables 2 and 3), led to a simplification of CP-82, "Colorado Procedure for Determining the In-place Density of Plastic Concrete by the Nuclear Method." It was necessary, however, to create a new procedure CP-63, entitled "Determining Maximum Theoretical Field Density of Freshly Mixed Concrete."

PHASE 4

With the acquisition of new calibration standards by the department, and plans for recalibration of all nuclear equipment in the state, it was decided to extend the study to a fourth phase. It was desirable to investigate the effects of re-steel on other types of gauges.

After sitting in a dry, well-ventilated environment for more than three months, three blocks from phases two and three were selected and the remaining blocks discarded. One block contained no steel, one had steel at a depth of 2-1/2" and the third had steel 1-1/2" deep.

To minimize errors caused by surface roughness and the slight depression left by the nuclear gauge, a thin layer of dry cement powder was spread evenly over each block. As far as possible, the source-detector configuration was kept the same regardless of gauge type. A standard time base was used for all gauges. Only backscatter densities were taken; gauges having multiple backscatter positions were used in all such backscatter positions.

After all gauges had been run across the blocks, it was decided to compare the nuclear densities to core densities. A six-inch core was taken in each block in the area that was read by the gauges. Each core was sawed twice (see Figure 4).

For each type of gauge the average nuclear density minus the top 1-1/2" core density is given in Table 4. The differences are given in lbs/cu ft. It appears that the Troxler 2401 in the backscatter position, the Troxler 3401 in the backscatter position, and the Campbell MC-1A in the backscatter AC position (for measuring asphalt concrete densities) were least affected by re-steel 2-1/2" deep. The Troxler 2401 in the backscatter position and the Campbell MC-1A in the backscatter AC position were least influenced by the steel 1-1/2" deep. On an individual basis, all gauges were influenced to some extent by the presence of re-steel. In reviewing the data, it should be noted that the minimum change in density detectable by most nuclear gauges in the backscatter position (one-minute counts) is approximately 0.6 lbs/cu ft.

RECOMMENDATIONS

At the present time, the DOH standard concrete design cover over the top re-steel is 2-1/2" and projects are still being completed where the design cover is 2". Due to variability in field work, the concrete cover could be as low as 2" under present standards (95% confidence), and as low as 1-1/2" under previous standards (95% confidence).

It appears the least influence on density readings due to proximity of the steel can be assured by using certain model gauges.

When the steel has 2" or more of cover, it is recommended that the Troxler 2401 and 3401 be used in the backscatter or 1" transmission mode, or the Campbell MC-1A be used in the backscatter AC position or 1" transmission mode. When the cover is less than 2", it is recommended that the Troxler 3401 not be used in the backscatter mode.

The only gauge used in 1" transmission mode in the study was the Troxler 2401. Because of the design differences, between the Troxler 2401 and 3401, and the 2401 and Campbell MC-1A, it cannot be guaranteed that the two newer gauges (3401 and MC-1A) will give similar results in the 1" Transmission mode.

The bottom of the gauges can be kept clean very easily, when using the backscatter modes by laying a thin sheet of plastic, such as a section of plastic trash bag, on the test sight, or fastening it to the bottom of the gauge.

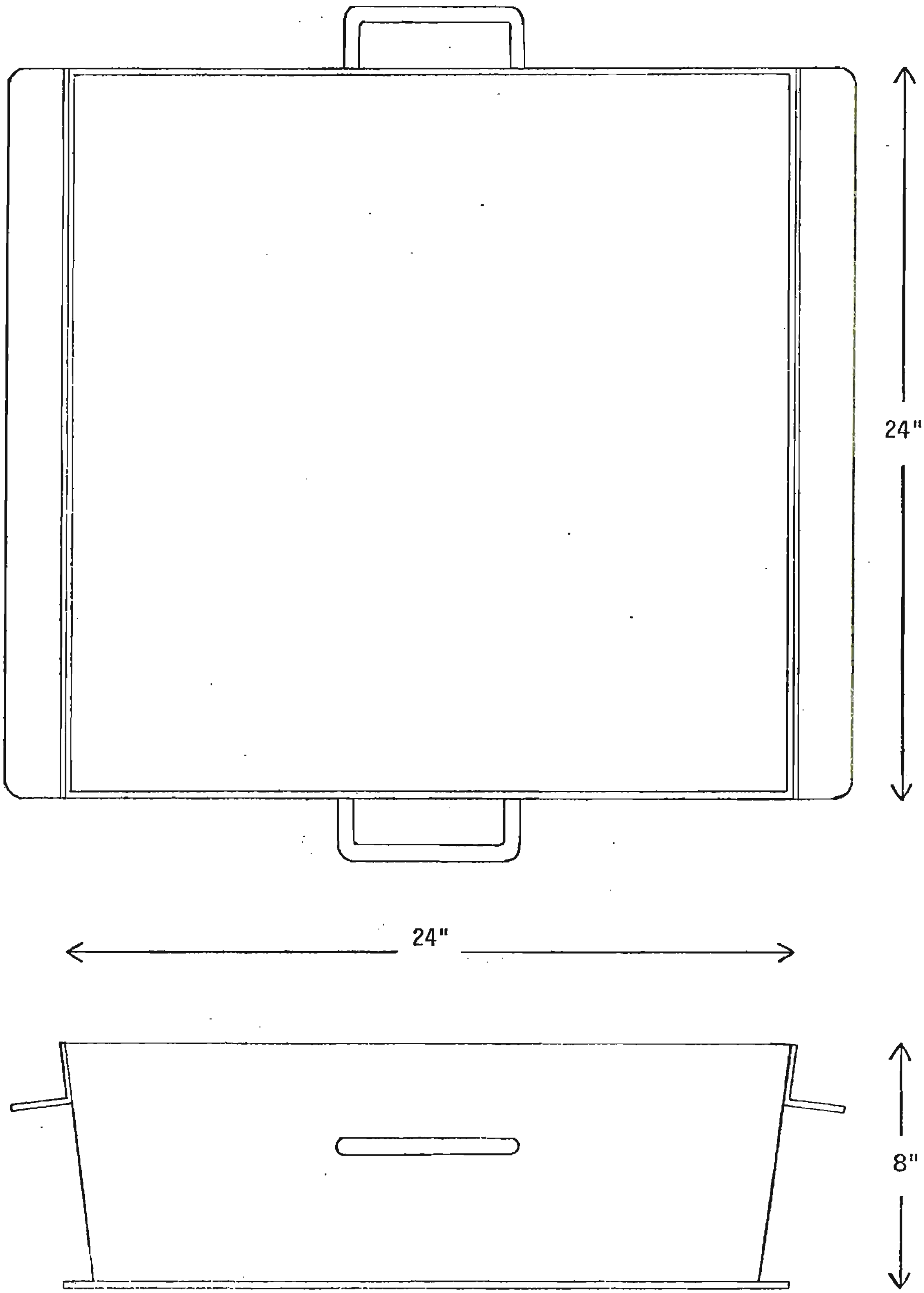
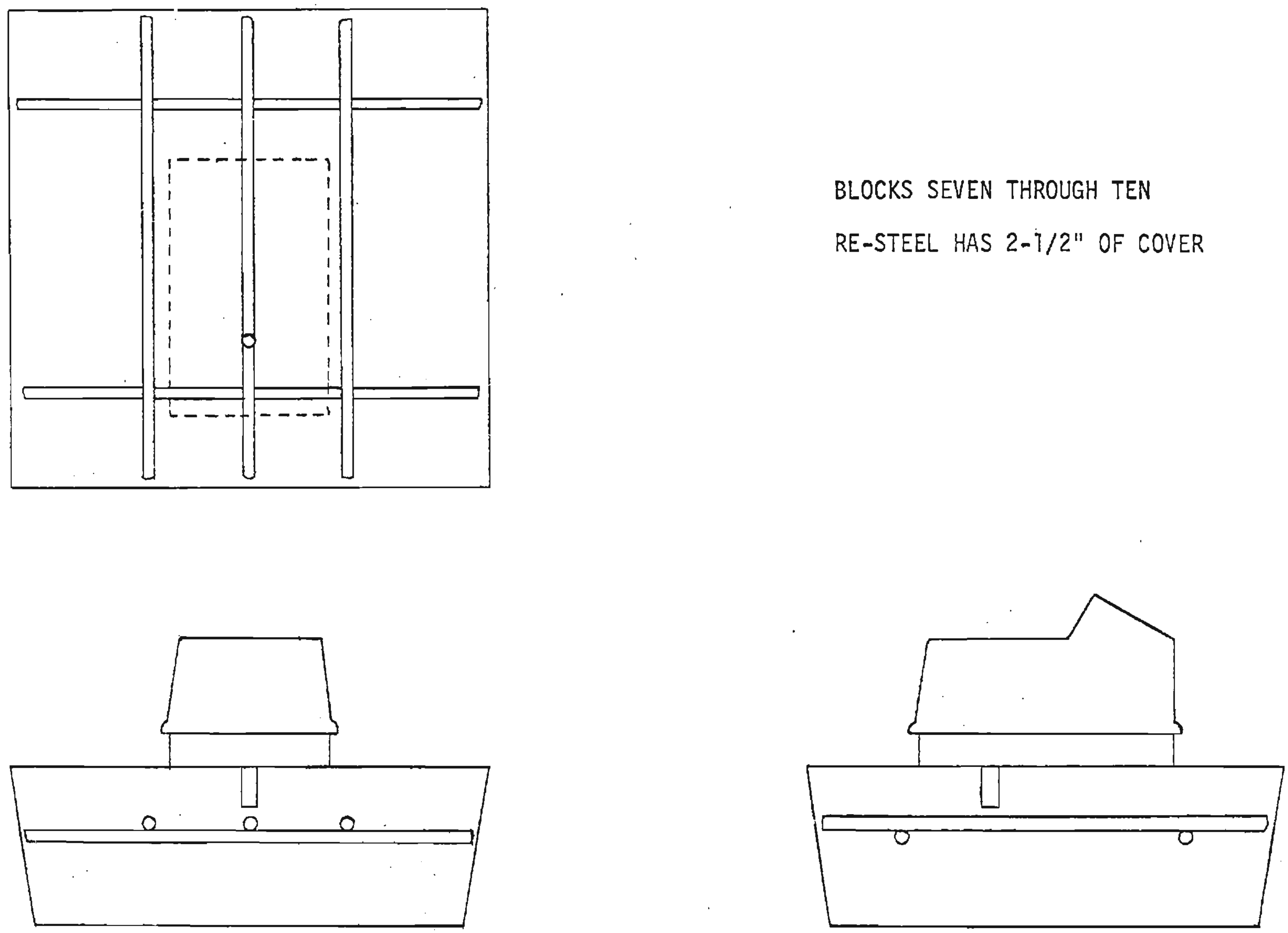


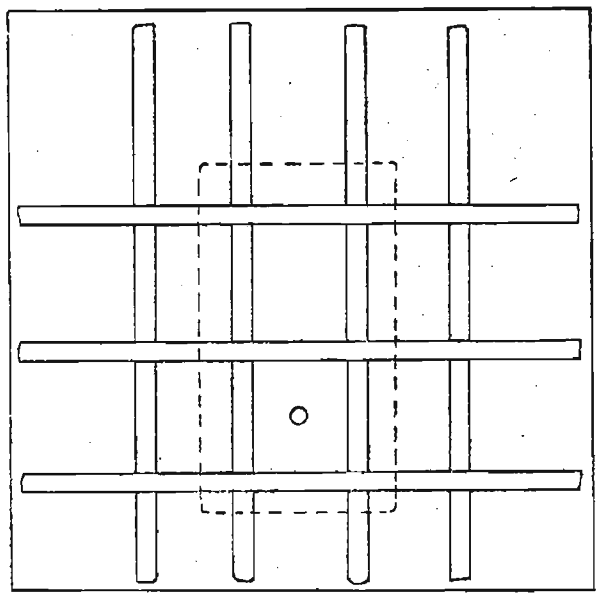
FIGURE 1



BLOCKS SEVEN THROUGH TEN

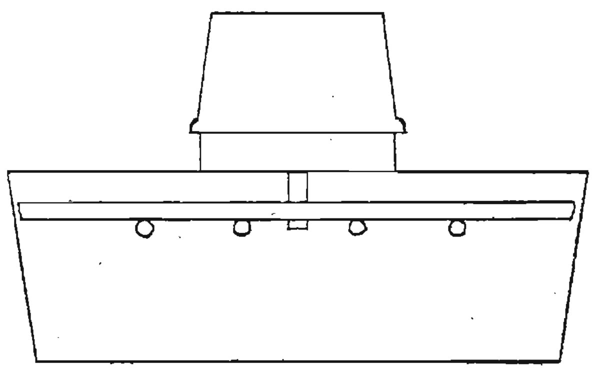
RE-STEEL HAS 2-1/2" OF COVER

FIGURE 2



BLOCKS ELEVEN THROUGH FOURTEEN

RE-STEEL HAS 1-1/2" OF COVER



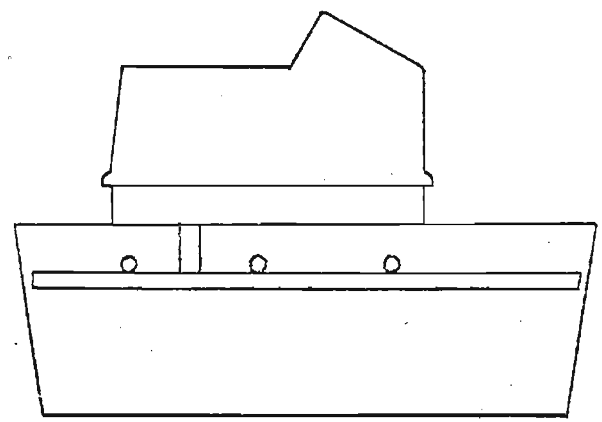
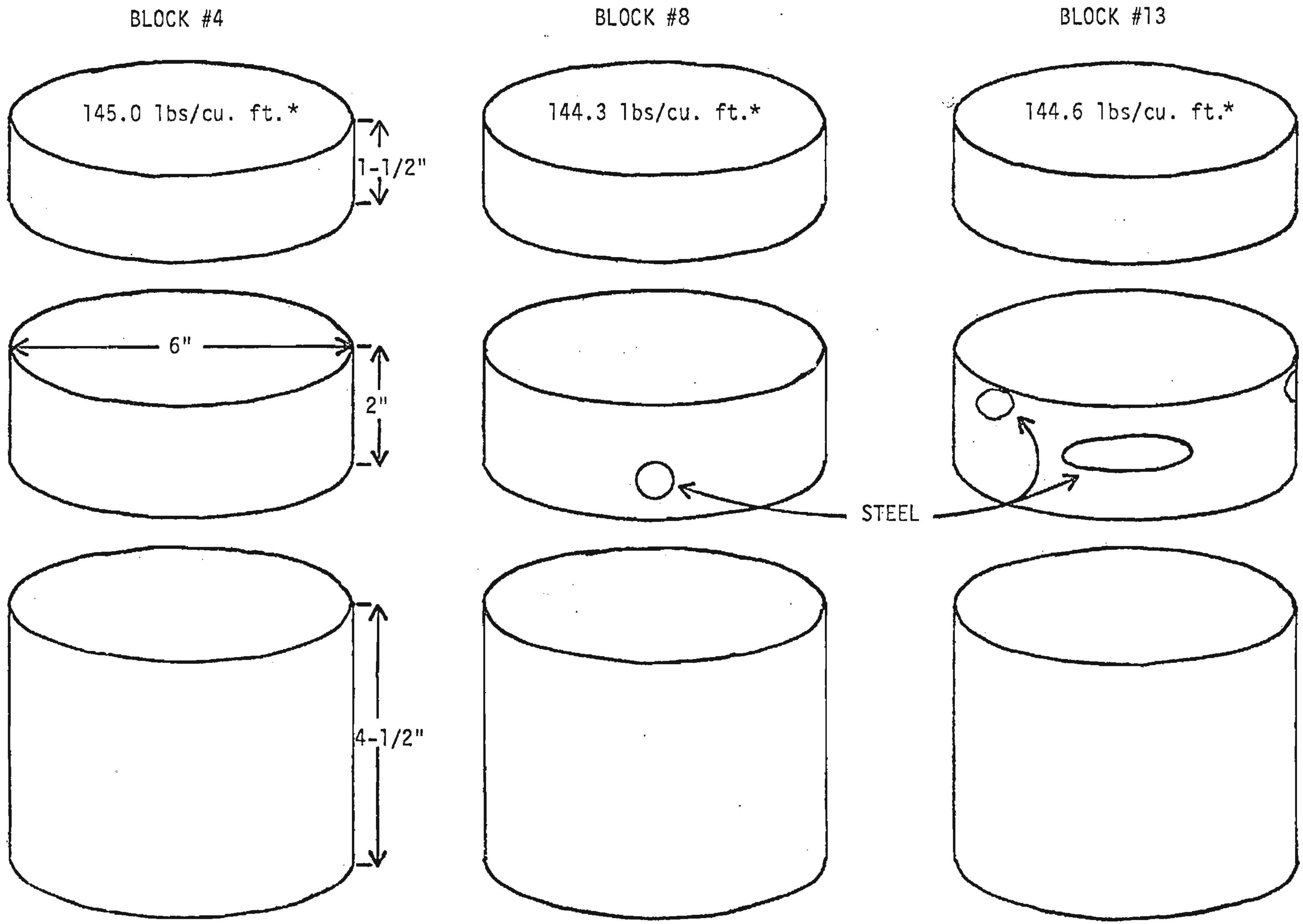


FIGURE 3

SKETCHES OF CORES TAKEN FROM BLOCKS



* Determined gravimetrically

FIGURE 4

CONCRETE AGGREGATE

Screen Analysis

Fine Aggregate % Passing		Coarse Aggregate % Passing	
3/8"	100	1"	100
# 4	99	3/4"	98
# 8	92	1/2"	68
# 16	70	3/8"	42
# 30	41	#4	9.6
# 50	19		
#100	5		
%-200	1.4		
Sp. Gr.	2.60	Sp. Gr.	2.63
% Absorption	1.1	% Absorption	1.0
Fineness Modulus	2.74	Fineness Modulus	6.50

DESIGN MIX

1/10 Cu. Yd.

Concrete Class	"D"
Water/Cement Ratio	.379
Martin Marietta Cement	66.0 lbs
Fine Aggregate	120.0 lbs
Coarse Aggregate	180.0 lbs
Water	25.0 lbs
Pozz 300N Admixture	77.0 c.c.
MBVR AEA	180.0 c.c.
Air Free Weight/Cu Ft	151.97
Unit Weight	144.81
Yield	.972 Cu Yd

TABLE 1

NUCLEAR GAUGE DENSITY MINUS SCALE DENSITY

Test Blocks without Resteel

Block #	Backscatter Mode Wet	Backscatter Mode Dry	2" Transmission Mode Wet	2" Transmission Mode Dry
4	-1.7	-7.3	+ .3	- .2
5	-1.8	-4.0	- .2	0
6	- .9	-5.3	+1.0	+ .1
Avg.	-1.5	-5.5	+ .4	- .1

Test Blocks with Resteel 2-1/2" from Surface

Block #	Backscatter Mode Wet	Backscatter Mode Dry	2" Transmission Mode Wet	2" Transmission Mode Dry
7	-1.2	-3.9	+ .7	+ .2
8	- .4	-3.1	+ .5	- .4
9	+ .4	-3.4	+1.2	+1.0
10	-1.0	-4.5	+1.4	+1.5
Avg.	- .6	-3.7	+1.0	+ .6

Test Blocks with Resteel 1-1/2" from Surface

Block #	Backscatter Mode Wet	Backscatter Mode Dry	2" Tran. Wet	2" Tran. Dry	1" Tran. Wet	1" Tran. Dry
11	+3.1	+ .6	+6.1	+5.8	Not Taken	+1.3
12	+3.4	-1.2	+6.5	+4.8	+ .2	+ .3
13	+3.2	+ .3	+8.0	+7.5	+2.6	+1.3
14	+3.4	-4.2	+5.6	+2.8	+2.4	-1.8
Avg.	+3.3	-1.1	+6.6	+5.2	+1.7	+ .3

TABLE 2

	AIR CONTENT (%)			UNIT WEIGHT			
				AIR METER BASE			MOLD
TEST BLOCK NUMBER	RODDED	VIBRATED 5 Sec.	VIBRATED 15 Sec.	RODDED	VIBRATED 5 Sec.	VIBRATED 15 Sec.	SCALE
4	3.6	2.8		148.1	149.9		152.2
5	3.5	2.7		148.3	149.8		151.7
6	3.7	2.6		147.5	149.6		151.4
7	3.4	2.7		148.2	149.8		152.2
8	3.6	3.0	1.9	148.1	149.0	150.6	151.7
9	3.3	2.9	2.5	148.4	149.5	150.0	151.3
10	3.8	3.2	2.4	147.2	148.2	150.1	151.2
11	4.0	3.4	2.4	146.6	148.0	149.3	150.8
12	4.4	3.8	2.9	145.4	147.4	148.9	149.6
13	3.3	2.7	1.9	147.4	148.7	150.1	150.6
14	3.3	2.4	1.8	147.9	150.0	151.4	152.3
Mean	3.6	2.9	2.3	147.6	149.1	150.1	151.4
S.D.	.34	.40	.40	.90	.89	.82	.81

TABLE 3

AVERAGE GAUGE DENSITY MINUS CORE SP. GR.

Top 1-1/2" of Core Used

GAUGE MODEL	NUMBER OF GAUGES	DEPTH SETTING	NO STEEL	STEEL 2.5" DEEP	STEEL 1.5" DEEP
Troxler 2401	10	BS	-1.8	-1.1	-1.5
Troxler 3401	2	BS	-0.3	+0.5	+6.2
Campbell A-MK-2	10	BS	+1.3	+2.6	+5.9
Campbell B(R)	3	AC	+1.2	+2.1	+4.1
		BS	+1.8	+3.1	+6.9
Campbell B(R)C	3	AC	+0.8	+1.8	+3.8
		BS	+2.0	+4.2	+8.8
Campbell MC-1A	7	AC	-0.6	-0.3	+0.8
		BS	+0.4	+2.2	+5.3

TABLE 4