THE UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING
Department of Naval Architecture and Marine Engineering

Final Report

MODEL EXPERIMENTS TO DETERMINE THE EFFECT OF SHIP MOTIONS UPON BULK CEMENT

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STATEMENT OF THE PROBLEM

The Huron Portland Cement Company has been transporting bulk cement by vessels on the Great Lakes since 1916. All these vessels have been fitted with one or more longitudinal bulkheads limiting the possibility of a dangerous shift of cargo. During this period of forty-five years, no shift of cargo due to heavy weather has been reported.

Early in 1959, this company first considered the fitting of a self-unloader which would carry cement from Alpena and coal to that port. It seemed advantageous to consider the elimination of longitudinal bulkheads.

To provide information which would satisfy the U. S. Coast Guard that such longitudinal bulkheads could safely be eliminated, the Huron Portland Cement Company contracted with The University of Michigan Research Institute to make model experiments to this end.

The following is a report on these experiments.

CONCLUSIONS

The one significant conclusion to be made is that these tests did show the centerline bulkhead to be necessary in bulk cement carriers. Several other facts were uncovered.

First it was found that the problem was far more complex than was first suspected. From the preliminary shear tests, it was found that the four types of cement have about the same shear strength. Dry cement was found to fail in a "brittle" manner. That is, deflection was very small up to the point of complete shearing fracture. This total fracture was found to be independent of time. Only a very weak correlation was found between normal pressure and shear strength.

DESCRIPTION OF TEST EQUIPMENT

It was proposed to attack the problem by demonstrating the stability of bulk cement both in a static and a dynamic condition. Shear strength was used as the criterion for static strength. The measure of shear strength was made with a device borrowed from the Michigan Highway Department Soil Testing Laboratory. The highway department designed this equipment to measure shear strength of fine granular materials. Qualitative tests were made to determine the relative shearing strength of the four types of cement supplied by the Huron Portland Cement Company. The effects of temperature and pressure were also investigated.

The heart of the device consists of three short sections of thin walled tube which were placed end to end horizontally and filled with cement. A fixture supports the two end cylinders and leaves the center section free to fall, forming two potential shear planes. A lateral or "normal" force is applied at the ends of the long composite tube and weights are hung on the center portion. In this way, the cement is subjected to a known and controlable double shearing force. As the center section falls away, deflection is measured with a dial indicator. Figure 1 is a diagramatic sketch of the device.

The second, more pertinent phase of testing consisted of the dynamic tests. These were done on a 1/12 scale model of the M/V Paul H. Townsend. The model was made principally of plywood which was well finished on the working surfaces so as to simulate steel plates. A removable centerline bulkhead was included so tests could be made with and without it.

Motion was achieved by suspending the model on knife edge supports to allow it to roll back and forth like a pendulum. The supports were on the centerline roughly 3/4 of the way up from the bottom of the model. The pivot point was selected so that the surface accelerations at the top of the load in the model would be equal to those in the actual ship. An accelerometer was placed so to measure the accelerations at the top of the load.

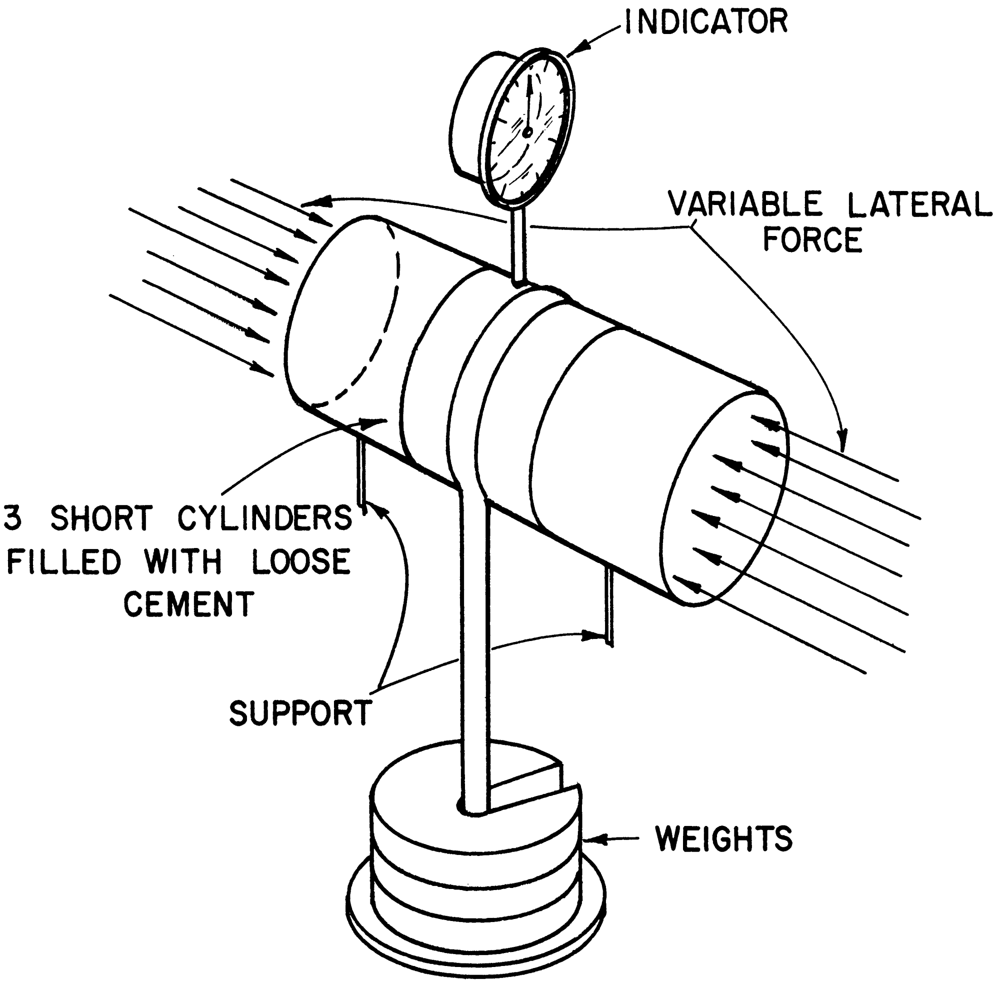


Fig. 1. Diagram of device.

Displacement was measured with an SR-4 electric strain gauge mounted on a piece of steel band as shown in Fig. 3. As the model oscillated back and forth on its pivot, the steel band was alternately bent and unbent. The strain gauge detected and resultant stretching and compressing of the upper face on the steel band. The voltage variations from the strain gauge and accelerometer were amplified and recorded on a two-channel Brush penmotor. The resulting graphs were calibrated to read directly in ft/sec and degrees of heel.

A clear plastic deck plate was used for two reasons. First, it allowed observation of the load during the tests; second, the plate had a grid of small holes drilled in it. These holes allowed many measurements to be made of the distance between the load top and the deck plate. From these data, the topographical sketches included later were made.

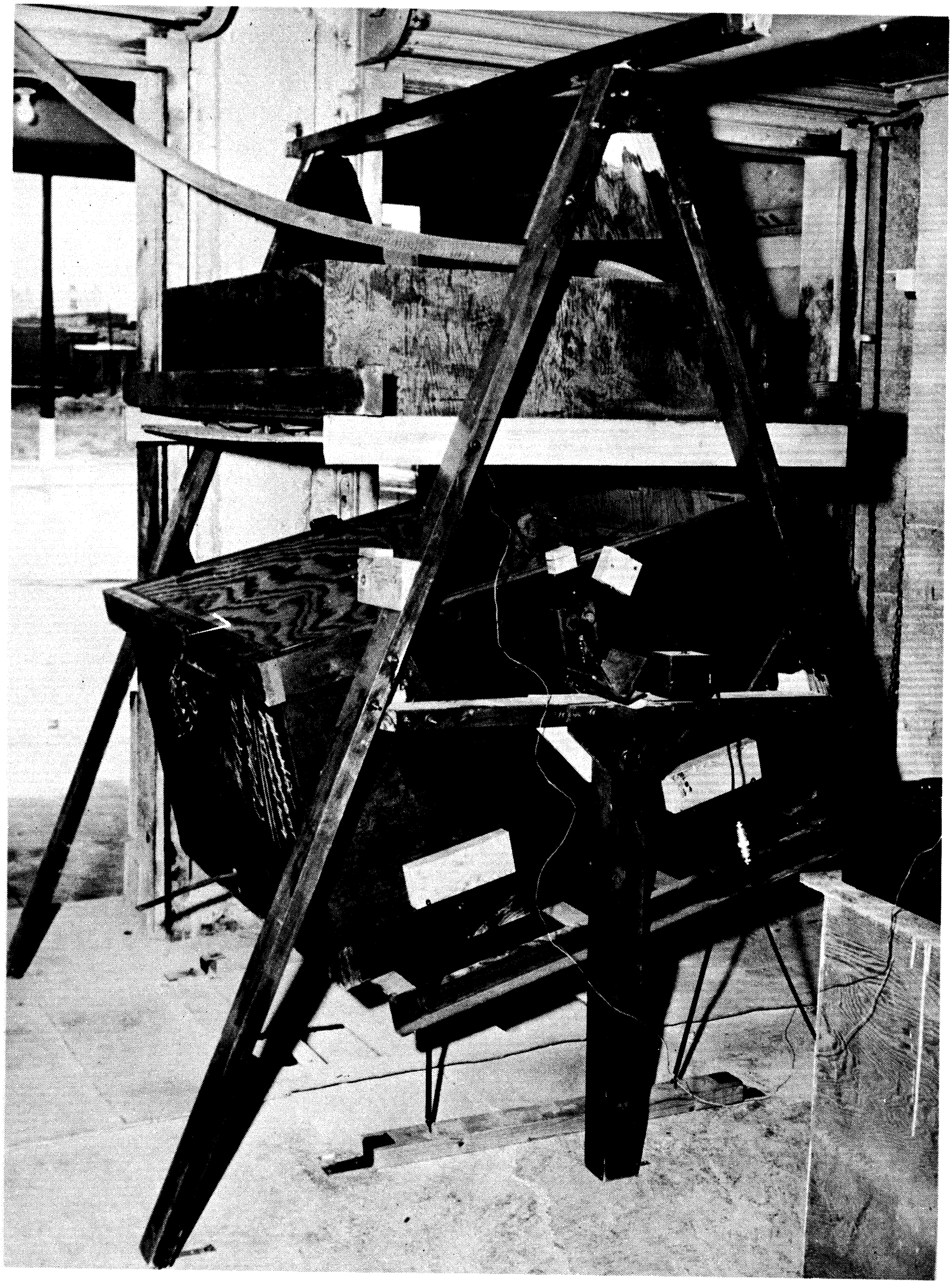


Fig. 2 The setup.

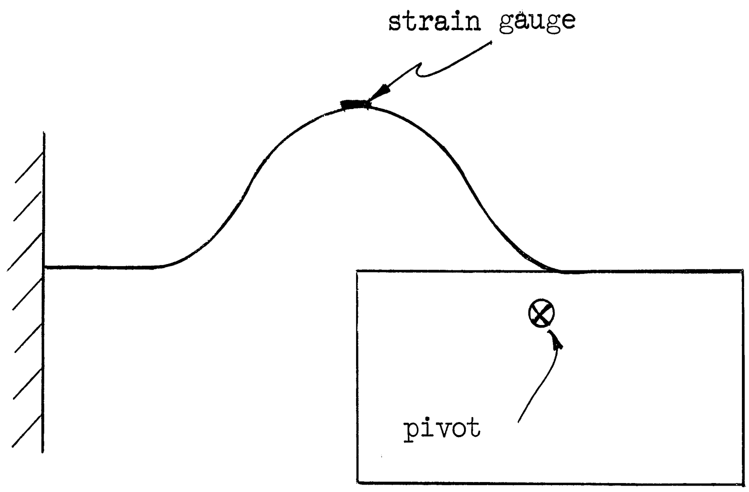


Fig. 3. Measurement of displacement.

PROCEDURE

The shear tests were very straightforward. The long tube was filled with dry cement and lateral pressure was exerted with a spring-loaded screw device. Then small increments of load, 1/4- or 1/2-lb weights were added very carefully to avoid impact. At each weight step, the deflection was measured to the nearest 1/1000 in. This was continued until the center of the tube dropped out completely. Rough load-deflection curves were drawn so that comparisons could be made.

The dynamic tests were made in series of three.

TEST NO. 1

The first test was designed to simulate the regular rolling of a ship. The loaded model was forced to swing back and forth like a pendulum supported on the knife edge bearings. The oscillations were made increasingly larger until a 20° roll was reached or until major shifting occurred.

TEST NO. 2

The second test was intended to duplicate the action of a ship with an initial heel, as with a ship with the wind on the beam. The model was loaded as usual and then a weight was added on to one side to cause an 8° list. The model was then swung as in Test No. 1, in increasingly larger arcs until a 20° roll was made or until major shifting occurred.

TEST NO. 3

The third test was designed to simulate the motion of a ship as it is hit by an offbeat wave. The model was forced to oscillate about its equilibrium position in a constant 10-12° roll. However, after this roll was achieved, a spring as shown in Fig. 4, was hooked onto the model during 1/2 of the roll cycle. The spring was not hooked on every half cycle but every other or every third cycle.

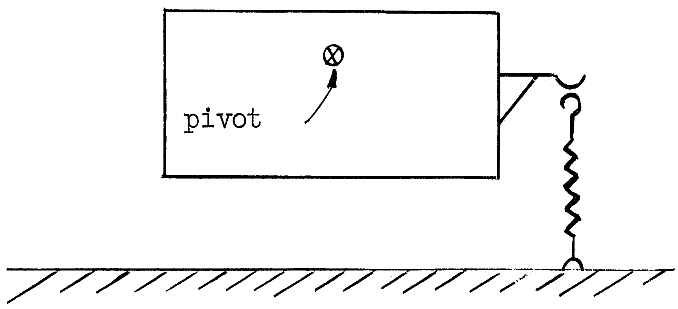


Fig. 4. Spring hooked onto model.

DISCUSSION

A machine to duplicate the actual motion of a ship would be impossibly complicated. In simplifying the model it was decided to ignore the three translational components of motion, since the corresponding accelerations are negligible. This left three degrees of freedom; pitch, roll, and yaw. Pitch and yaw were also neglected because the motions are ordinarily very small in magnitude. Also, the forces caused by pitching action do not tend to cause transverse shifting. Roll was the one remaining motion and it was modeled. It should be said that these assumptions on ship motion are rather broad. It is generally agreed that this model did not accurately reproduce the conditions found on a ship. This is so because there was shifting in the model, even with the centerline bulkhead and none has ever occurred in a ship.

It should also be mentioned that the loading method used in these tests did not accurately reproduce the conditions found on an actual ship. The cement in the model stood in sixteen conical piles, each of which would be between 2 and 5 feet tall in a ship. Observation on a loaded ship revealed a fairly flat, even load, falling away with a slope of 1:4.

It was found that all shifting in settled cement occurred along well-defined shear planes. These shear planes seemed to form at or slightly below the base of the cones. Once they formed, they would propagate left and right to the boundaries of the body. There was little tendency for the shear planes to move in a longitudinal direction. It was observed that if one portion of the load began to shift, like the shaded area shown in Fig. 5a, this portion would shift left to right while the rest of the load would stay fixed. When this happened, a well-defined boundary would form between the fixed part of the load and the part which was shifting. The boundary was where the shear plane surfaced, as indicated in Fig. 5b.

When the centerline bulkhead was used, it stopped the shear plane at the centerline and thus, in boundary cases, half the load was saved from shifting. Usually, however, each side of the load started shifting independently of the other and the bulkhead served to reduce the maximum shift distance by 1/2. This had a great stabilizing effect on the load.

This partial shifting, as shown in Fig. 5a, seems to indicate some connection between load geometry and load stability. Although nothing definite can be said, it is felt that a flat load would tend to increase load stability.

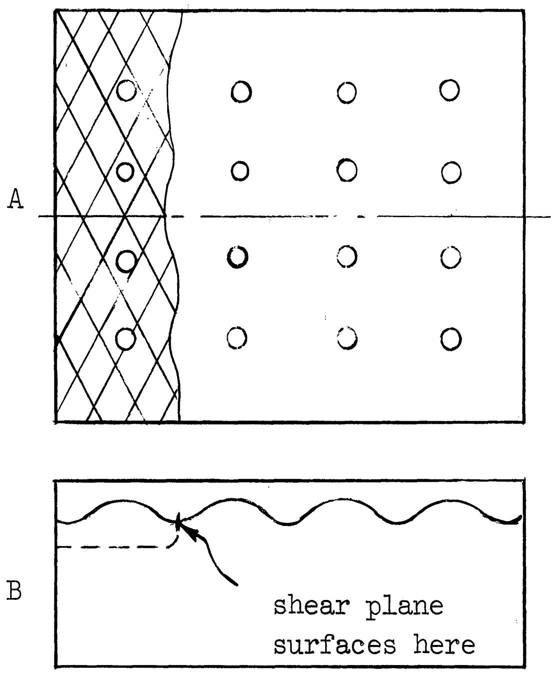


Fig. 5. Shift of load.

Present plans by the Huron Portland Cement Company call for a new loading system which would blow the cement into the holds. This would certainly lead to a flatter load which should be even more stable then those of today. This loading method, however, would be practically impossible to duplicate in a model because of the scale velocity effects.

Vibration was found to have a very stabilizing effect on cement. All the vibration of loading and maneuvering in a real ship is probably what gives actual cargoes so much more stability than was displayed by cement in the model.

Figure 6 shows some typical load-deflection curves of the preliminary shear tests. It displays the "brittle" type of failure.

Table I shows all the possible dynamic tests which could have been made and those which were actually carried out. It was felt that these tests were sufficient to allow prediction of results of the rest of the tests.

RESULTS

The results of the dynamic tests are shown here. The relevant information of each test is given along with the topographical sketches of the load, made before and after the test.

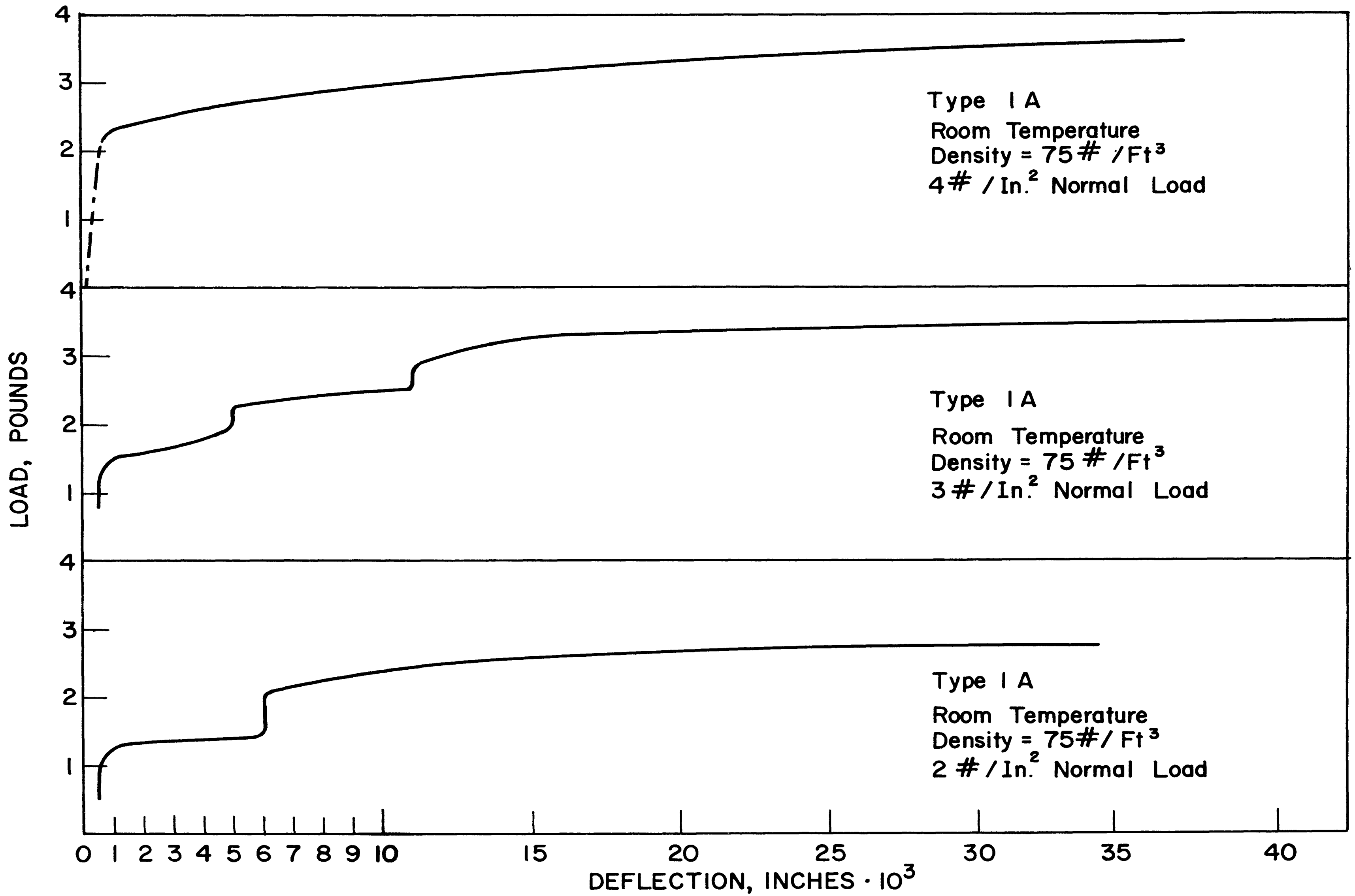


Fig 6. Typical load-deflection curves.

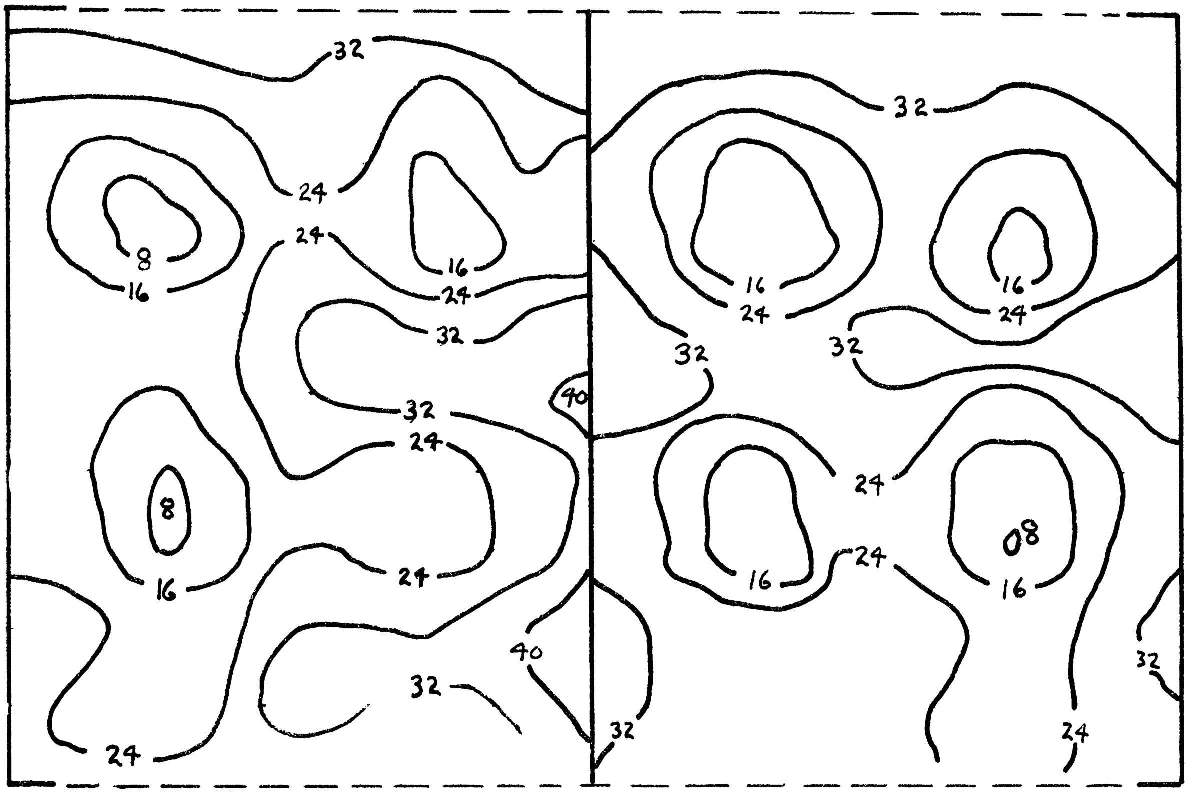
TABLE I

TESTS WHICH WERE CARRIED OUT OF ALL POSSIBLE DYNAMIC TESTS

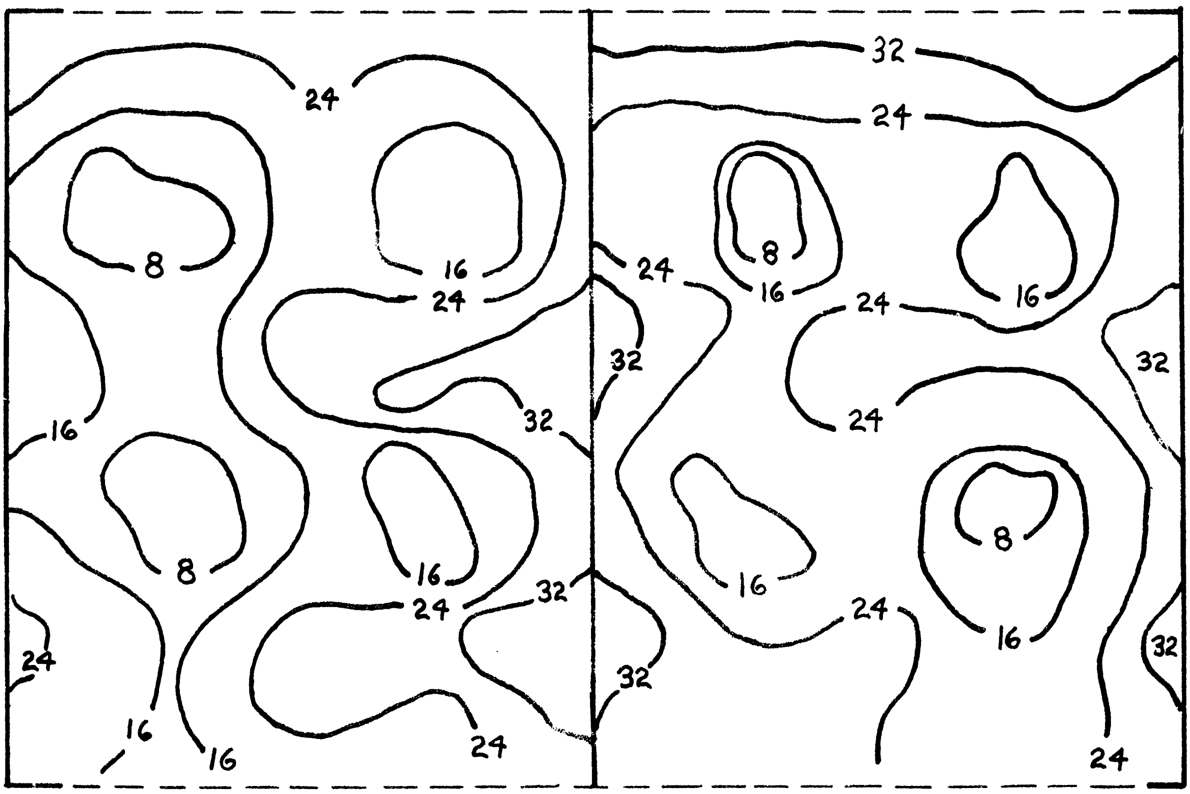
		Mortar	Air Entraining	Regular	High Early
Without Centerline	Test No. 1	X		X	
With Centerline		X	X	X	
Without Centerline	Test No. 2	X	X		
With Centerline		X	X		
Without Centerline	Test No. 3	X			X
With Centerline		X			

Test No. 1
Air Entraining Cement
Initial heel: 0°
Final heel: 0°
Displacement of first shift: None

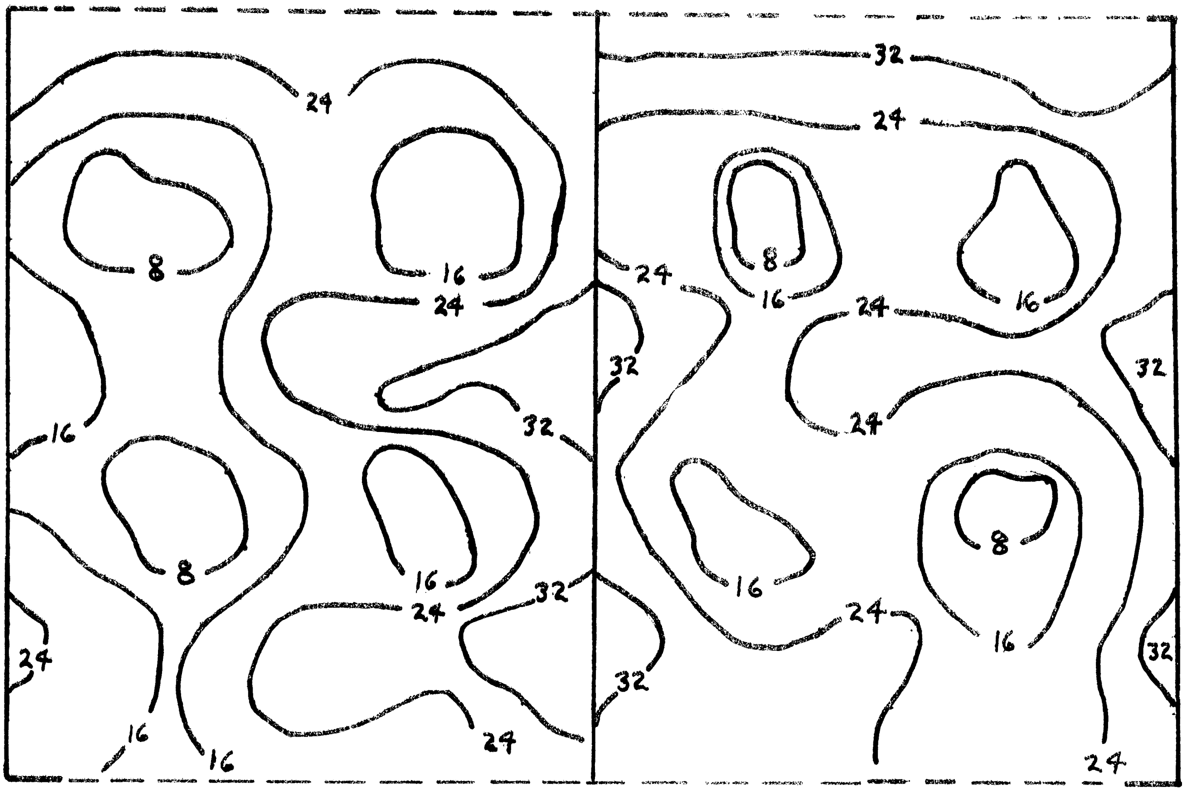
Maximum positive roll: 23°
Maximum negative roll: 24°
Maximum acceleration: .4g
With Centerline Bulkhead



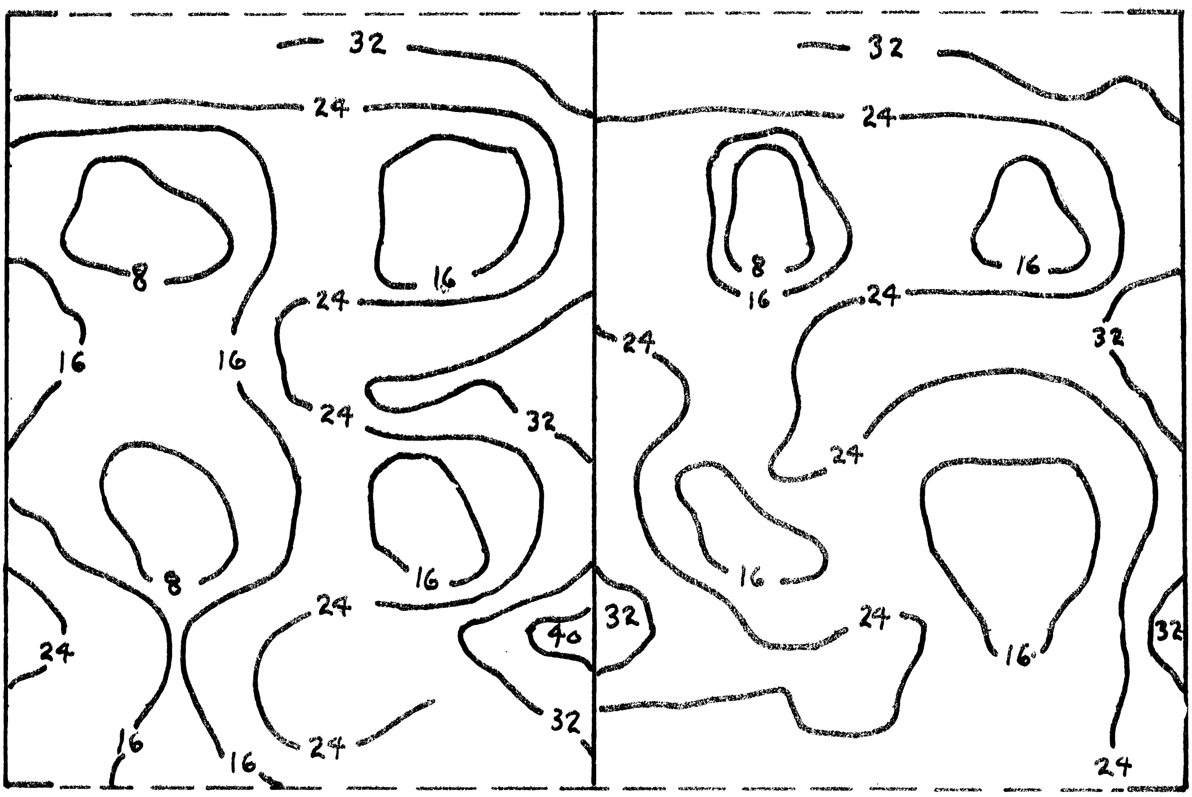
Before



After Vibration



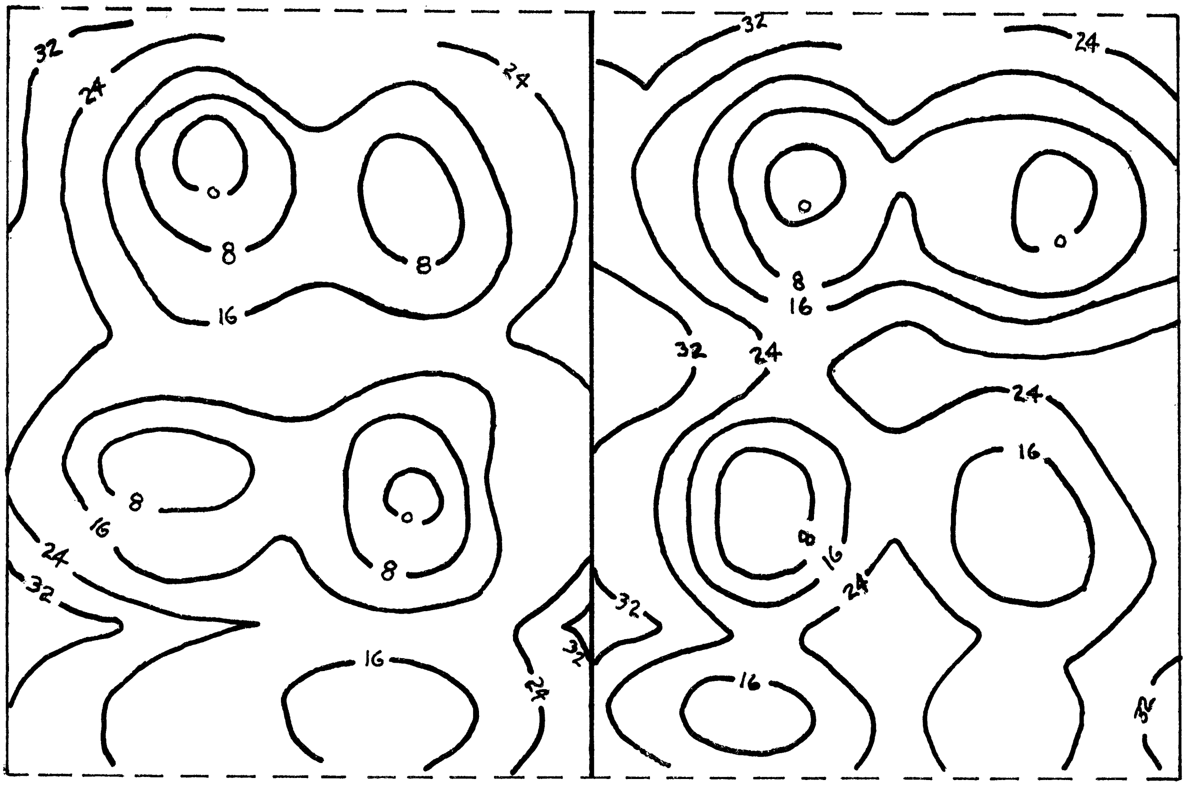
After Vibration



After Testing

Test No. 1
Cement type: Regular
Initial heel: 0°
Final heel: 2°
Displacement of first shift: 18°

Maximum positive roll: 20°
Maximum negative roll: 15°
Maximum accelerations: .36g
With Centerline Bulkhead



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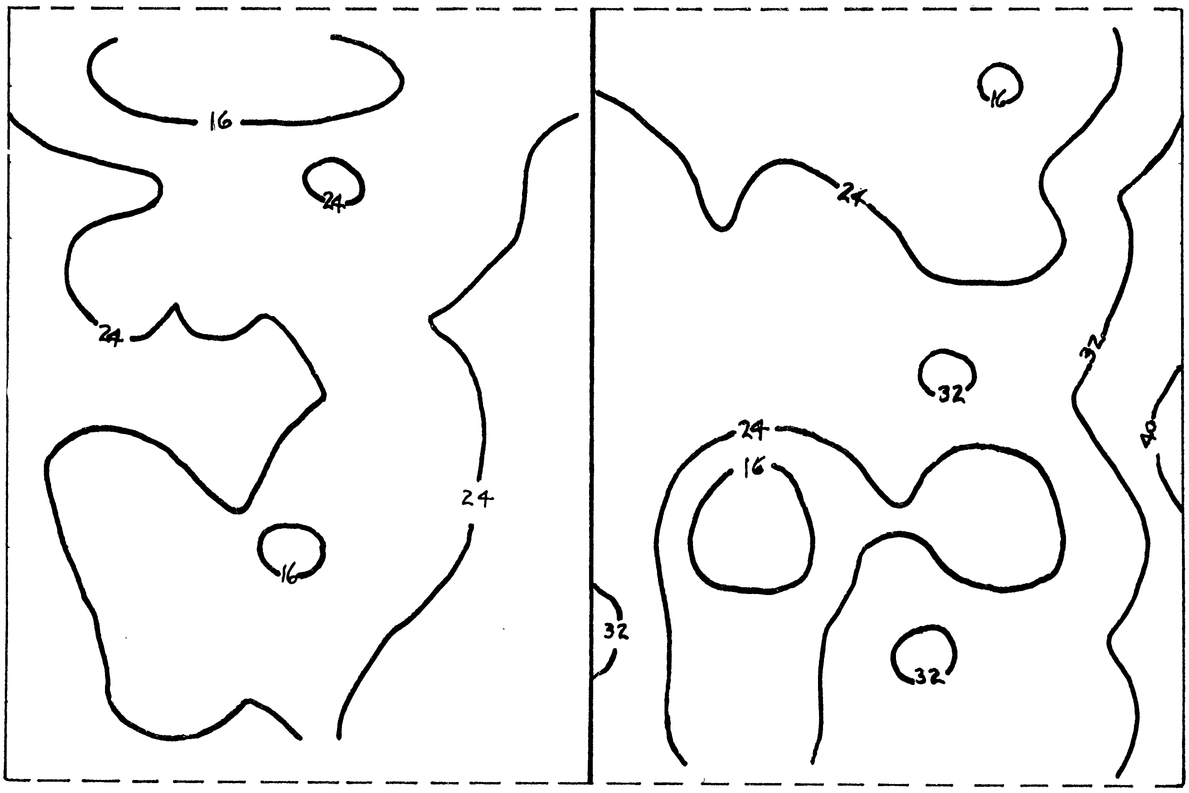
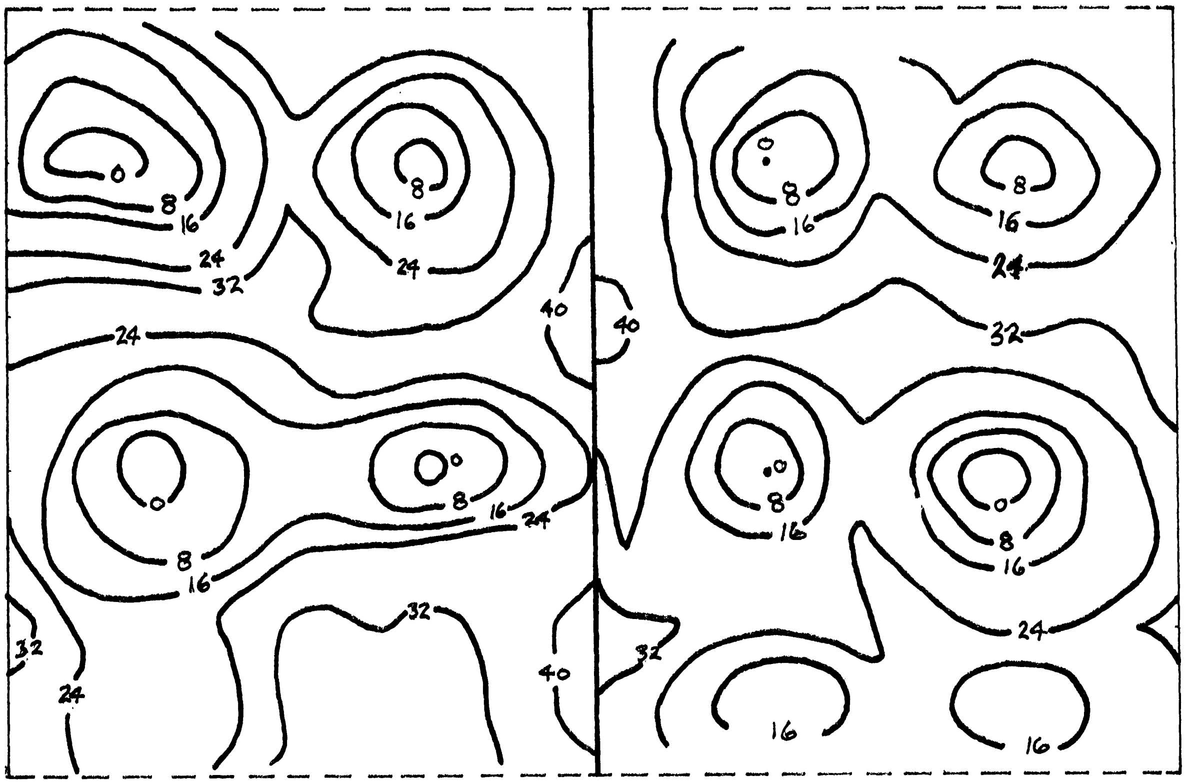


After

Test No. 1
Cement type: Mortar
Initial heel: 0°
Displacement of first shift: 17°

Maximum positive roll: 19°
Maximum negative roll: 19°
Maximum acceleration: .44g

With Centerline Bulkhead



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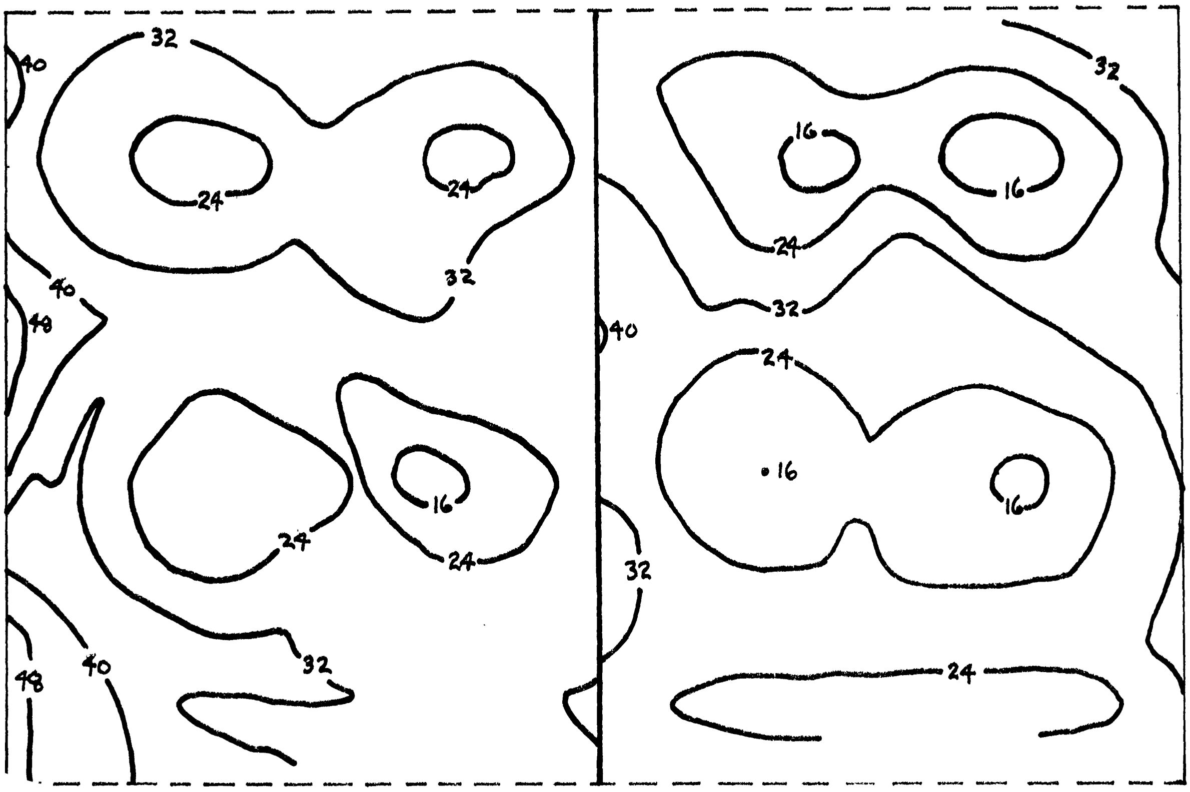
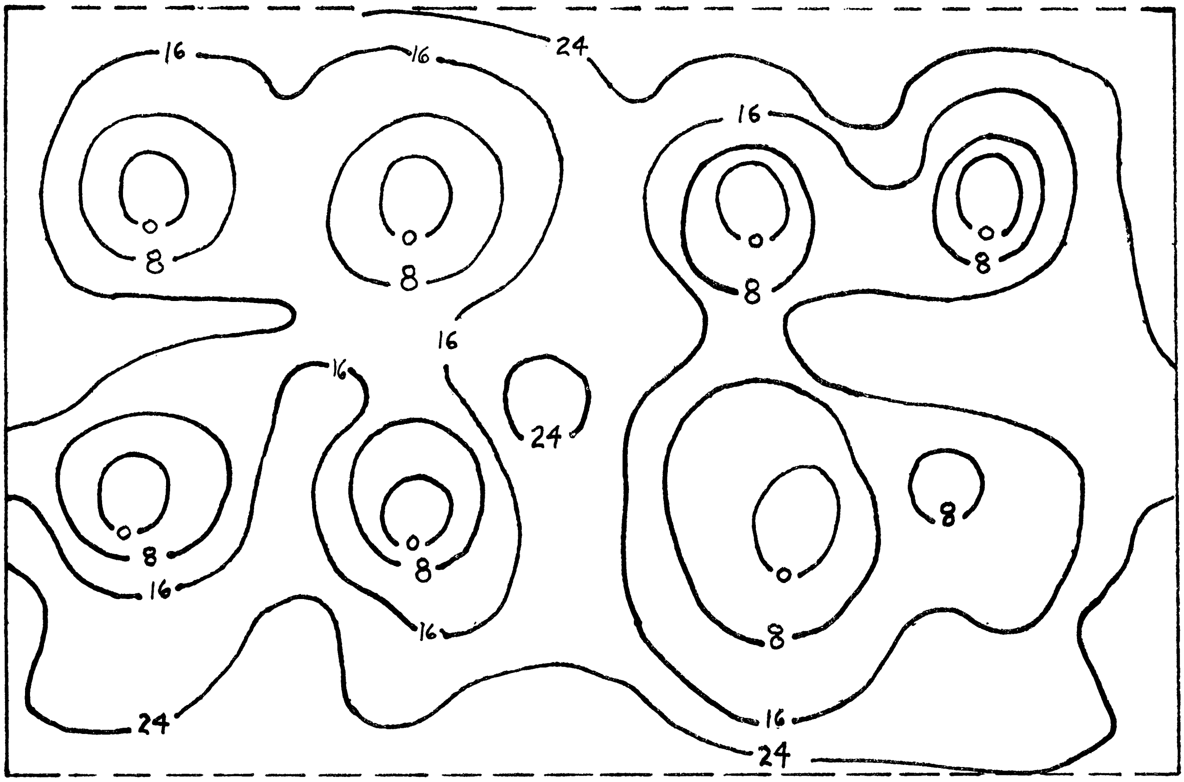


After

Test No. 1
Cement type: Regular
Initial heel: 0°
Final heel: 11°
Displacement of first shift: 15°

Maximum positive roll: 18°
Maximum negative roll: 19°
Maximum acceleration: .4g
Without Centerline Bulkhead



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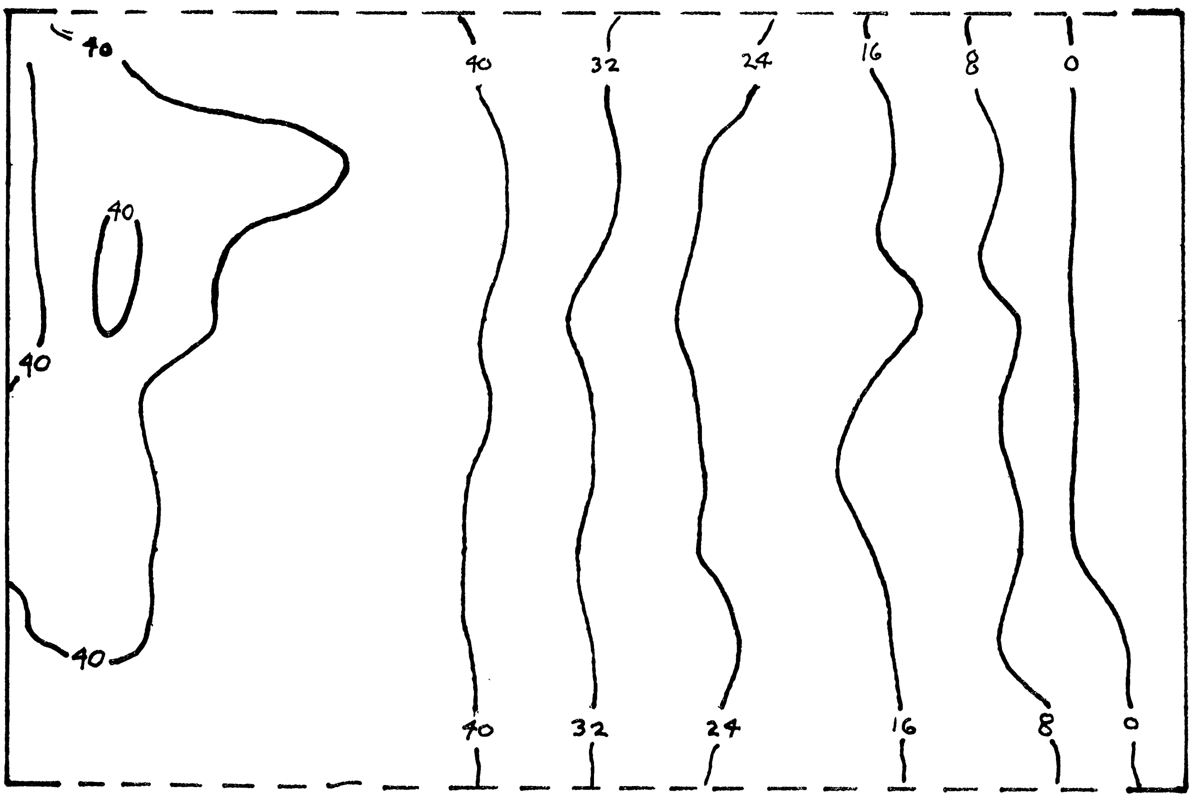
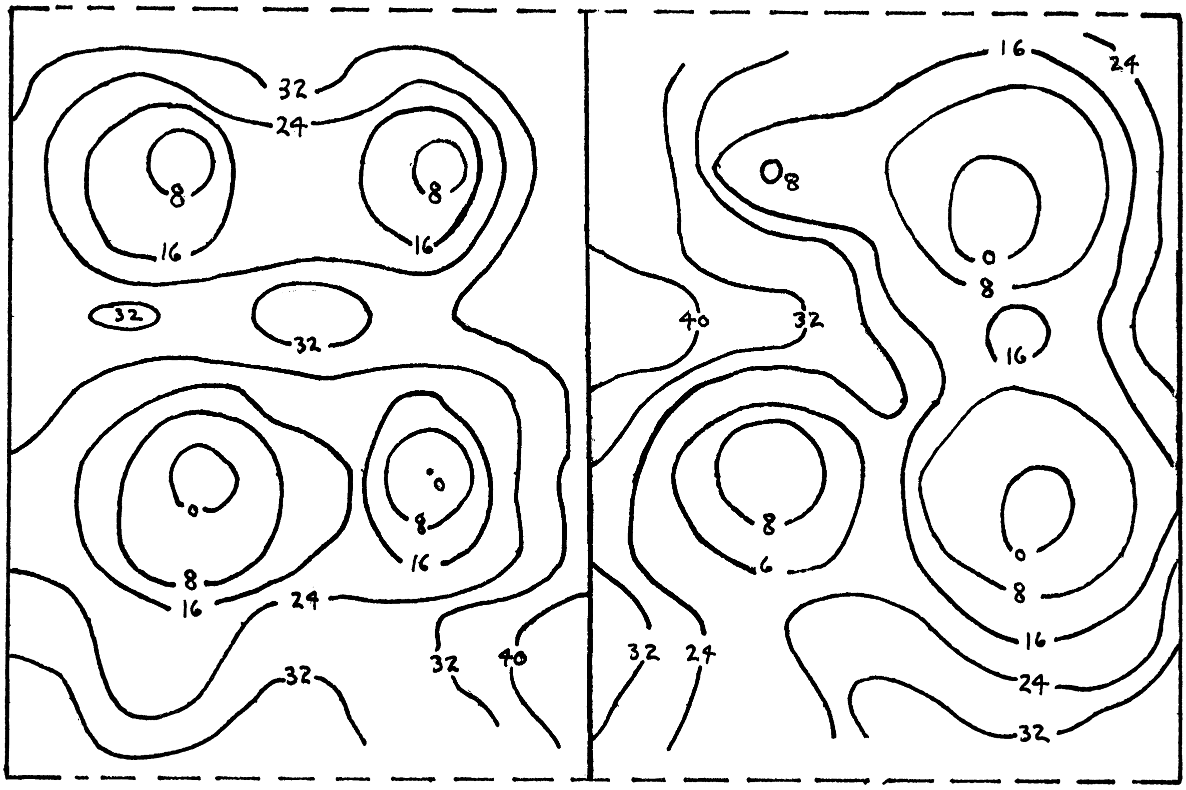


After

Test No. 1
Cement type: Mortar
Initial heel: 0°
Final heel: 0°
Displacement of first shift: 15°

Maximum positive roll: 22°
Maximum negative roll: 18°
Maximum acceleration: .4g
With Centerline Bulkhead



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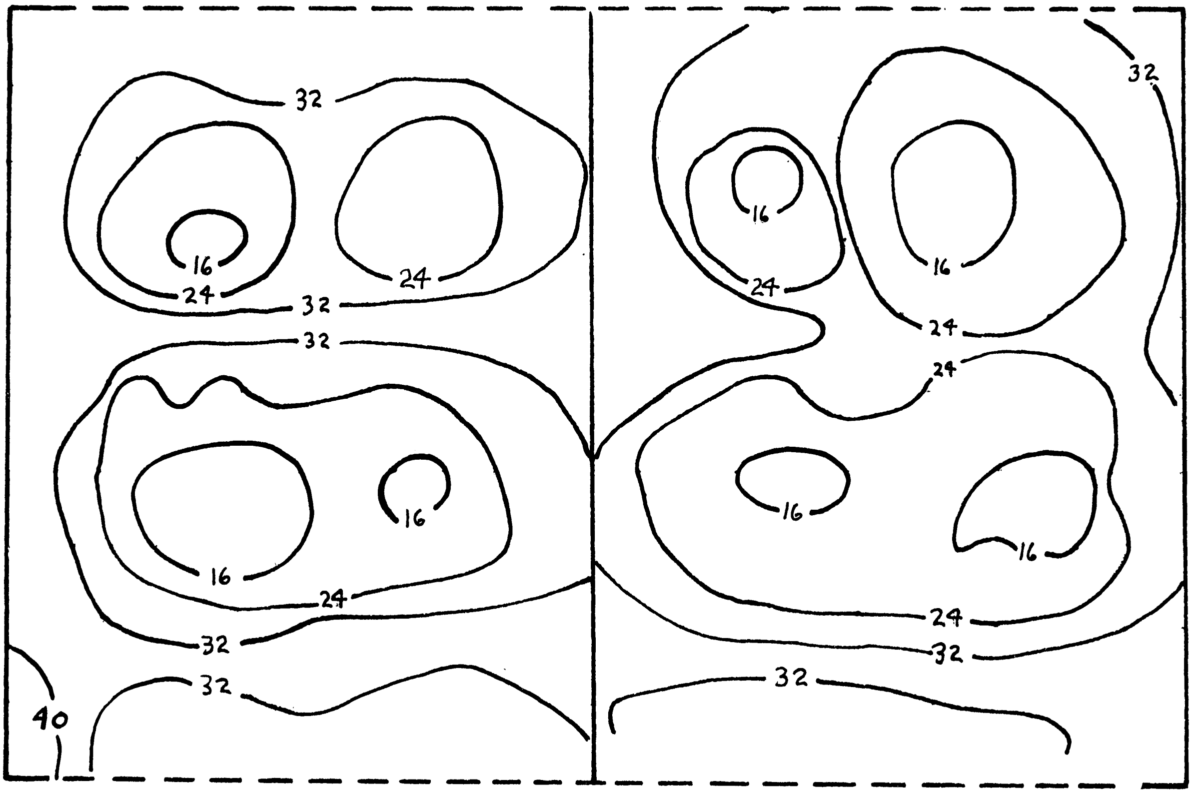
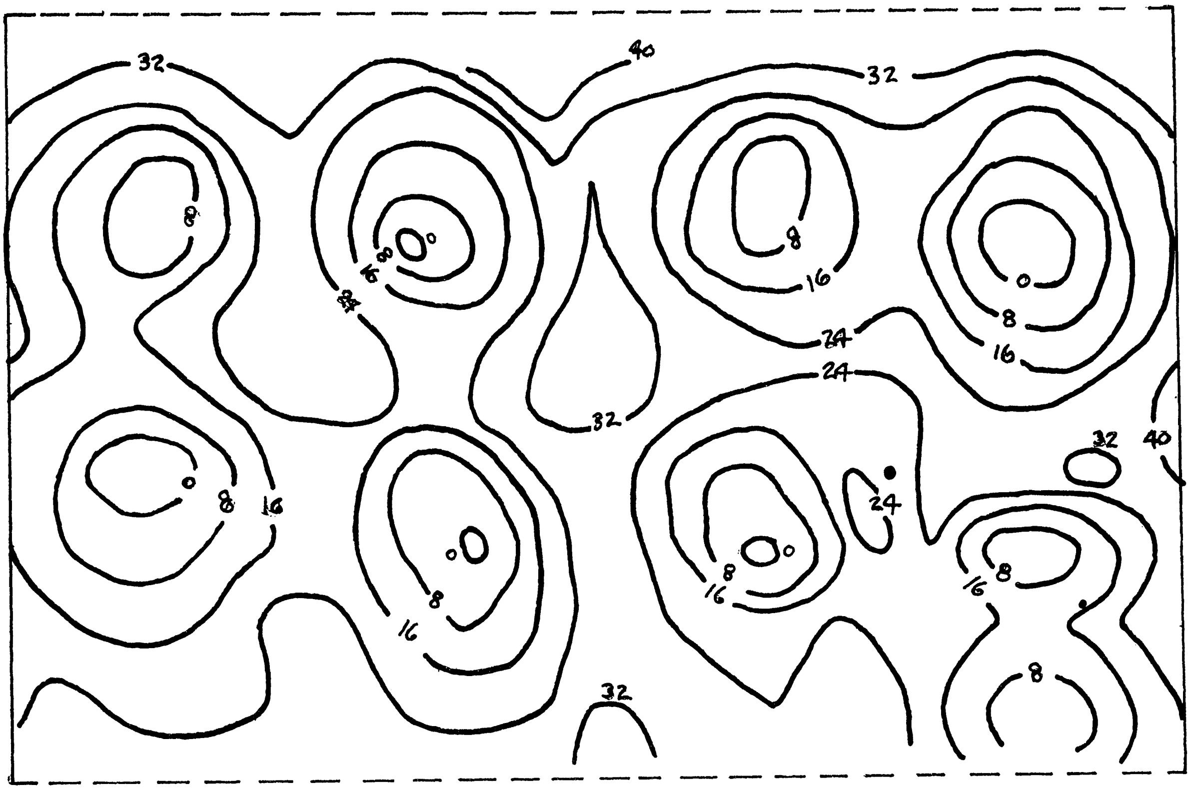


After

Test No. 1
Cement type: Mortar
Initial heel: 0°
Final heel: 5°
Displacement of first shift: 15°

Maximum positive roll: 24°
Maximum negative roll: 18°
Maximum acceleration: .44g
Without Centerline Bulkhead



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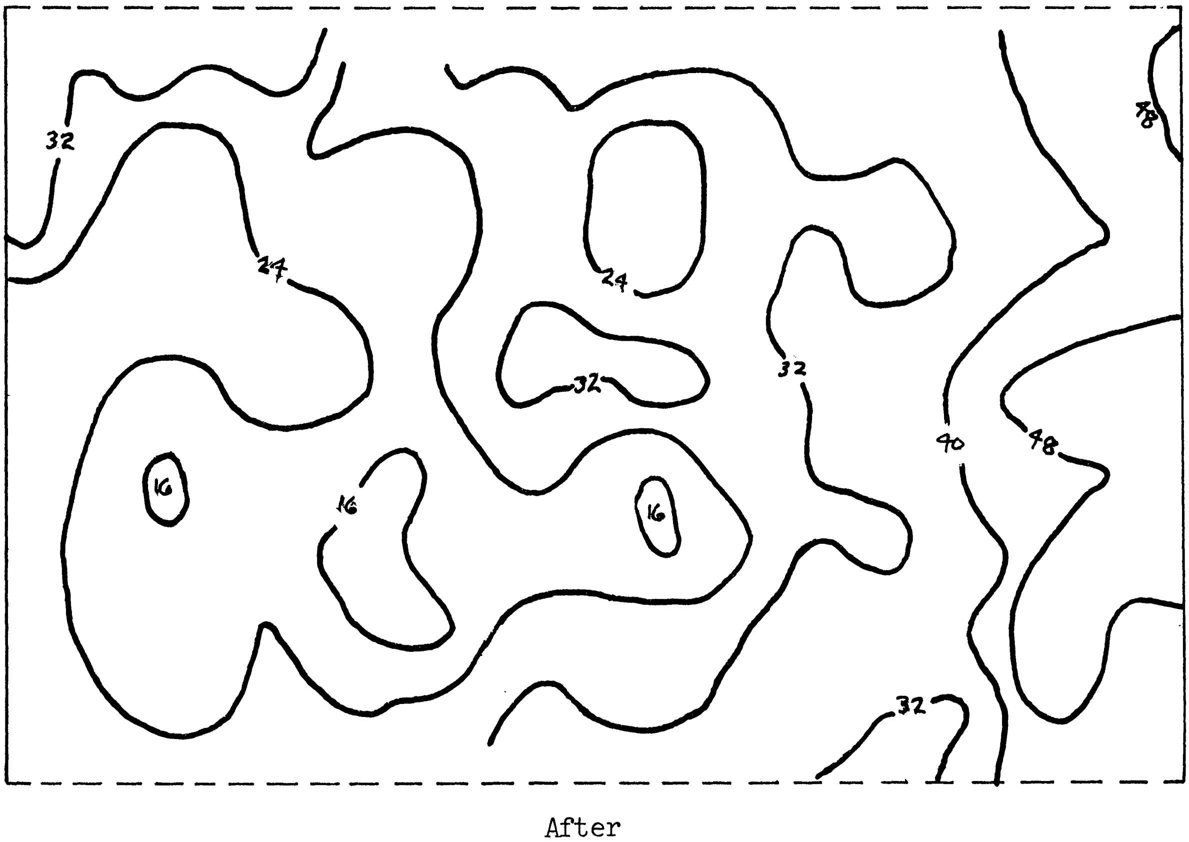
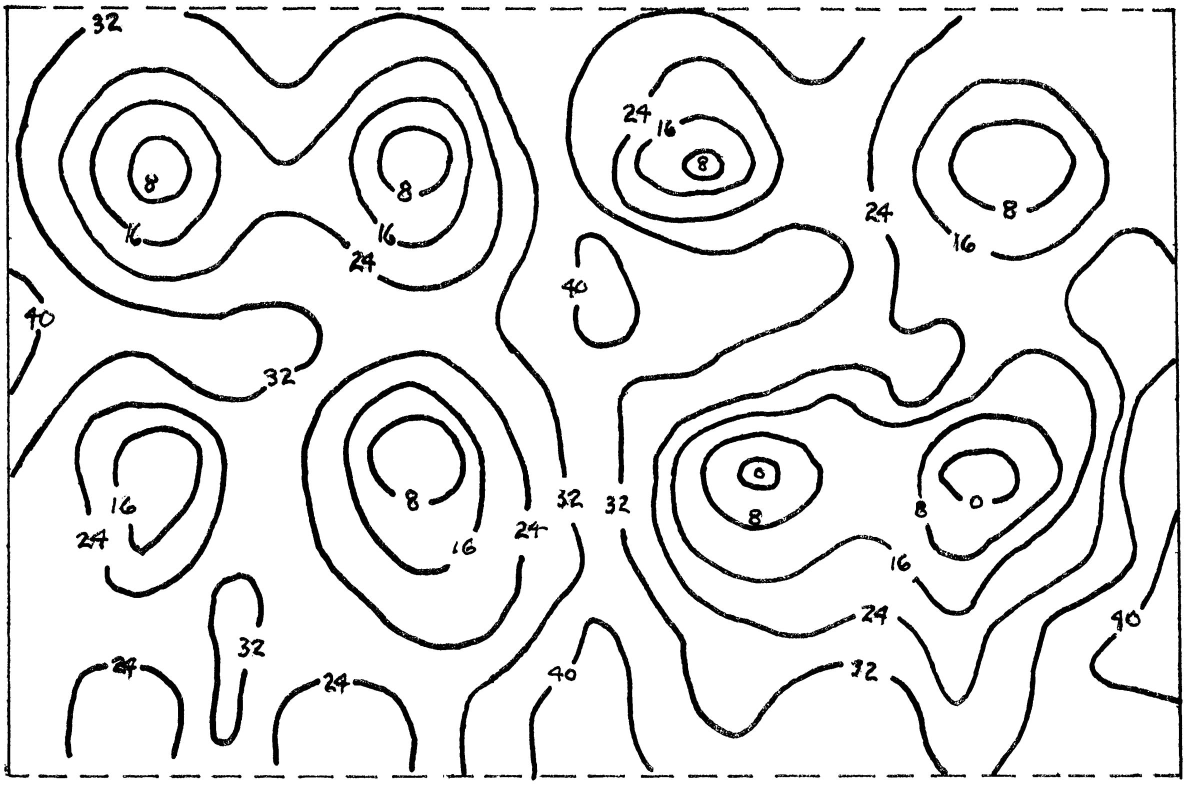


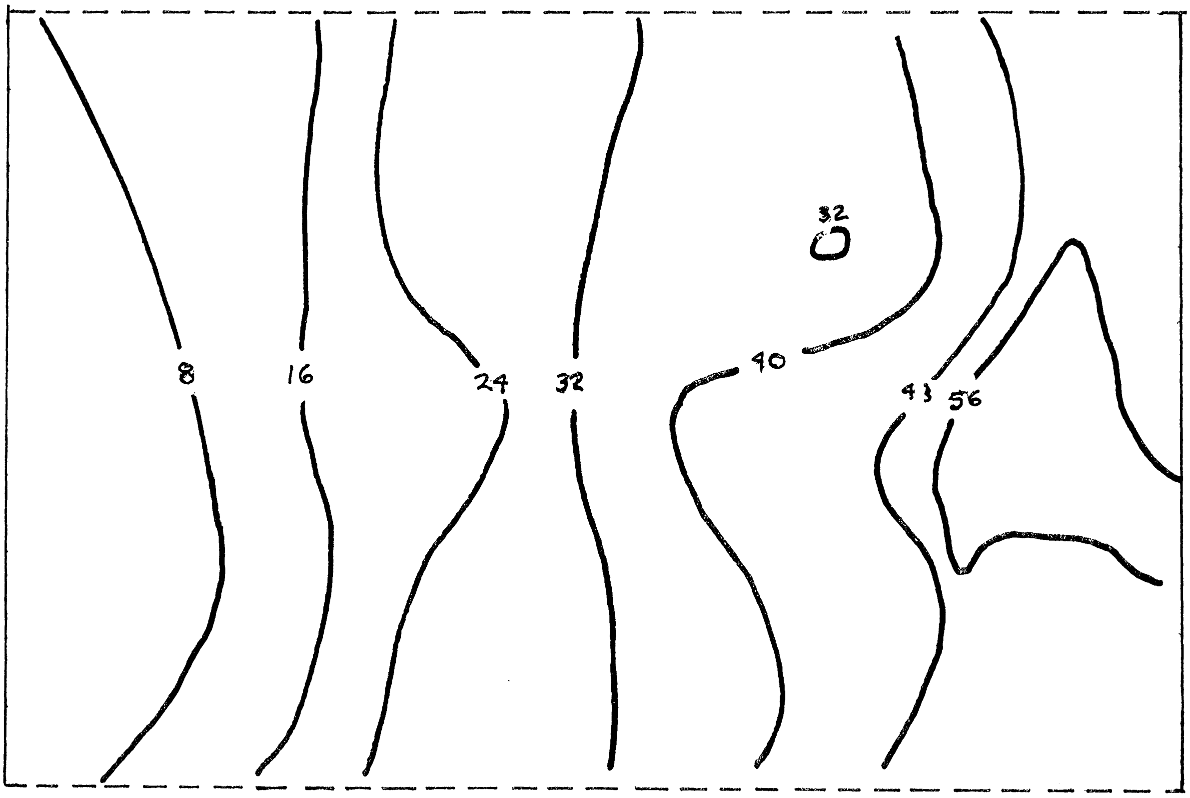
After

Test No. 1
Cement type: Mortar
Initial heel: 0°
Final heel: 14.5°
Displacement of first shift: 13°

Maximum positive roll: 15°
Maximum negative roll: 14°
Maximum acceleration: .4g
Without Centerline Bulkhead



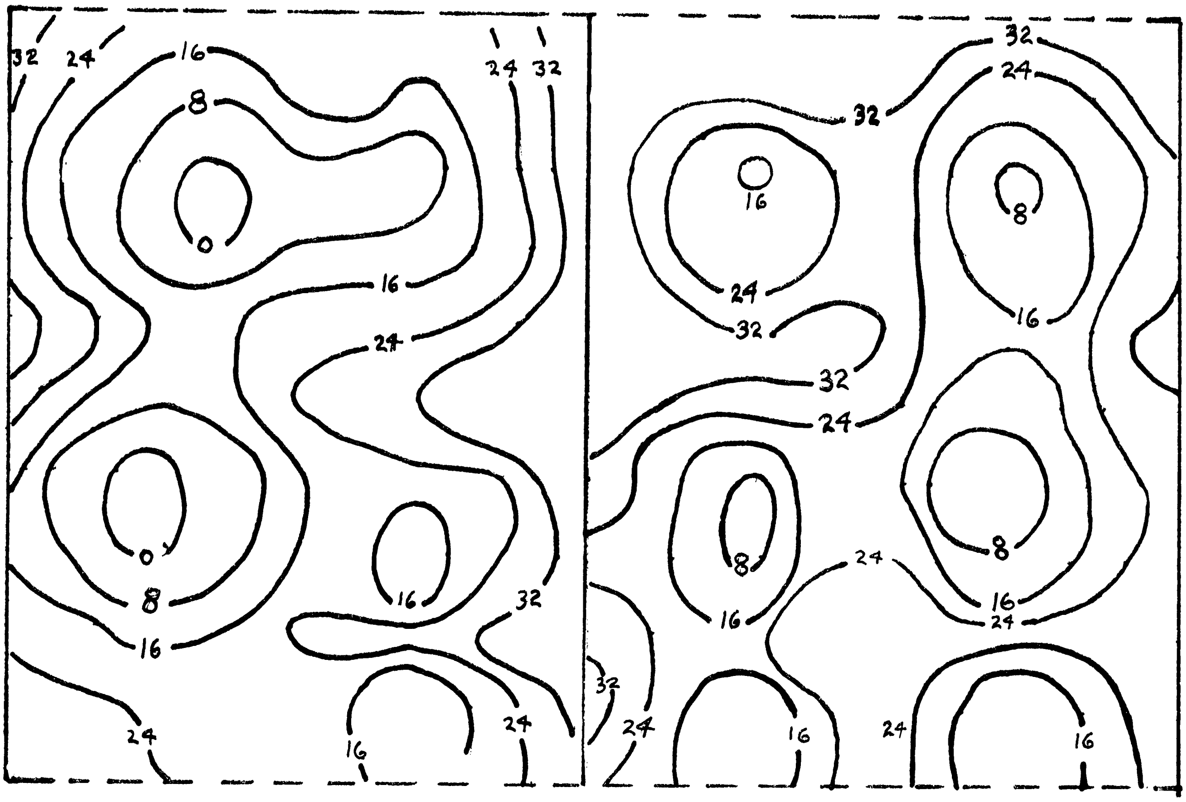
Before



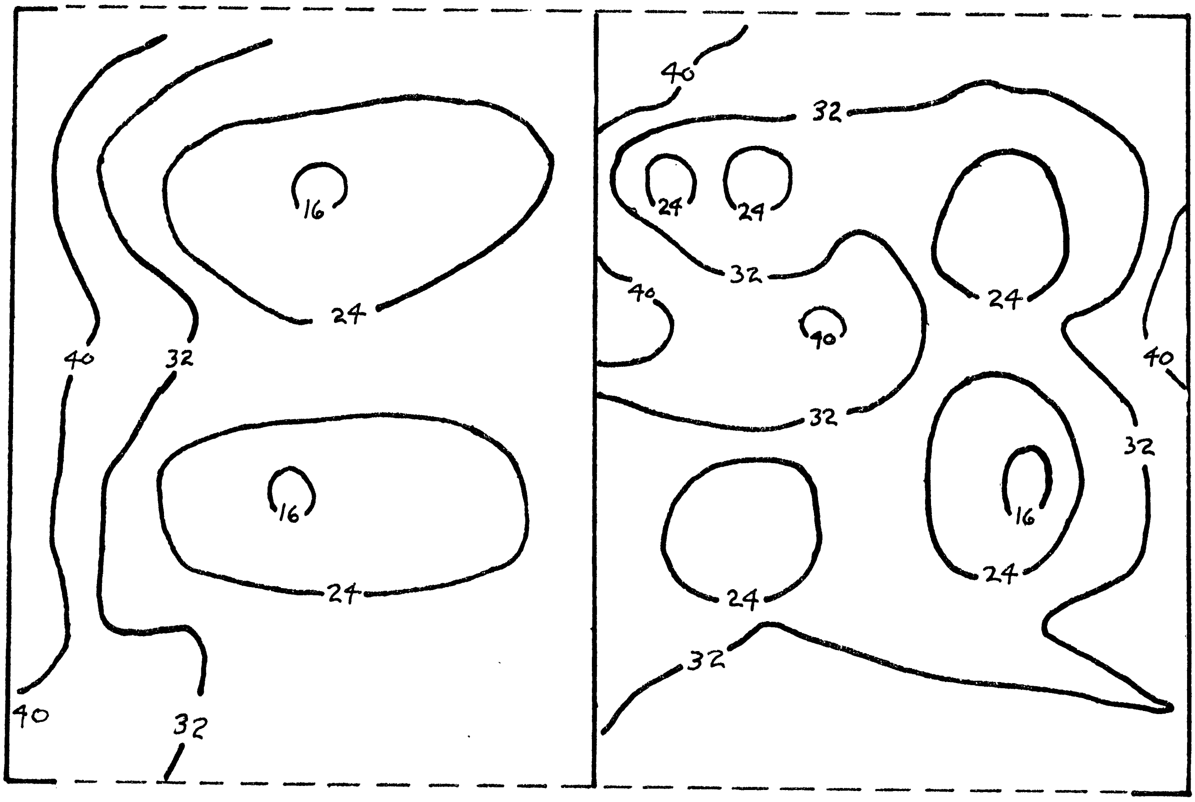
After

Test No. 2
Cement type: Mortar
Initial heel: 18°
Final heel: 17°
Displacement of first shift: 12°

Maximum positive roll: 3°
Maximum negative roll: off scale
Maximum acceleration: off scale
With Centerline Bulkhead



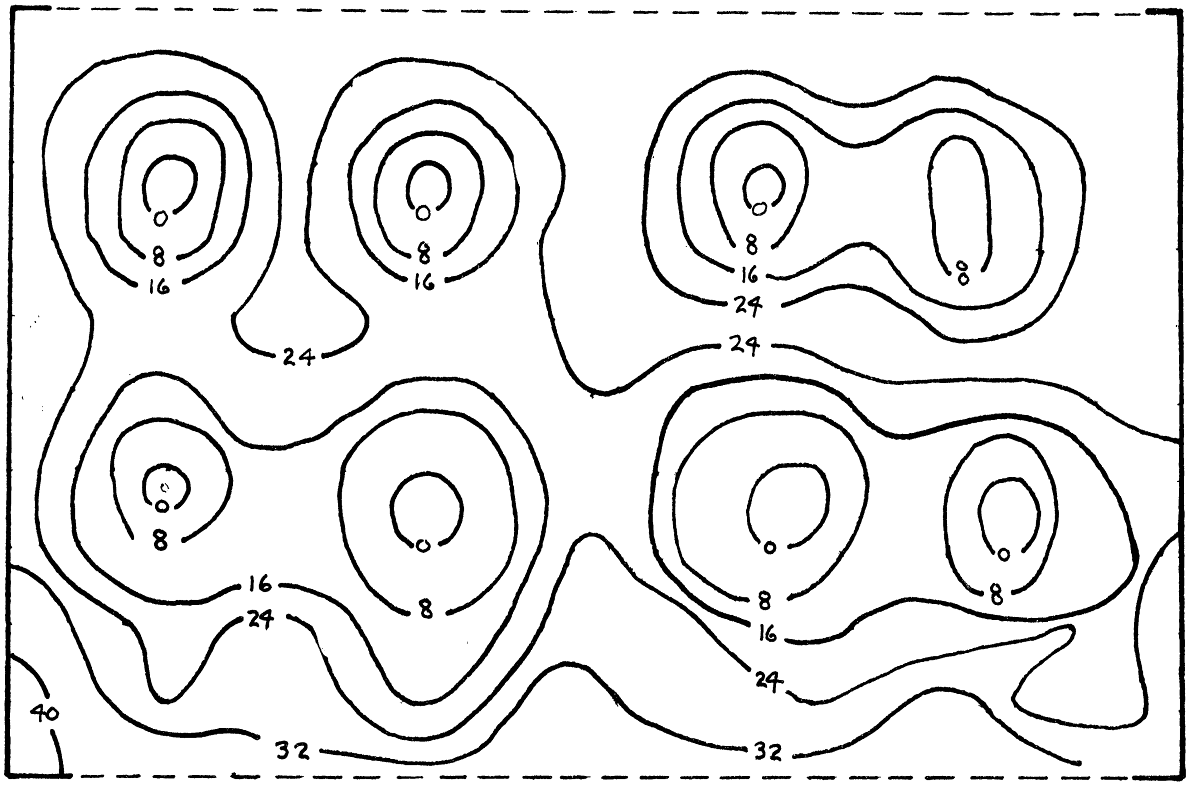
Before



After

Test No. 2
Cement type: Mortar
Initial heel: 9°
Final heel: 21°
Displacement of first shift: 11°

Maximum positive roll: 22°
Maximum negative roll: 22°
Maximum acceleration: .38g
Without Centerline Bulkhead



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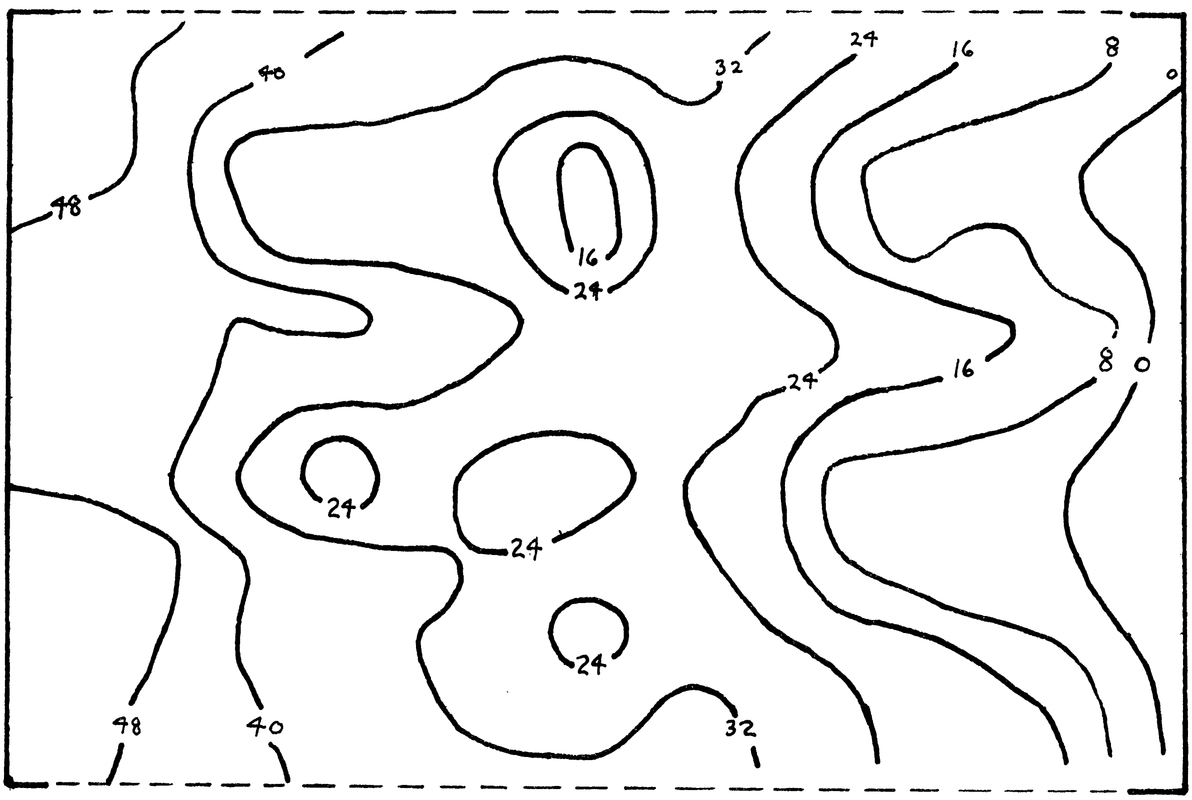


After

Test No. 2

Cement type: Air entraining

Initial heel: 8°

Final heel: 20°

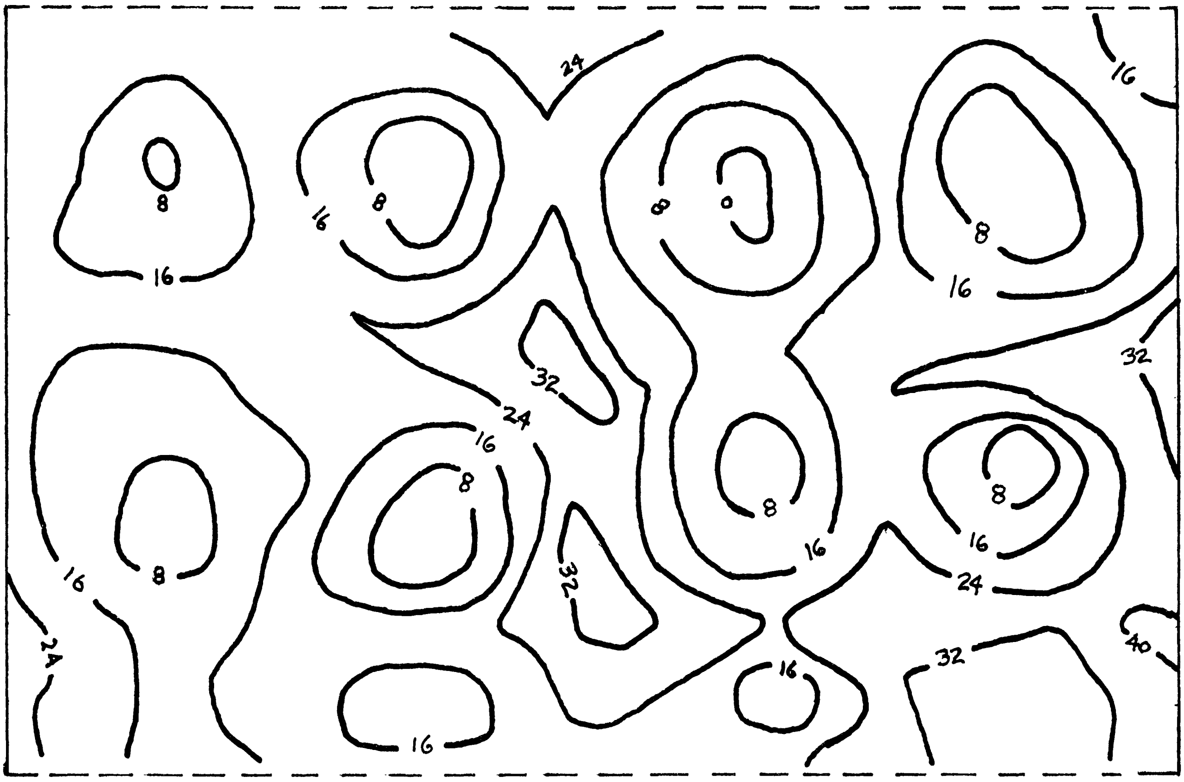
Displacement of first shift: 14°

Maximum positive roll: 14°

Maximum negative roll: 22°

Maximum acceleration: .4g

Without Centerline Bulkhead



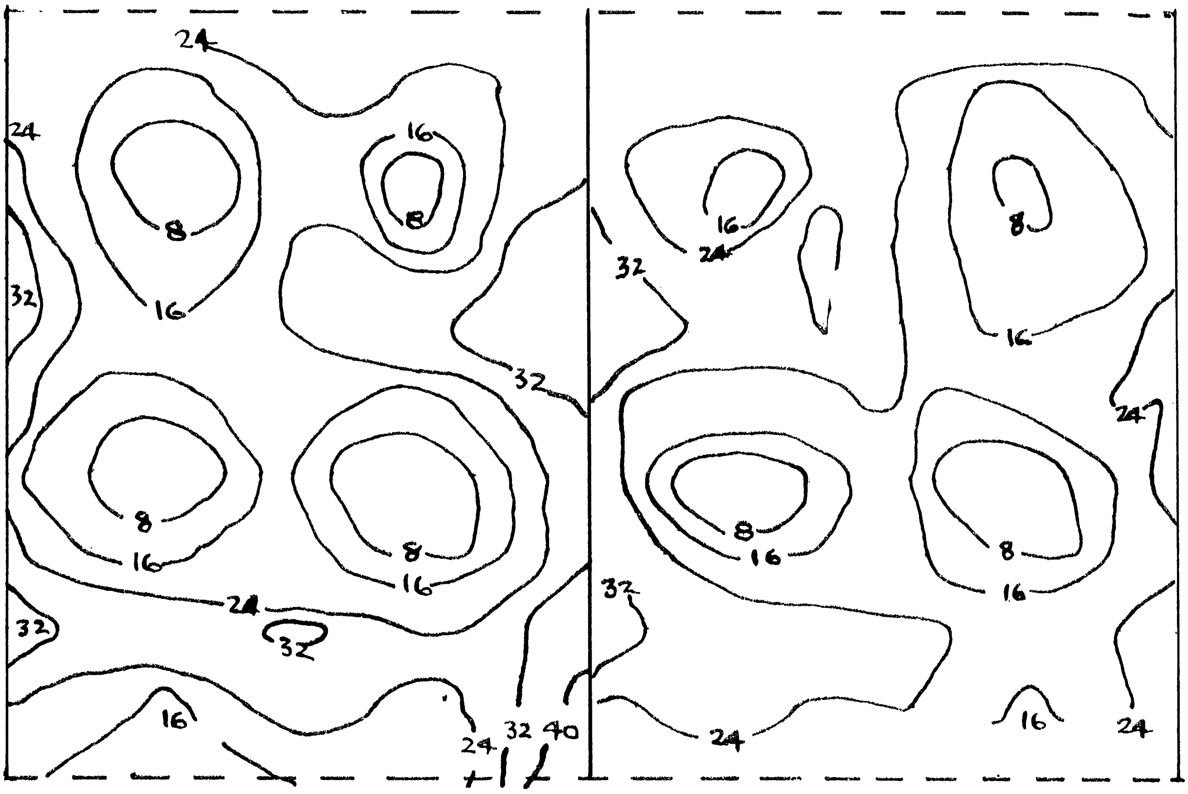
Before

During this test the cement was so unstable that it pushed out over the edge of the model. Too much cement was lost to make topographical measurements valuable.

After

Test No. 2
Cement type: Air entraining
Initial heel: 8°
Final heel: 17°
Displacement of first shift: 20°

Maximum positive roll: 9°
Maximum negative roll: 23°
Maximum acceleration: .4g
With Centerline Bulkhead



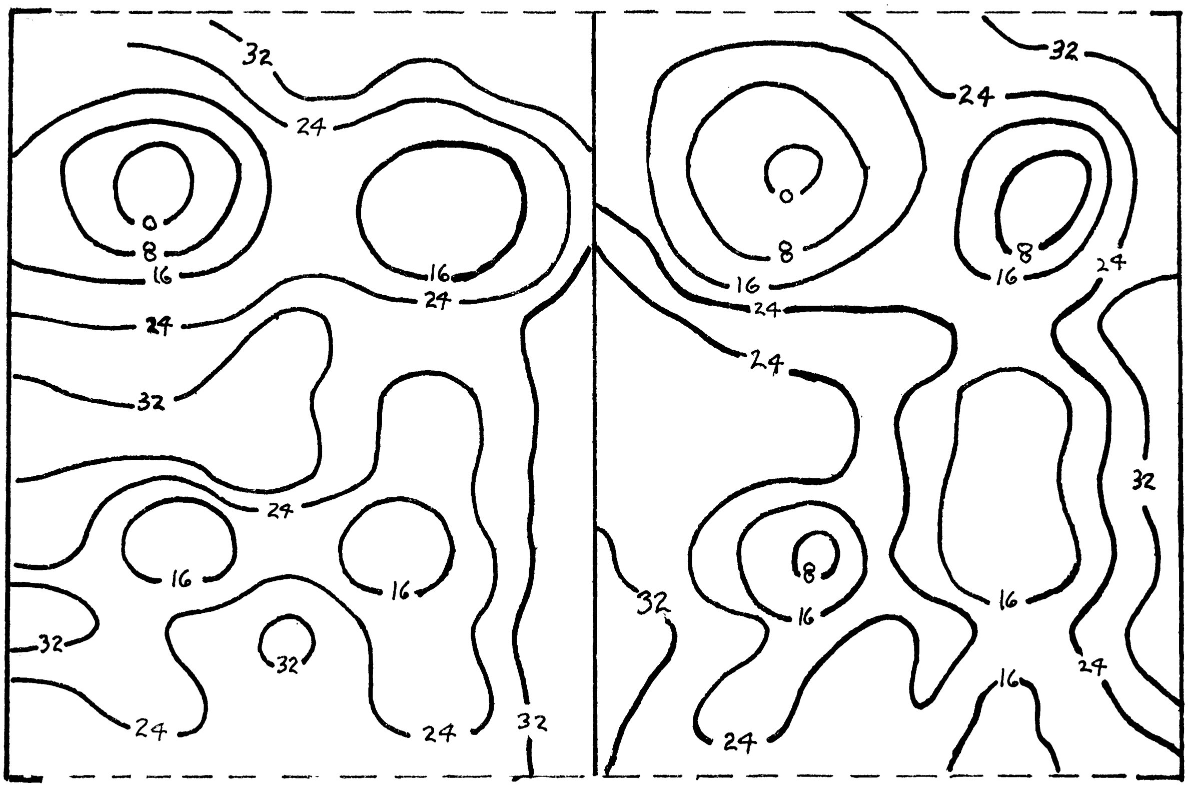
Before

No after measurement was taken because the centerline bulkhead tore loose during this test. Cement was lost over the side again.

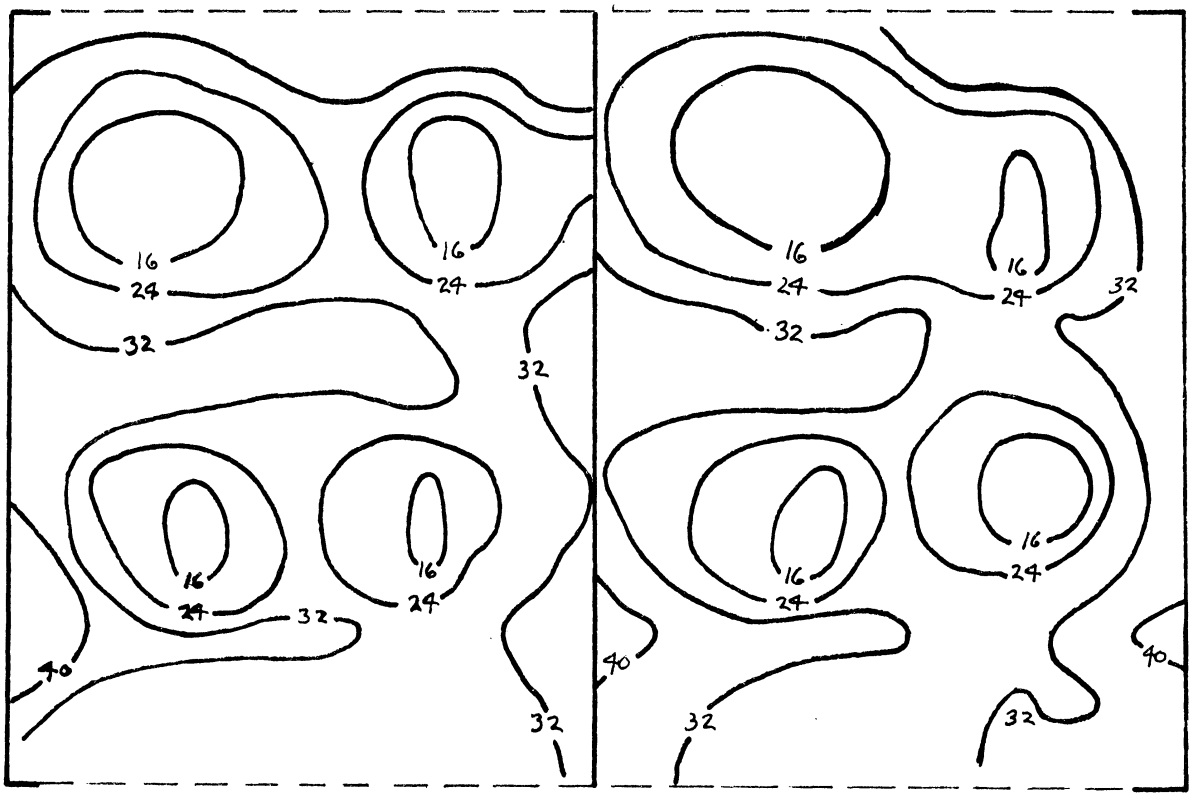
After

Test No. 3
Cement type: Mortar
Initial heel: 0°
Final heel: 0°
Displacement of first shift:

Maximum positive roll: 11°
Maximum negative roll: 18°
Maximum acceleration: .4g
With Centerline Bulkhead



Before



After

Test No. 3

Cement type: Mortar

Initial heel: 0°

Final heel: 1°

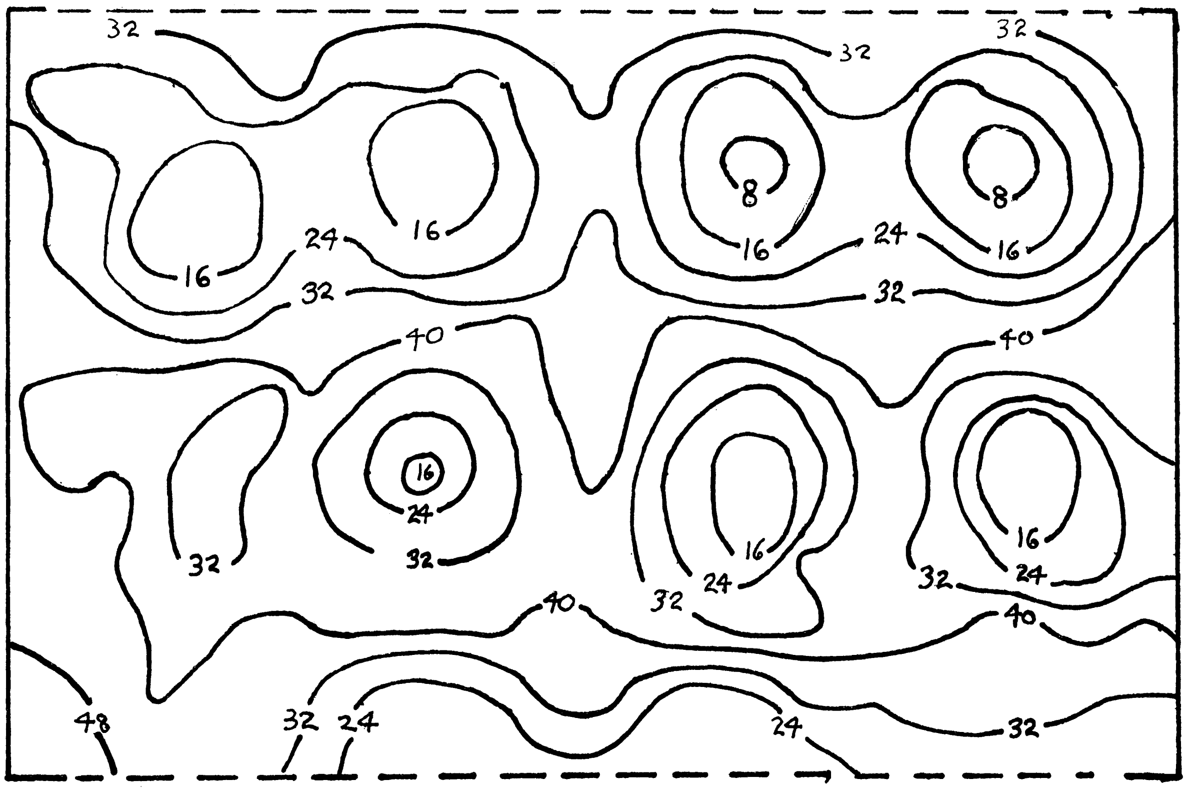
Displacement of first shift:

Maximum positive roll: 10°

Maximum negative roll: 16°

Maximum acceleration: .38g

Without Centerline Bulkhead



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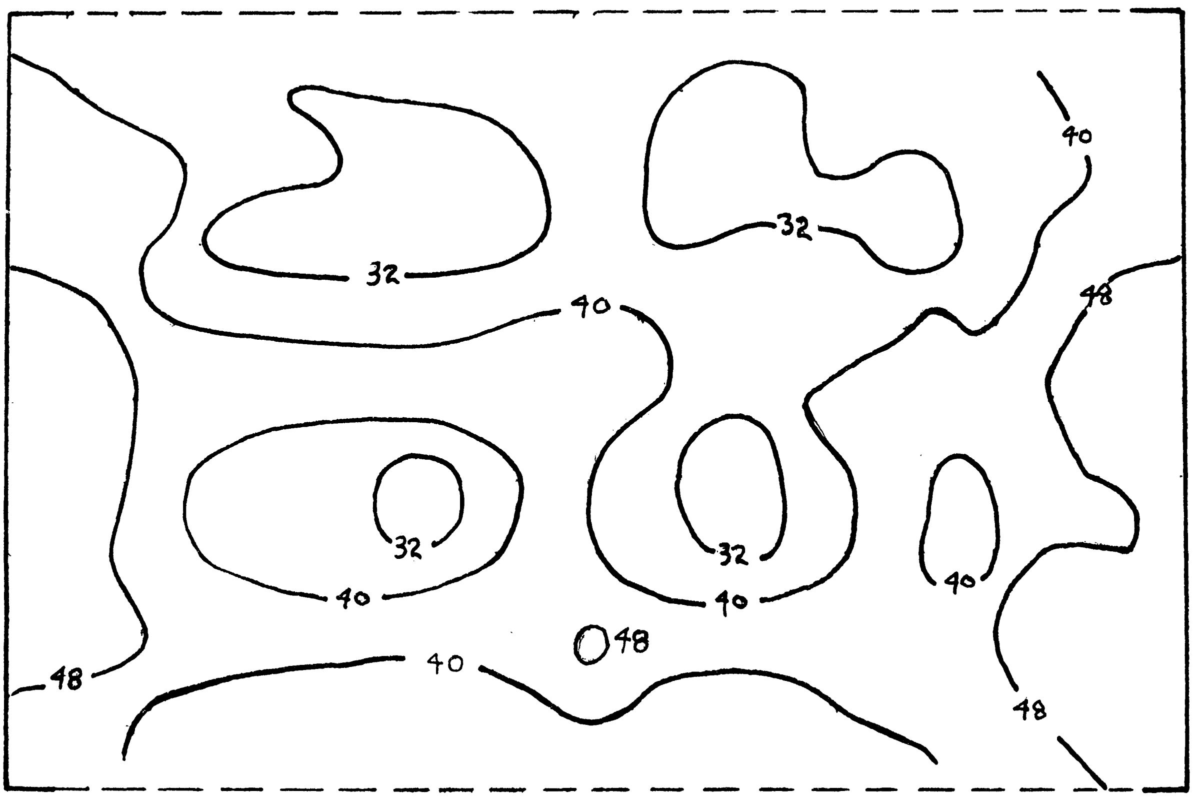

After