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

Final Report

# INVESTIGATION OF EFFECT OF SHIP MOTION ON THE TRANSPORTATION OF THE NEW ORE CONCENTRATE

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UMRI Project 2810

under contract with:

PICKANDS MATHER AND COMPANY
DULUTH, MINNESOTA

administered by:

THE UNIVERSITY OF MICHIGAN RESEARCH INSTITUTE ANN ARBOR

January 1959

## STATEMENT OF PROBLEM

The problem discussed in this report has to do with the effect of ship motion on the transportation of the new ore concentrate.

Because this ore concentrate is a new material, no information was available on its shipping properties. Therefore it seemed desirable to compare the properties of this ore to some similar materials which are shipped on the lakes. Two materials were used: one for which there are no particular shipping problems, and one for which some precautions must be taken. Wheat and flax meet these requirements respectively, and thus the properties of wheat, flax, and the new ore concentrate were compared through the tests described in the following pages.

# OUTLINE OF TESTING PROCEDURES[1]

The tests used to determine the static and dynamic properties of wheat, flax, and ore were as follows.

## TEST I

This test consisted of determining the angle of repose and the density of the materials as a function of moisture and loading procedures.

## TEST II

In this test the effects of vibration and moisture on the angle of repose were investigated.

## TEST III

This group of experiments was designed to simulate the motion of a ship by using a model as a pendulum.

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[1]A detailed description of these tests and the data obtained from them will appear later.

## RESULTS

From the data obtained, it can be concluded that the new ore concentrate is no more dangerous to ship than wheat. To our knowledge, no precautions are taken when wheat is shipped on the lakes.

It was also found that the "flatter" the ore is originally loaded, the more stable the cargo will be. However, if for some reason a slight cargo shift does occur, the ore is sufficiently mobile to allow the cargo to redistribute itself properly.

### NOTE

During the study of the physical properties of the ore, it was found that a crust could be formed on a pile of ore by spraying the surface with water. This crust will remain for several days and stop any surface shift of the ore.

## TEST I

The density of wheat, flax, and ore was determined for both the packed and unpacked conditions. Ore of three different moisture contents was used. The results of this test are given in Table I.

To determine the angle of repose[2] of these materials, a drop test was set up. To simulate different loading conditions, two drop tests of different types were used on the ore. The wheat and flax were subjected only to the low test because the loading properties of these materials were not of interest. It was found that a high drop test would give a sharper pointed cone. It was also found that the dry ore would give a flatter cone. The apparatus used in this drop test is shown in Fig. 1. The data from this test are shown in Table II.

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[2] Actually the included angle of the cone was recorded in place of the angle of repose because it seemed more pertinent. However, the angle of repose in degrees is $(180-\phi)/2$, where $\phi$ is the included angle of the cone in degrees.

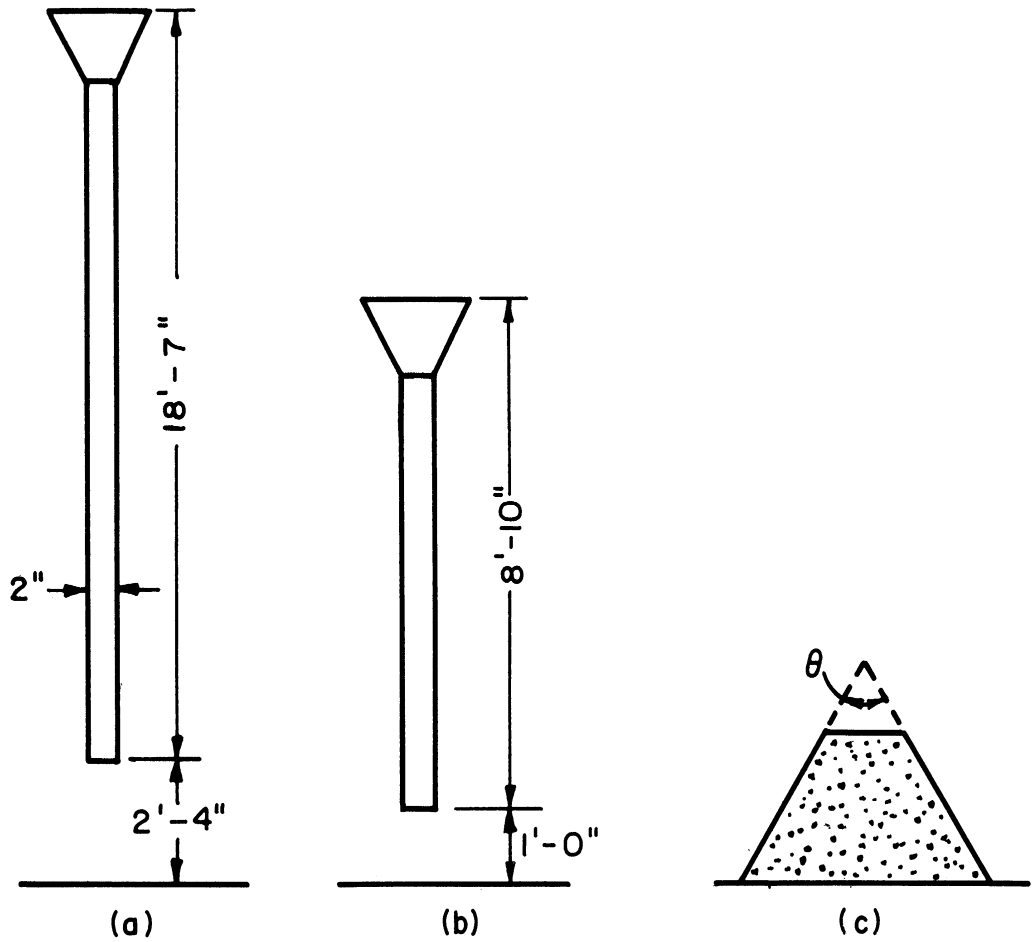


Fig. 1. Drop test. (a) shows the high drop test; (b) shows the low drop test; (c) shows a typical truncated cone of ore, wheat, or flax. It was possible to obtain a full cone by pouring the last of the material slowly. However, this did not affect $\phi$.

TABLE I

PHYSICAL PROPERTIES OF CARGOES TESTED
(Density in $lb/ft^3$)

| Ore | | | | | | Wheat | | Flax | |
|---|---|---|---|---|---|---|---|---|---|
| Wetted[a] | | "As Is"[b] | | Dry[c] | | | | | |
| Packed[d] | Unpacked | Packed | Unpacked | Packed | Unpacked | Packed[d] | Unpacked | Packed[d] | Unpacked |
| 180 | 119 | 145.5 | 137 | 166 | 153.5 | 51 | 49.6 | 45.4 | 42 |
| 178.3 | 148 | 139 | 131 | 173 | 155.5 | 49.5 | 47.6 | 44.8 | 41.4 |
| 178.3 | 144 | 137 | 113.5 | 168 | 153.5 | 50.4 | 48.5 | 44.8 | 41.4 |
| 180 | 151 | 134.5 | 111 | 166 | 155.5 | | | | |
| 183 | 152 | 139 | 114 | 168 | 153.5 | | | | |
| 183 | 146.5 | 138 | 116 | 168 | 148.5 | | | | |
| 183 | 150 | 137 | 113 | 173 | 151.5 | | | | |
| 178 | 138 | 135 | 108 | 178 | 151.5 | | | | |
| 183 | 142 | 134 | 112 | 178 | 153.5 | | | | |
| 183 | 142 | 132.5 | 111 | | | | | | |
| Average | | | | | | | | | |
| 181 | 146 | 137 | 116.7 | 171 | 152.8 | 50.3 | 48.6 | 45 | 41.6 |

a. The term "wetted" means that the ore was saturated with water.
b. The term "as is" means that the ore which was received was used directly.
c. The term "dry" means that all the moisture was removed from the ore.
d. The packed condition was obtained by shaking a container until no more packing could be observed.

TABLE II

INCLUDED ANGLE OF CONE IN DEGREES

| Ore | | | | Wheat | Flax |
|---|---|---|---|---|---|
| Dry | | "As Is" | | | |
| High Drop | Low Drop | High Drop | Low Drop | Low Drop | Low Drop |
| 109 | 115 | 77.5 | 80 | 133 | 134.5 |
| 105 | 116 | 80 | 80 | 127 | 139.5 |
| 106.5 | 118 | 80.5 | 80.5 | 131.5 | 135 |
| 114 | 118 | 91 | | | |
| 108 | | 77.5 | | | |
| | | 74 | | | |
| | | 75 | | | |
| | | 71 | | | |
| | | 80 | | | |
| | | 81.5 | | | |
| | | Average | | | |
| 108.5 | 116.7 | 80 | 82 | 130.5 | 136.3 |

Note:
When the data were not consistent, more tests were performed.

## TEST II

In this test a small container was connected to a vibrating table and samples of ore, wheat, and flax were tested. It was found that the angle of repose of the materials was affected by acceleration more than by velocity. It was also found that dry ore is the most unstable. In the "as is" condition, the ore was mobile, but as more water was added the ore became more stable.

## TEST III

This series of experiments was the most pertinent to the problem.

### DESCRIPTION OF APPARATUS USED IN DYNAMIC TESTS

A 1/24-size plywood model of 72 ft of the hold of an ore carrier was constructed. The model was supported by 3/4-in. pipe flanges and nipples placed at the ends of the model. These nipples were placed on smooth metal supports which would permit the model to oscillate freely and simulate the rolling of a ship.

The points of support were so placed that the surface acceleration of the ore in model and prototype was constant.[3]

A transducer and oscillograph were used to obtain the dynamic data. The angular displacement of a model could be read directly from the oscillograph.

The model is shown in Fig. 2.

### DESCRIPTION OF DYNAMIC TESTS[4]

General Remarks.—For a 1/24-size model of three hatch openings, 520 lb of ore was needed. In the tests on wheat and flax, an attempt was made to keep the geometry of the loads the same. This required 172 lb of wheat and 166 lb of flax. These weights of wheat and flax would not give the correct weight loads for the model, but in these tests the geometry was the important factor.

For all three materials, the loading was accomplished by slowly pouring the material into the center of the hatch openings. This made the load consist of three cones with intersecting bases. This loading procedure gave the most unstable load, which was desirable for testing purposes.

All the ore used in these tests was dried because it was found that this was the most unstable ore condition.

Ore, wheat, and flax were used in all the following tests.

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[3]Previous tests on a vibrating table showed that the angle of repose is affected by acceleration, rather than by velocity.

[4]Data from these tests will appear later in tabular form.

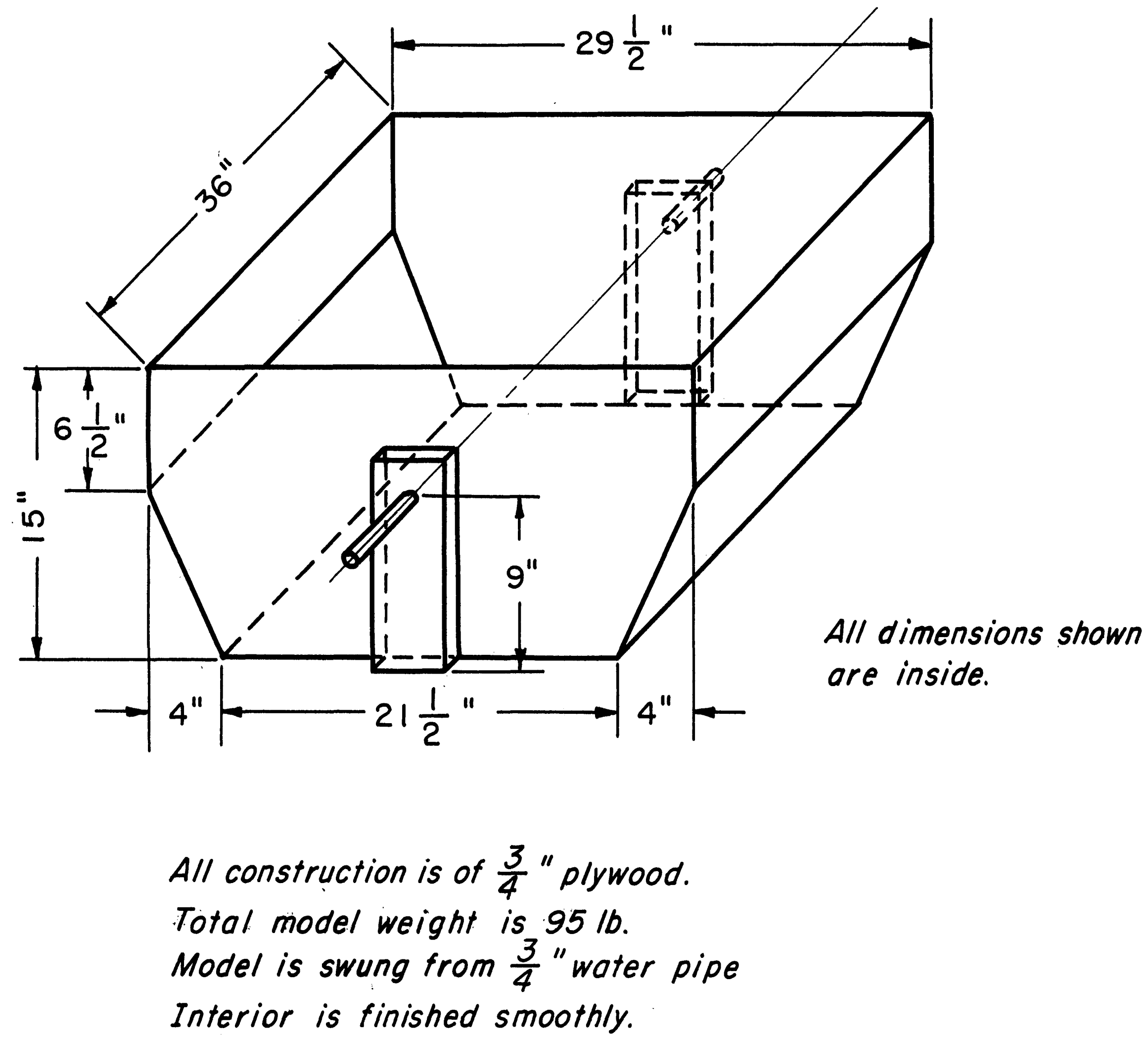



Fig. 2. Model of three hatch openings (1/24 size).

Test III-1.—This test was designed to simulate the rolling motion of a ship. The model was loaded and forced to oscillate about its natural equilibrium position.

The data recorded on the test were the angular deflection which first caused the particles to move along the surface of the several materials, the maximum angular deflection, and the final angle of heel.

Test III-2.—This test was designed to simulate the case of a ship with an initial heel (which might be caused by a broadside wind).

First the model was loaded and then a weight was added to one side of the model. This gave the model an initial heel and a new equilibrium position, about which the model was then forced to oscillate. When the model came to rest, the weight was removed and the model was forced to oscillate about its natural equilibrium position. This second oscillation was used to equalize any cargo shift caused by the first oscillation.

The recorded data were: the angular deflection caused by the added weight, the maximum deflection of both oscillations, and the angle of heel after both oscillations.

Test III-3.—This test was designed to simulate the case of a wave which is out-of-phase striking a ship during its natural rolling motion. In this test, the model was loaded and forced to oscillate about its natural equilibrium position. However, a spring was placed a short distance from the model which interfered with the model's natural oscillation. The model assumed its natural angular deflection on one side of the equilibrium position but not on the other side.

Two different positions of the springs were used in this test.

The recorded data were: the distance from the spring to the model, the maximum angular deflection on both sides of the equilibrium position, and the final angle of list.

Test III-4.—This test was designed to simulate a ship slowly rolling over to give angular deflection and then beginning to oscillate. This might be encountered when a ship turns into a large broadside wave.

The model was loaded and then slowly forced into an initial angular deflection. Then it was permitted to oscillate about its natural equilibrium position. This test was made twice, using two different initial angles.

The recorded data were: the initial angle and the final list.

## SYMBOLS USED IN FOLLOWING TABLES

| Symbols | Quantity | Dimensions |
|---|---|---|
| h | Height of cone-of-cargo | Inches |
| $\phi$ | Included angle of cone | Degrees |
| $\alpha$ | List of model | Degrees |
| $\beta$ | List of model caused by added weight | Degrees |
| $\theta$ | Angle of oscillation | Degrees |

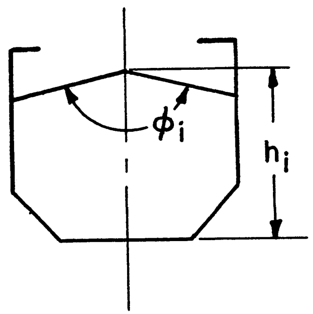
Subscript i's are used to indicate that the quantity is an initial quantity (measured before the test).

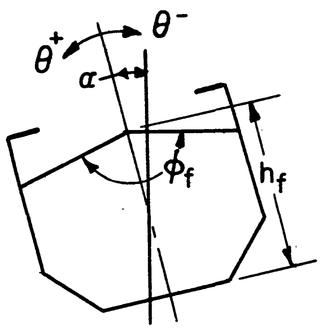
Subscript f's are used to indicate that the quantity is a final quantity (measured after the test).

A subscript 1, 2, or 3 is used to indicate that quantity will be used again. In some tests $\alpha_1 = \alpha_f$, and $\alpha_1 = \alpha_i$ for another test. This means that the final angle of list from one test is used as the beginning angle of list for the next test.

Test III-1

Simulation of Rolling Motion



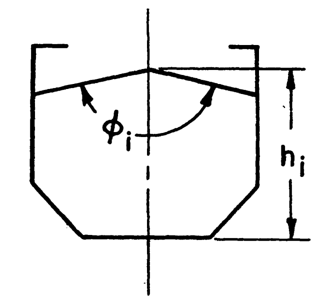



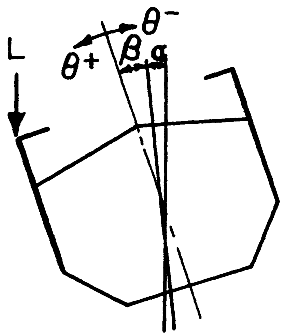

A rocking motion of increasing amplitude gave an angle of first shift, and $|\theta^+|_{max} = |\theta^-|_{max}$

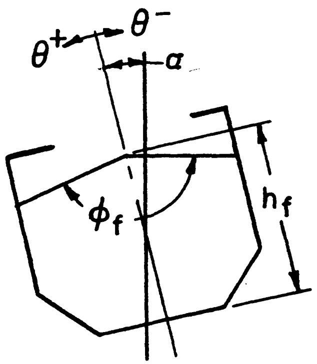
| | Wheat | Flax | Ore |
|---|---|---|---|
| $h_i$ | 9-1/4 | 10-3/4 | 10-1/2 |
| $\phi_i$ | 140 | 130 | 117 |
| $h_f$ | 7-3/4 | 8-1/2 | 9-3/4 |
| $\phi_f$ | 164 | 158 | 134 |
| $\alpha_i$ | 0 | 0 | 0 |
| $\theta_s$ | 6 | 6 | 3-1/2 |
| | 16 | 15 | 15 |
| $\alpha_f$ | 0 | 3/4 | 1/2 |

Test III-2

Simulation of a Heel Caused by an External Force



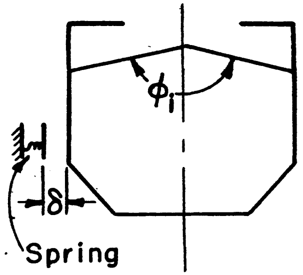



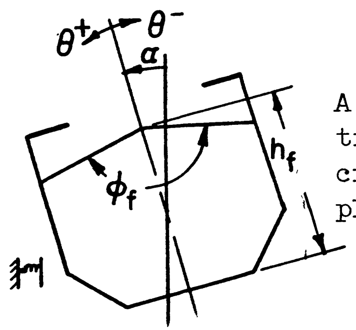

| | | Wheat | Flax | Ore |
|---|---|---|---|---|
| | $h_i$ | 9-1/2 | 10-3/4 | 10-1/2 |
| | $\phi_i$ | 140 | 130 | 119 |
| | $h_f$ | 7-1/2 | 8-1/4 | 9-1/4 |
| | $\phi_f$ | 167 | 157 | 135 |
| A weight L caused an angle | $\alpha_i$ | 0 | 0 | 0 |
| | $\beta_i$ | 6 | 6 | 5 |
| A rocking motion caused $\lvert\theta^+\rvert_{max} = \lvert\theta^-\rvert_{max}$ | | 14 | 14 | 14 |
| When oscillation had stopped | $\alpha_f + \beta_f$ | 8 | 9 | 6 |
| When L was removed there was an angle of heel | $\alpha_f = \alpha_1$ | 3-1/2 | 3-1/2 | 2 |
| | $\alpha_i = \alpha_1$ | 3-1/2 | 3-1/2 | 2 |
| A rocking motion gave $\lvert\theta^+\rvert_{max} = \lvert\theta^-\rvert_{max}$ | | 14 | 13 | 14 |
| | $\alpha_f$ | 3 | 2 | 1 |

Test III-3

Simulation of Out-of-Phase Wave



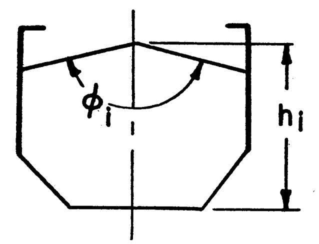

| | $\delta_1 = 5\text{-}1/2''$ Wheat | Flax | Ore | $\delta_2 = 4\text{-}1/4''$ Wheat | Flax | Ore |
|---|---|---|---|---|---|---|
| $h_i$ | 9-1/4 | 10-3/4 | 10-1/4 | 9-1/4 | 10-3/4 | 10-1/4 |
| $\phi_i$ | 140 | 128 | 115 | 139 | 129 | 119 |
| $h_f$ | 8-1/4 | 9-1/4 | 9-3/4 | 7-3/4 | 8-3/4 | 9-1/4 |
| $\phi_f$ | 159 | 150 | 131 | 159 | 152 | 135 |
| $\alpha_i$ | 0 | 0 | 0 | 0 | 0 | 0 |
| $\lvert\theta^+\rvert_{max}$ | 14 | 13 | 13 | 14 | 14 | 12 |
| $\lvert\theta^-\rvert_{max}$ | 11-1/2 | 9 | 11 | 9 | 7 | 7 |
| $\alpha_L$ | 1/2 | 0 | 0 | 1/2 | 1/2 | 0 |



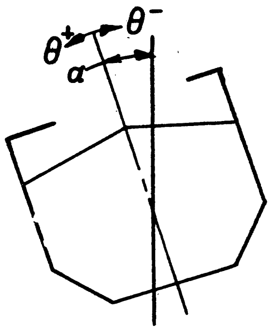

A rocking motion of increasing amplitude caused

## Test III-4

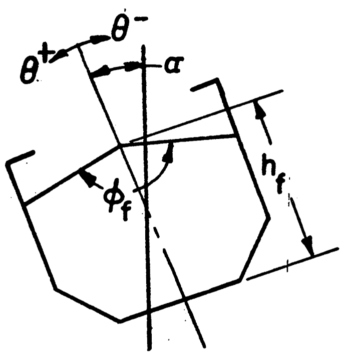
### Simulation of Slow Roll




| | | Wheat | Flax | Ore |
|---|---|---|---|---|
| | $h_i$ | 9-1/4 | 10-1/2 | 10-1/4 |
| | $\phi_i$ | 142 | 124 | 116 |
| | $h_f$ | 7-1/2 | 9 | 8-1/2 |
| | $\phi_f$ | 165 | 155 | 140 |




| | | Wheat | Flax | Ore |
|---|---|---|---|---|
| The model was slowly inclined to an angle | $\alpha_i$ | 0 | 0 | 0 |
| | $\lvert\pm\theta\rvert_{max}$ | 8 | 7-1/2 | 11 |
| The model was then allowed to oscillate until it stopped, leaving an angle | $\alpha_1 = \alpha_f$ | 1 | 1/2 | 0 |




| | | Wheat | Flax | Ore |
|---|---|---|---|---|
| The model was slowly inclined to an angle | $\alpha_1 = \alpha_i$ | 1 | 1/2 | 0 |
| | $\lvert\pm\theta\rvert_{max}$ | 17 | 14 | 19 |
| The model was then allowed to oscillate until it stopped, leaving an angle | $\alpha_f$ | 2 | 2 | 3 |