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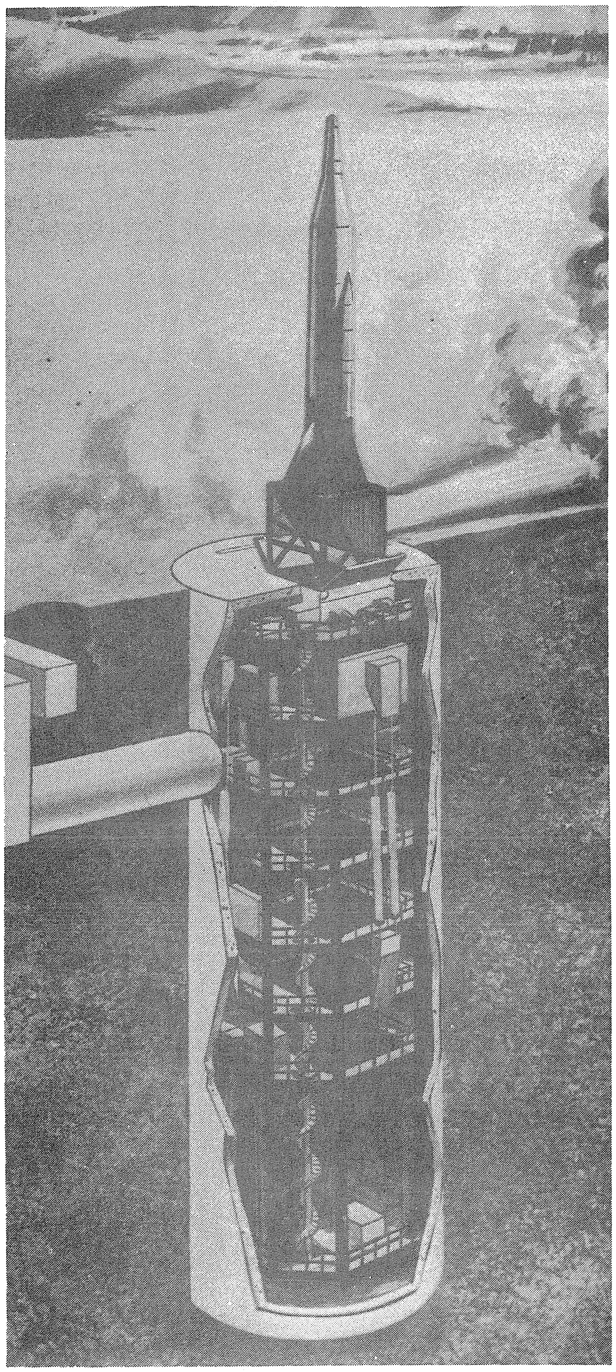

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WEIGHING THE ATLAS SILO CRIB

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SUMMARY

One means of storing the Air Force Atlas ICBM missile in a state of readiness is the underground unitary silo. Inside the silo, entirely suspended by shock absorbing springs, is an eight-sided steel crib structure containing all the elements necessary to launch an Atlas missile. A 50-foot tunnel connects the silo to a two-level launch control center, also underground and shock isolated.

The crib suspension-system springs were stiffness calibrated by the supplier so that the crib's elastic center could be calculated. However, the calculated weight and the center of gravity were not known to the accuracy desired. For maximum effectiveness, the elastic center of the suspension system must coincide with the crib's center of gravity. This reduces the spurious crib perturbations and, with the action of damping units, tends to keep the oscillations vertical harmonic motions. The weighing and center of gravity determination program was undertaken to satisfy these requirements.

The weighing systems used for this program were essentially electronic weigh kits with one million-pound capacities; four were used in each weighing. Auxillary hydraulic cylinders and a power unit transferred the crib load to the load cells.

Four hundred and thirty two readings were taken, 27 for each of sixteen load cells (four per kit). Mean values were obtained by averaging. Random dispersions were treated statistically to yield 99% probability, 90% confidence limits. Overages and shortages were reconciled and estimates of their uncertainties were combined with "as-weighed" limits to give the overall weight and tolerance limits. The center of gravity and its limits was calculated in a similar manner.

INTRODUCTION

There are several means of storing Air Force Atlas ICBM missiles in the readiness state. The underground unitary silo is the most recent means developed and offers the possibility of retaliation with the shortest reaction time. The unitary silo is so named because it contains almost all of the equipment required to maintain an Atlas with the silo encasement. An underground launch control center, containing launch-control and communication equipment and personnel, is connected to the silo by a 50-foot tunnel (Figure 1).

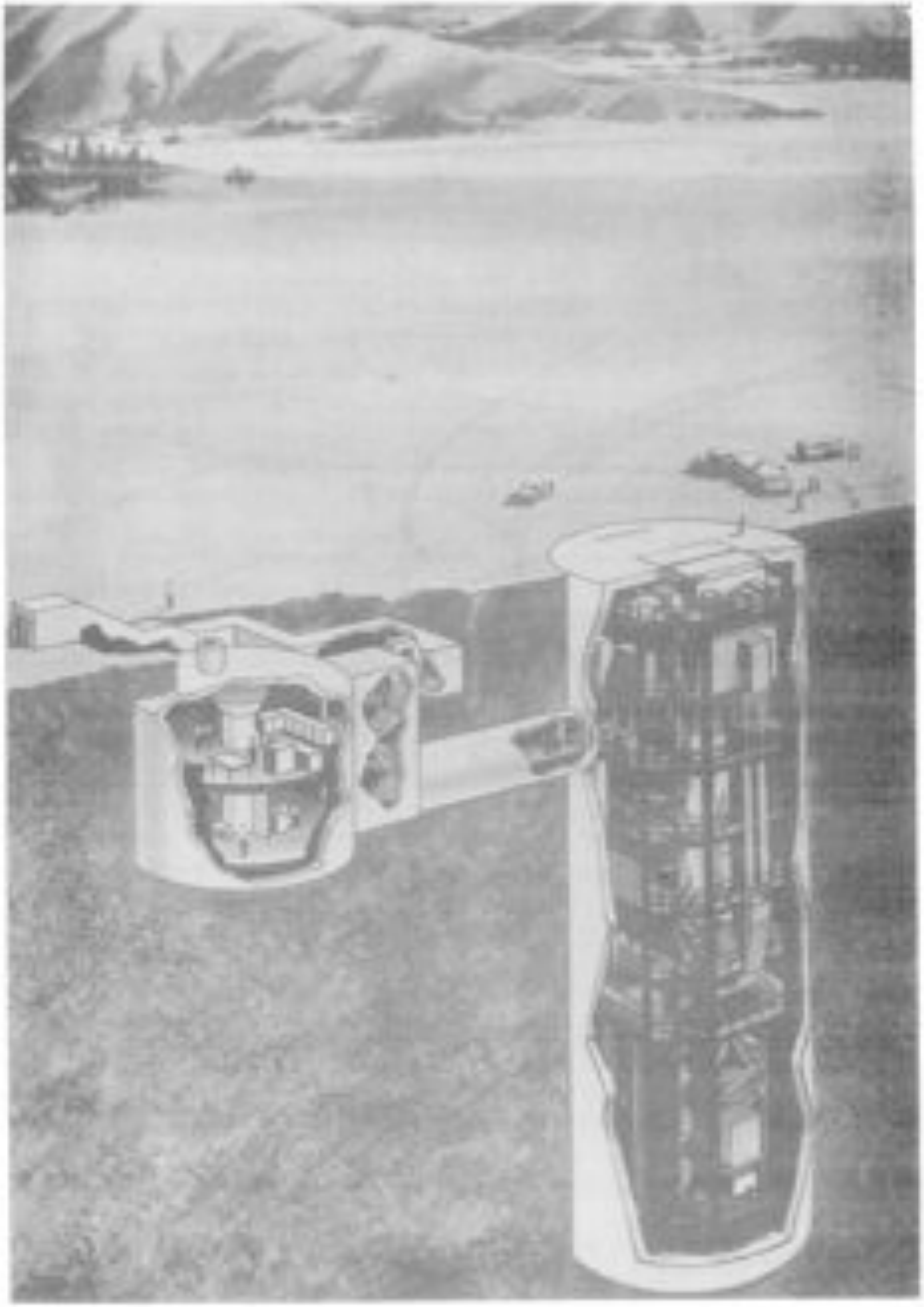

FIG. 1

INTRODUCTION (Continued)

The silo has an outer encasement of reinforced concrete about 52 feet in diameter and 174 feet deep. A ground-level reinforced concrete cap offers blast protection. The missile is supported vertically on an elevator which raises it completely out of the silo for launching. Hinged doors allow the missile to be raised into launch position. Inside the silo, entirely suspended by shock absorbing springs, is an eight-sided steel crib structure containing all the elements necessary to the health and welfare of a ready-status missile.

An isolated spring suspension protects the missile against the shock, heat and radiation of a nuclear near miss. This presents a problem in controlling and damping crib oscillations caused by heavy shocks. A desirable characteristic to enable controlling the oscillations, is to align the elastic center with the center of gravity; this requires accurate knowledge of each. Although the suspension springs had all been calibrated and coded by the manufacturer so that the elastic center computations could be made,the weight and center of gravity calculations were not felt to be adequate to permit proper alignment. Also, there was concern that the resonant frequency of the crib might be too near that of the missile. Thus, a weight and center of gravity determination program was undertaken.

EQUIPMENT

Many weighing systems were considered for the crib weighing task. Several methods of weighing were also considered. The final selection was made on the basis of cost, as well as accuracy and versatility. The portion used for weighing is actually an electronic weigh kit with a one-million-pound capacity (250,000 lb. per load cell). Four kits were used for each weighing, making a total of 16 load cells and a capacity of four million pounds.

A hydraulic system was designed to transfer the load to the cells during the weighing and to actually lift the entire crib. This system was also useful in spring calibrations and rod replacement. The man shown in Figure 2 is working on the upper plate of the weighing tool.

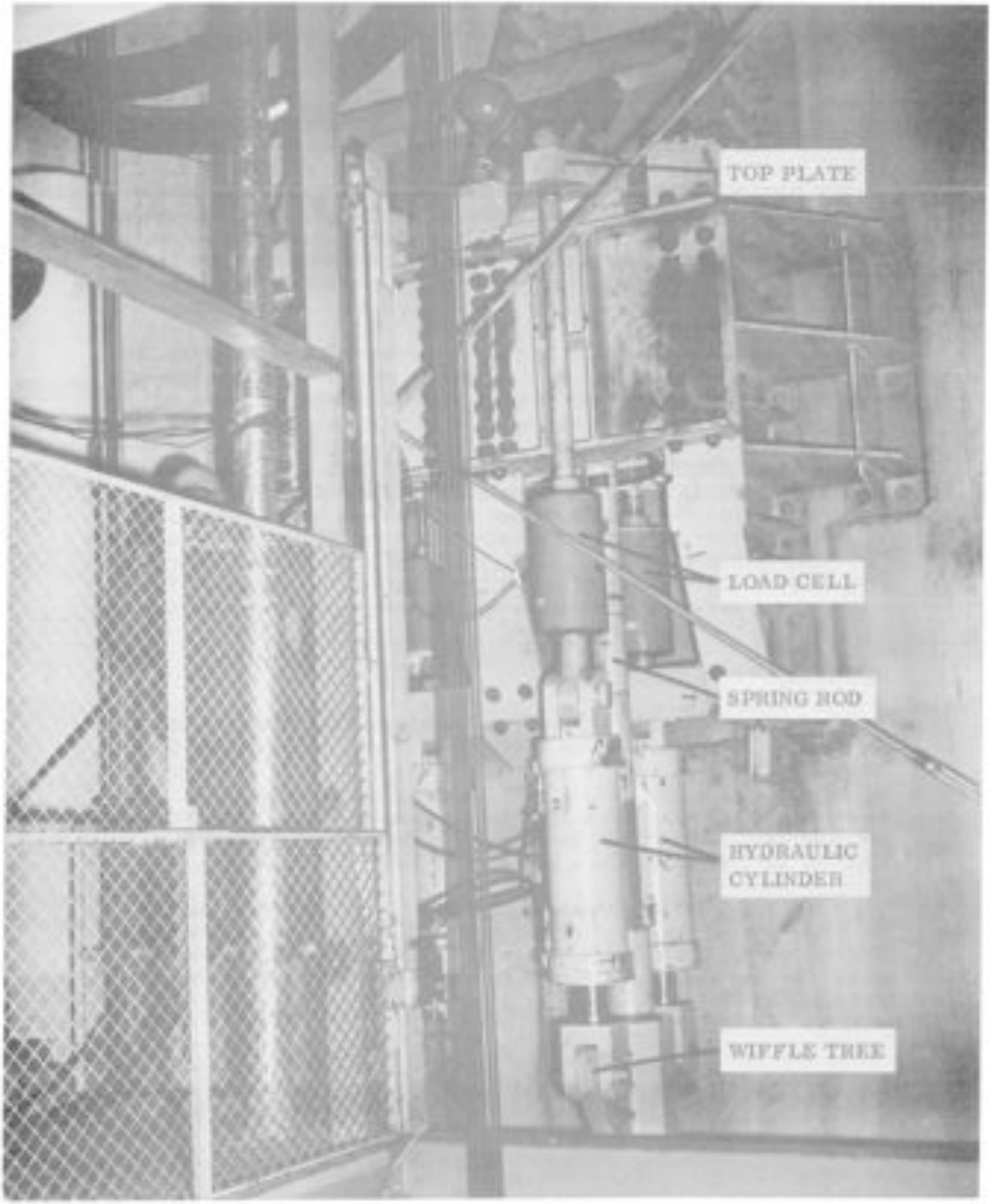
TOP PLATE
LOAD CELL
SPRING ROD
HYDRAULIC CYLINDER
WIFFLE TREE

FIG. 2

EQUIPMENT (Continued)

The weighing equipment is suspended from the upper plate (which fits loosely around the main spring rod). The hydraulic cylinder rods are pinned to a wiffletree which also fits loosely around the main spring rod. Lifting is accomplished by retracting the cylinders, causing the wiffletree to lift upward on the rod coupling. Figure 3 shows the hydraulic control unit on the left and several of the weigh kit readouts. To show crib elevation, pointers were clamped to the wall brackets and marks were made on the main spring rods.

CALIBRATION

The weight system calibration can be traced to the National Bureau of Standards. The standard masses used at the Bureau in the dead weight force calibrator have an error of less than 0.02% for up to 111,000 lb. This machine was used to calibrate secondary standards called proving rings which were certified to have less than 0.05% error. The proving rings were brought to General Dynamics/Convair, where they were used to calibrate (and periodically check) a master calibrating cell. The cell was then rated at less than 0.1% error for up to 500,000 lb. force. The master calibrating cell was used for all weighing system calibrations. The systems were required to have less than 0.2% error and it was felt that they were actually much better than that in the laboratory calibrations. Each weighing system was calibrated as a system, with each cell, cable and readout plug identified for subsequent field matching. Figure 4 shows the arrangement of the load cells in the calibrating press. The cells were calibrated in tension only and were arranged in series so that the same load would be applied to each cell.

WEIGHING PROCEDURE

Weight readings were taken in the following manner:

1. The cells were exercised by applying and releasing full load five times just before the weighing was begun.

2. With the load released after the fifth preload the readout zero was checked and adjusted if necessary.

3. The crib was raised 1/4-inch above the starting level for the first weighing plateau.

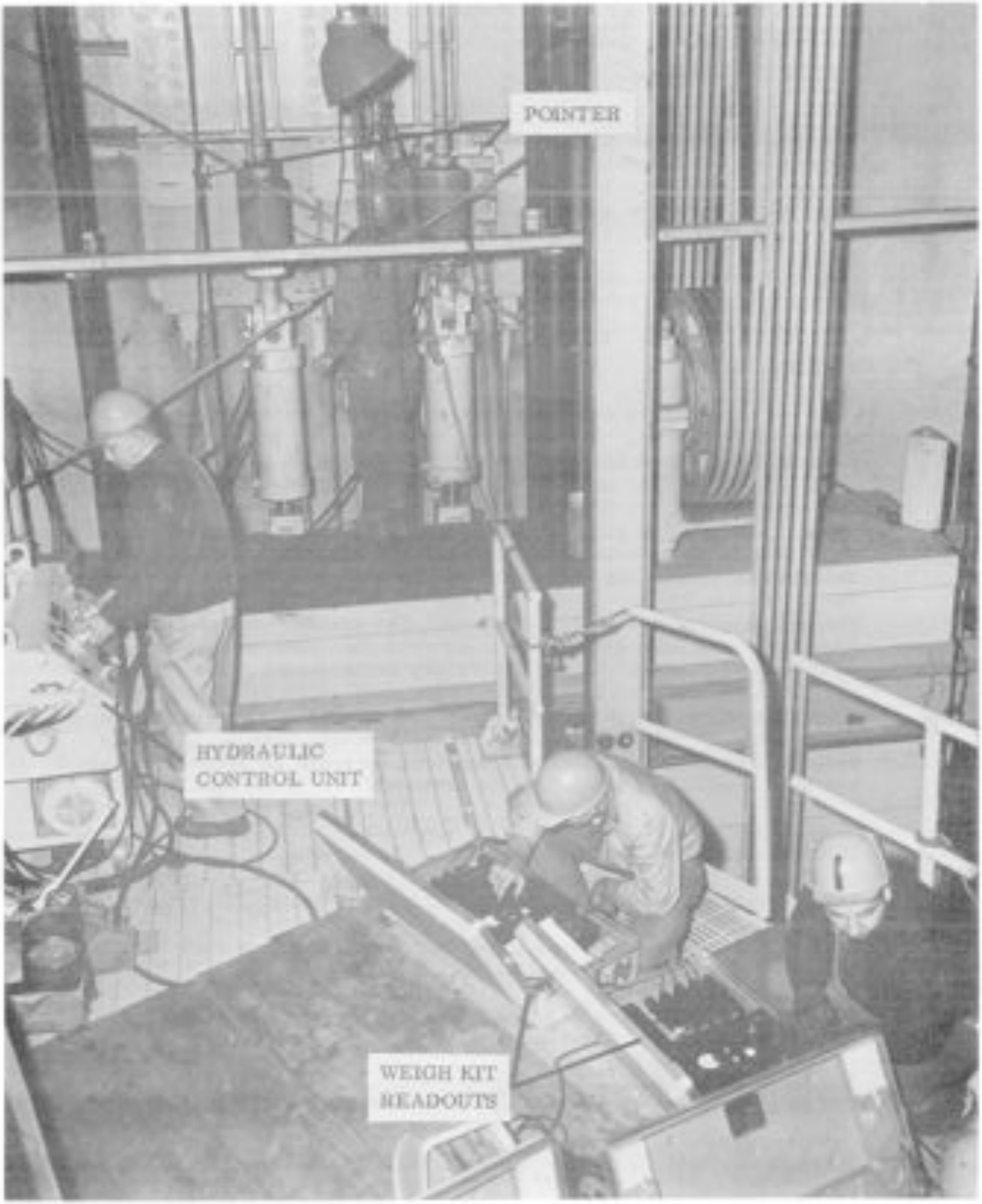

FIG. 3

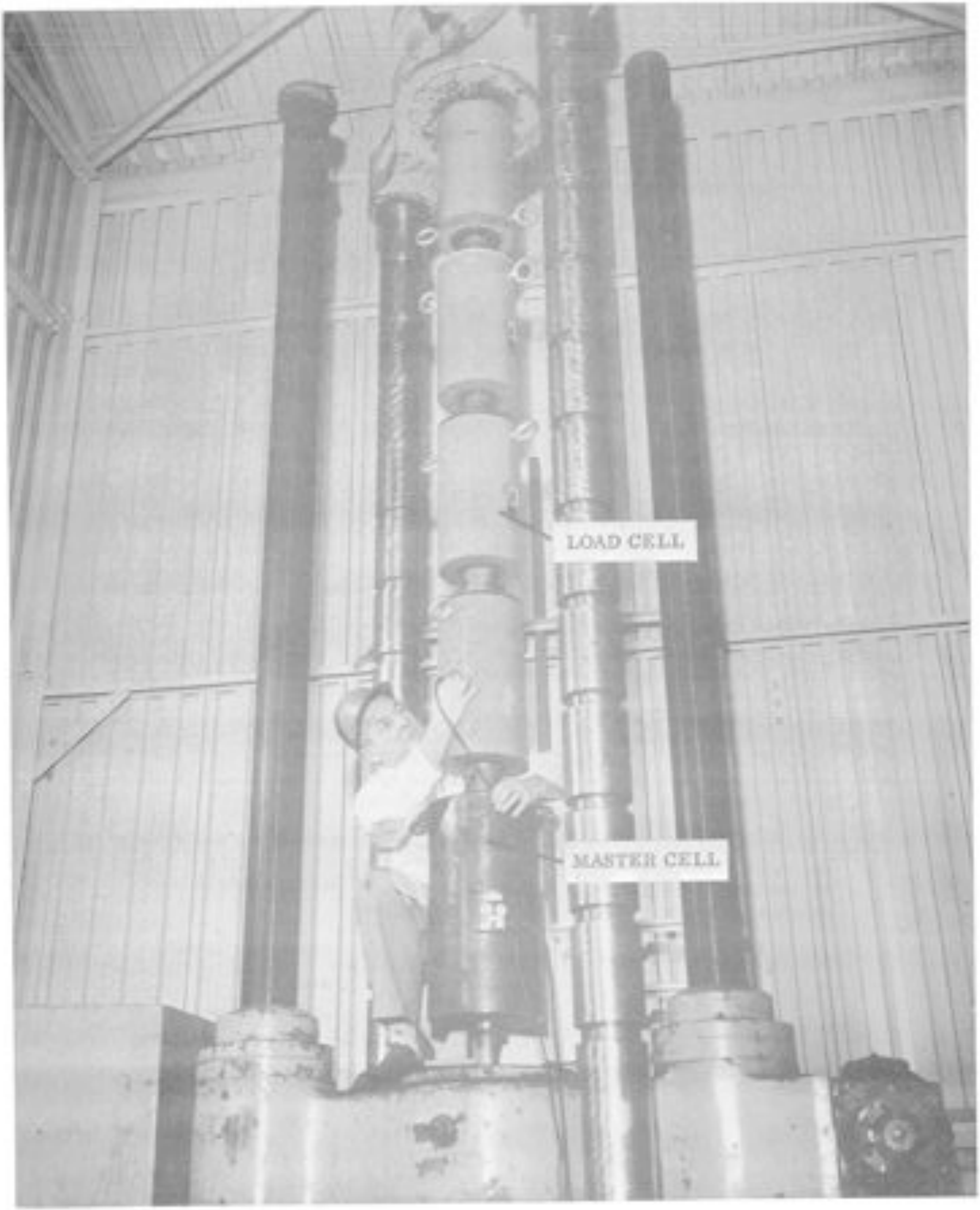

FIG. 4

WEIGHING PROCEDURE (Continued)

4. A set of weight readings was obtained by switching the readout from cell to cell.
5. Two additional sets of weight readings were obtained in the same manner before proceding to the next plateau.
6. The crib was raised to 1/2-inch above the starting level and another three sets of readings were taken.
7. The crib was raised to 3/4-inch above the starting level and another three sets of readings were taken.
8. The crib was lowered to the starting or zero level and the weight systems were checked for possible zero shift.
9. The entire process, steps 3 through 8, was repeated two additional times.
10. A total of 432 readings were made, 27 per cell.

DATA REDUCTION

There were three sets of readings taken for each cell at each load plateau. Each three sets of readings for each cell were averaged to obtain the best values. This resulted in one weight reading for each cell at each of the nine load plateaus. To obtain the lateral center of gravity, the weight readings for the four cells of each side were added. The distances from the center of each cluster of four cells to arbitrary X-X and Y-Y axes were established. Moments were calculated and summed, then divided by the total weight to obtain X and Y arms for each of the nine load plateaus.

Statistics were used in the further process of the data to determine the uncertainty of the center of gravity and weight. Means of the nine load plateaus for X and Y arms as well as weight were calculated to obtain the most probable value.

$$\bar{X} = \frac{\Sigma X}{n}$$

where

Σ = summation (sigma)

$\bar{X}$ = mean

X = sample values

n = number of samples

DATA REDUCTION (Continued)

Next the standard deviation was calculated.

$$S = \sqrt{\frac{\sum (X - \bar{X})^2}{n - 1}} \quad \text{where} \quad S = \text{standard deviation}$$

Concerning only the results, approximately two-thirds of the standard deviation could have been called the probable error. (This is defined as the value of uncertainty which would have equal probability of being exceeded or not exceeded.) However, the weight and center of gravity had to be known to a rather high degree of accuracy and high confidence limits. Consequently, the standard deviation was multiplied by 4.098, a tolerance factor chosen from a Statistics Handbook for nine samples, 99% probability and 90% confidence. This gives 90% confidence that 99% of the values will fall within the limits calculated. Or, 90% of the time 99% of the values will fall within these limits. This took care of the mean, as well as the uncertainties of the weight and center of gravity of the crib in the as-weighed condition.

The configuration check to determine shortages and overages was next. This usually involved several trips through the crib and some research. Overage items were recorded and weights obtained when possible. Because these items were often contractors equipment, estimates had to be used where weights were not available. Shortage items required in some cases, fluid level or pressure observations and extensive calculations. Estimates of uncertainties were also made. In all cases we considered only random uncertainties, and used the same significance levels as used in the as-weighed values.

Total weight and weight uncertainties were obtained by summing the as-weighed, overage and shortage items. Both X and Y arms were calculated by summing the moments and dividing by the sum of the weights. The X and Y uncertainties were calculated from the weight uncertainties using the form:

$$\Delta X = X - \frac{\sum WX}{\sum (W + \Delta W)} \quad \text{where}$$

W = weight

ΔW = weight uncertainty

X = moment arm

ΔX = moment arm uncertainty

DATA REDUCTION (Continued)

The resulting moment arm uncertainties (ΔX values) were multiplied by their weights (not weight uncertainties) to obtain the proper significance level for each. Next, the ΔXW moments were root-sum squared to obtain the best estimate of ΔXW. This, when divided by the total weight, gave the best estimate of ΔX, the uncertainty attached to X.

$$X = \frac{\sqrt{\sum (\Delta X W)^2}}{W}$$

Since a high level of significance was maintained in each uncertainty, the final values have the same level of significance.

A few of the weight readings were widely dispersed from the rest of the readings. However, no evidence of malfunction or other reason could be found to discard these values. When any mean was affected by these extreme values, a statistical test was applied. This test assumes a normal population and is designed to tell whether the value in question is taken from the same population as the rest of the values. It is called the Gross Errors test and is applied in the following way:

$$r_{11} = \frac{X_2 - X_1}{X_{n-1} - X_1}$$

where r_{11} = test ratio

X_1 = questionable value

The values are first ranked in order of magnitude starting with the questionable extreme as X_1, the next value as X_2 and the next to last value X_{n-1}. For our use, having nine values for each weighing, if the test ratio exceeded 0.672, there was only 1% probability that the questionable value came from the same population and should be included in the set of values.

RESULTS

From one to six silo cribs per base were weighed for a total of fifteen weighings. Since nine weights were obtained for each crib (three runs times three elevations) a total of 135 data points were available in evaluating the entire weighing exercise. Although the final summary report has not been released at this writing, preliminary calculations show a total weight tolerance limit of 30,000 lb. and a mean weight of nearly 3,400,000 lb. This is believed to be the largest mass ever weighed in this manner. It should be noted that tolerance limits of the same high probability and confidence levels were very small for individual cribs, running as low as 30 00 lb.

BIBLIOGRAPHY

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