Presentation for AISI Operating Committee

October 11, 1990

Radisson Hotel
Merrillville, Indiana

The structural damage to the heating walls in coke oven batteries is caused by stresses induced in the walls refractories as the result of unbalanced forces, originating within the ovens, and acting on the opposing sides of the walls during normal battery operations. These forces have been theorized to be of multiple origin, but carbonization gas pressure from coking of the coal has been considered the dominant source. It was further theorized that through the careful selection and blending of coals, these forces could be controlled at safe levels.

In 1985, the Task Force on Tall Coke Oven Collaborative Technology; which was formed following the an AISI Symposium "Tall Coke Ovens - Past, Present and Future" in 1983, elected to sponsor a project on the definition and measurement of heating wall movement in normally operating coke batteries. The purpose being to define when, and under what conditions the differential pressure is sufficient to cause heating walls to move. If conditions resulting in and controlling heating wall movement and therefore refractory stress could be defined, then means of minimizing or controlling that stress could be considered, and hopefully the operating life of the coke batteries extended. The project included the design and development of a sensor to accurately monitor wall movement. In its present state of development the deflection sensor mounted on an operating coke battery can automatically determine the lateral position of a heating wall to an accuracy of +/- 15 mils (0.015 inches) or better, once every minute.

During the three phases of the study the measurement of heating wall movement on three normally operating coke batteries at three different companies produced consistent results. When an oven is charged with coal, the force of the charged coal causes an essentially instantaneous primary movement of the wall away from the charged oven. From about 30 percent to essentially 100 percent of the movement takes place at this time. In many cases the primary movement was completed when charging was completed, and it was always completed 30 minutes after charging. A secondary movement may or may not follow the primary movement. Wall movement is reversed and the cycle repeated when the oven on the opposite side of the wall is charged. Therefore heating wall movement is cyclic, and strongly correlated to oven charging.

The following figures illustrate the movement of heating walls at different coke plants. In each case the wall position is presented relative to a zero or neutral position, and the coking cycles of the adjacent ovens are presented as a percentage of the cycle that is completed relative to the wall movement.

1. (OH-1A) First Phase
   USS - Gary No. 3 Battery
   Three test series conducted (OH-1A)

   * Damaged Wall - Low Differential Pressure
   * Damaged Wall - High Differential Pressure
   * "Undamaged" Wall - Low Differential Pressure

   Optical Method Used

   Objective -
   Wall Movement is in response to events in ovens
   Structural condition affects wall movement

   (OH-1) Example - Damaged Wall - Low Differential pressure
   Average Coking time - 12:44
   Average Charging Movement - 91 mils
   Average Total Movement - 327 mils

   Discussion - The Gary tests showed a) that a wall moved in response to events taking place in the ovens, namely oven charging, b) that the condition of the wall influenced how it moved and c) that measured internal gas pressures in the ovens did not correlate to wall movement.

   (OH -2) Example - Damaged Wall - High Differential pressure
   Average Coking Time - 12:40
   Average Charging Movement - 164 mils
   Average Total Movement - 362 mils

   Discussion - Walls behavior varies when opposite oven is empty, when both ovens are empty, and when charging against an empty.

2. (OH-3A) Second Phase
   Armco - Middletown No. 1 Battery
   Five Test Series

   * Four Wall Series
   * Low Bulk Density Charges
   * High Bulk Density Charges
   * Short Oven Charges
   * Delay Charge Time

   On Line Sensor Used for all series

Objective -
Does location in the battery affect wall movement
Does Coal Moisture (bulk density/charge weight) affect wall movement
Does pushing and charging off schedule affect wall movement

Discussion -

Four Wall - Results showed that except for near pinion wall, a walls movement is not related to its location in the battery. BD and Coal lined not measured and charge weight not calculated.

(OH-3)
Delay Charge - Results showed that operating delays as much as +/- 3 hours did not adversely affect wall movement. First use of second camera for simultaneous measurements on two walls. Mirror deflections result.

Low BD \ /Will be
Short Charge >< discussed as
High BD / \a group later

(OH-4) Example - High Bulk Density Series
Average Coking Time - 18:02
Average Primary Movement - 53 mils
Average Total Movement - 97 mils
Average BD - 46.6 wet
Average Charge Wt. - 31.0 tons

Discussion - This is an example of two step wall movement, a primary movement, which is essentially instantaneous on charging; followed by a longer term secondary movement. Some of the relationships associated with the average primary movement (defined as the average movement on charging for all of the charges within a series and the average total movement, that is primary + secondary,(defined as the average distance between the extreme wall positions), as well as the duration of secondary movement will be discussed later. The cyclic nature of the wall movement closely follows the charging cycles of the ovens adjacent to the wall.

3. (OH-5A) Third Phase
Inland Steel Company - No. 10 Battery, East Chicago, Ind.
Four Test Series

* Five Wall Series
* Low Bulk Density Charges
* High Bulk Density Charges
* Short Oven Charges

On line sensor used for all series
Internal flue targets had to be installed

Objective -

Corroborate the test results of Phase II

Discussion -

(OH-5)
Five Wall Series - Results similar to those from Armco, wall movement is not related to location of the wall within the battery. These data also show that the structural condition of the walls differ.

Low BD Series \ / Will Be
High BD Series >< discussed as a
Short Charge Series/ \ group later

(OH-6) Example - Low Bulk Density Series
Average Coking Time - 17:53
Average Primary Movement - 62 mils
Average Total Movement - 62 mils
Average Bulk Density - 41.9
Average Charge Wt. - 23.2 tons

Discussion - This is an example of single step wall movement, the primary movement and the total movement are essentially the same, and nearly all of the movement takes place within 30 minutes or less of the oven being charged. Again the cycle of wall movement is coincident to the cycles of oven charging.

<u>Coal Bulk Density / Charge Weight VS Wall Movement</u>

(OH-7) The data for the three test series on the B18 heating wall at Armco, previously mentioned is shown here:

Test Series	Wet Bulk Density, pcf	Calculated Charge Weight, tons	Movement, Mils Primary	Total	Time for Secondary Movement, hours
Lo BD	42.6	27.2	42	78	1:46
Hi BD	46.6	31.0	53	97	6:10
Sh Ch	44.3	26.1	33	60	2:50

The following figures illustrate some relationships derived from this data:

(OH-8) Charge Weight vs. Primary Movement (Armco)
(OH-9) Charge Weight vs Total Movement (Armco)

An excellent correlation between charge weight and wall movement is found. This shows that the greater the weight of the coal, the greater the force on the heating wall. If the equations presented are extrapolated to zero deflection these relationships would indicate that it would take charge weights greater that 16.7 and 16.8 tons respectively to initiate wall movement, that is to overcome wall resistance to movement primarily due to roof load. Based on the area of the wall, this would equate to a pressure of about 0.25 psi to initiate wall movement. Because the primary movements are nearly instantaneous, and therefore would have little temperature dependence, the pressures developed from charge weight that would be needed to cause the observed primary movements would be less than 0.5 psi.

In summary, the amount of wall movement increases with increasing weight of the coal charge, and again carbonization gas pressure was not found to be correlated with wall movement.

(OH-10) A summary of the Inland data for the three test series previously mentioned, plus the data from the five wall series on the No 12 wall is shown here:

Test Series	Wet Bulk Density, pcf	Calculated Charge Weight, tons	Primary & Total Movement, mils
Lo BD	41.9	23.2	62
Hi BD	47.7	26.7	78
Sh Ch	42.6	22.6	47
5-Wall	45.4	25.7	85

The following figure illustrates a relationship similar to that found for the Armco data.

water and/or oil on the coal. The varying period and magnitude of the pressure may be a function of not only the volume of gas generated (within some limits higher bulk density is associated with greater amounts of liquids mechanically attached to the coal), but also of its ability to escape through the coal bed (higher bulk density also is associated with lower bed permeability). In addition, variations in the thermal conductivity of the coal mass and variations in the mass of the coal blends could be factors.

Coal Properties

Because of the importance of the events and reactions taking place in the ovens during charging and during the following two to six hours of the coking cycle in regard to heating wall movement, Jenicke & Johanson, experts in the field of bin design and bin (wall) loading were consulted. A coal blend, similar to that used during the Armco tests, was submitted to them to attempt to define how pressures on the wall might develop early in the coking cycle, and to estimate the magnitude of those pressures. J&J concluded that the blend they tested was capable of developing a maximum lateral pressure of about 0.6 psi attributable to just the particulate loading of the coal during charging. The pressures due to mechanically entrapped gasses during charging (excluding any thermal affect) could reach a maximum of about 1.5 psi; with this pressure being sensitive to the coal's tendency to segregate by particle size. In addition, they also concluded that charging rate would have a significant affect on wall load during oven charging, with faster charging rates being associated with higher wall loads. The brief J&J study did not take into account the effects of temperature, and the rate at which gas would be generated due to the vaporization of water and oil; it did suggest however, that if bed permeability is considered, the formation of steam during heating up of the charge would play a significant role in generating additional pressures during the first few hours of the coking cycle.

SUMMARY (OH-13)

As a preamble to the summary let me say that over the past five years, the study of the movement of heating walls in operating coke batteries has indicated that a redefinition of the causes of wall movement and thus heating wall stress and damage should be considered. During the measurements made on the three batteries discussed here, and in two privately funded deflection measurements on two other coke batteries, the results have been consistent. That is the movement of a heating wall follows a cyclic pattern, and the cycle is initiated by the charging of one of the ovens adjacent to the wall, and reversed when the opposite oven is charged. THE CONSISTENCY OF THESE RESULTS MUST BE EMPHASIZED. In summary then:

1 The major movement of a heating wall takes place at and immediately following charging of an oven adjacent to the wall. (In most cases, primary movement has taken place by the time the charge was completed, and secondary movement, if present, was completed in 6 hours or less.)

2 The magnitude of wall movement increases with increases in the weight of the coal charge. (This was shown by the excellent correlations found between charge weight and wall movement data collected independently at both Armco and Inland, and by the similarities between the relationships at the two plants.)

3 The structural condition of a heating wall is reflected in its deflection response. (This was shown by the results of the five wall test series as conducted at Inland in which movement varied even though charge weight were comparable. It is also shown by the excellent correlation between charge weight and movement among different test series on the same wall. The latter relationship would indicate that the slope of the line or equation is a function of the walls condition.)

4 Differences in the form of a deflection response may be indicative of one mechanism through which wall pressure is generated. (That is the presence of a secondary movement and the relationship between its duration and the coals bulk density indicates a pressure source acting on the wall other than that from the force of the charged or dropped coal.)

5 Charging an oven by as much as +/- 3 hours from normal schedule does not adversely affect wall movement. (This was shown by the results of the delay charge test series conducted at Armco.)

6 The location of a wall within a battery structure does not affect its movement, and therefore its structural condition. (This was shown by both the four wall series at Armco and the five wall series at Inland.)

7 Carbonization gas pressure was not found to have any relationship to wall movement. (Gas pressure was measured in at least one oven throughout all of the test series. These measurement were made by inserting pipe probes into the charge immediately after the oven was charged. The pressures sensed by the probes were recorded throughout the coking cycles. In fact, significant wall movement was measured even when pressures would be normally considered at safe levels of less than 1.0 psi.)

FUTURE IMPACT OH-14

The ability to measure and the measurement of heating wall movement or deflection can impact future coke battery operations in at least two significant ways. First as a tool for use by the coke plant operator to evaluate, quantify and rate the physical or structural condition of a specific battery, and to accurately, and accurately must be emphasized, evaluate how operational changes affect that condition. Second, as a tool that can be used to attain a better understanding of what factors or variables in the coking process affect battery structure and therefore battery life.

First, as a tool for the operator, the consistent relationship between charge weight and deflection indicates that the slope of the line defined by a linear equation which expresses the relationship is a function of the structural condition of a wall. Therefore if the physical condition of some of the walls in a battery can be defined in terms of their load-deflection relationship at some point in time, then an operator can evaluate operational changes in terms of whether they adversely affect an anticipated predictable wall movement. In addition, periodic evaluation of the load-deflection response can provide a history of change in a batteries condition as a function of time or as a function of operational changes.

Second, the consistency of results that show the significance of oven charging to heating wall movement indicate that all aspects associated with charging operations should be investigated in terms of their affect on wall movement. This would include defining the effects of variables such as charging rate, type of charging, level of suction on the oven, and so forth. The bulk density-duration of movement relationship associated with secondary wall movement, as well as the results of the brief study done by Jenicke & Johanson indicates that some definition of the significance of variables associated with the particulate nature of coal should also be pursued. That is how does particle size distribution, interparticle friction, bed permeability, bed compressibility and so forth vary and influence wall movement. Specifically the impact load on charging and the development and entrapment of gasses during the early part of the coking cycle when movement takes place. A better understanding of wall pressure sources and application could lead to the definition of means of controlling these pressures, and prolonging battery life.

PHASE I

NO. 3 COKE OVEN BATTERY (PREHEATED COAL)

USS DIVISION, USX CORPORATION, GARY, INDIANA

THREE TEST SERIES CONDUCTED

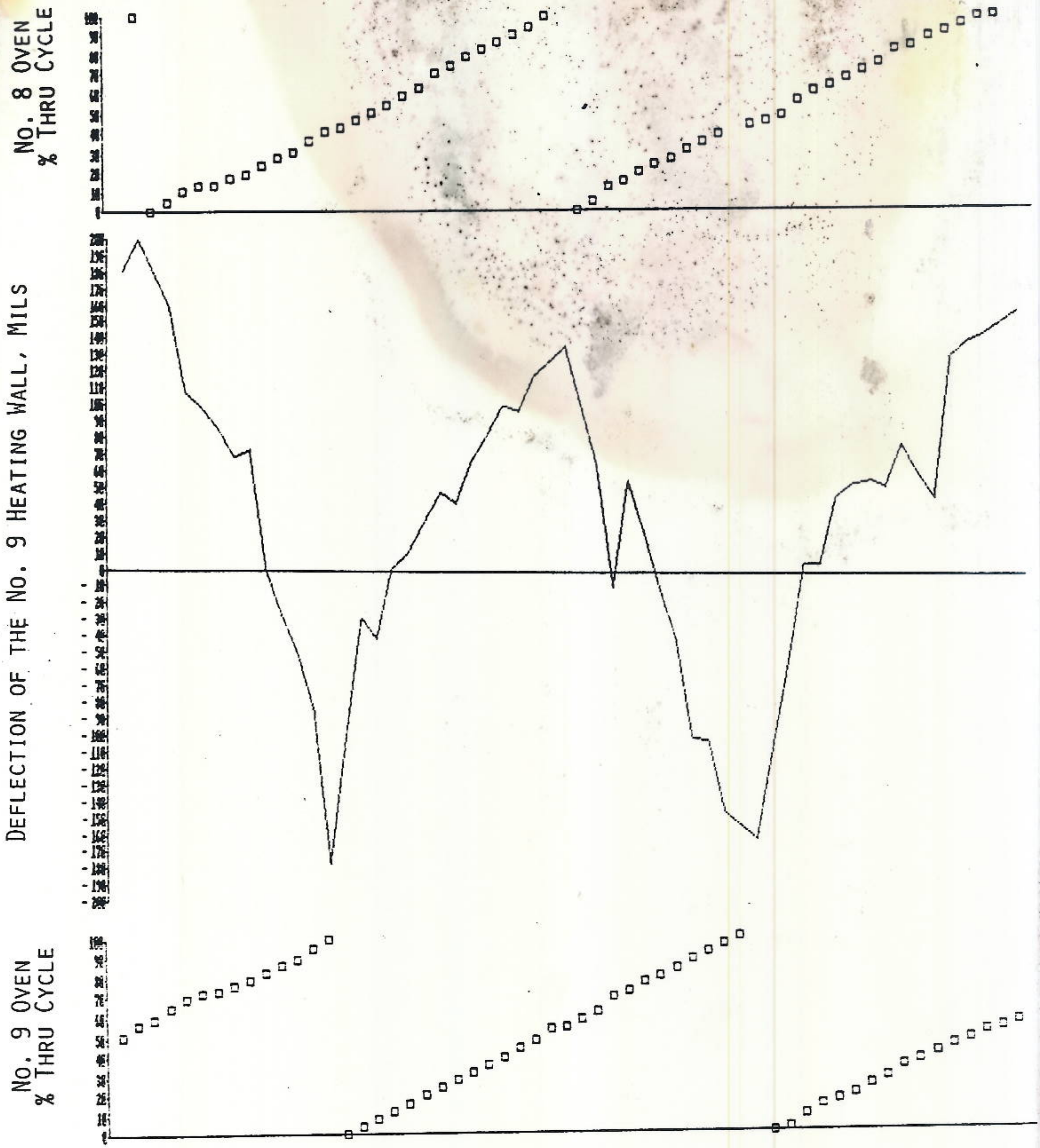
* DAMAGED WALL - LOW DIFFERENTIAL PRESSURE
* DAMAGED WALL - HIGH DIFFERENTIAL PRESSURE
* "UNDAMAGED" WALL - LOW DIFFERENTIAL PRESSURE

WALL MOVEMENT MEASURED USING OPTICAL METHODS

OBJECTIVE

HEATING WALLS MOVE IN RESPONSE TO EVENTS TAKING PLACE IN THE OVENS.

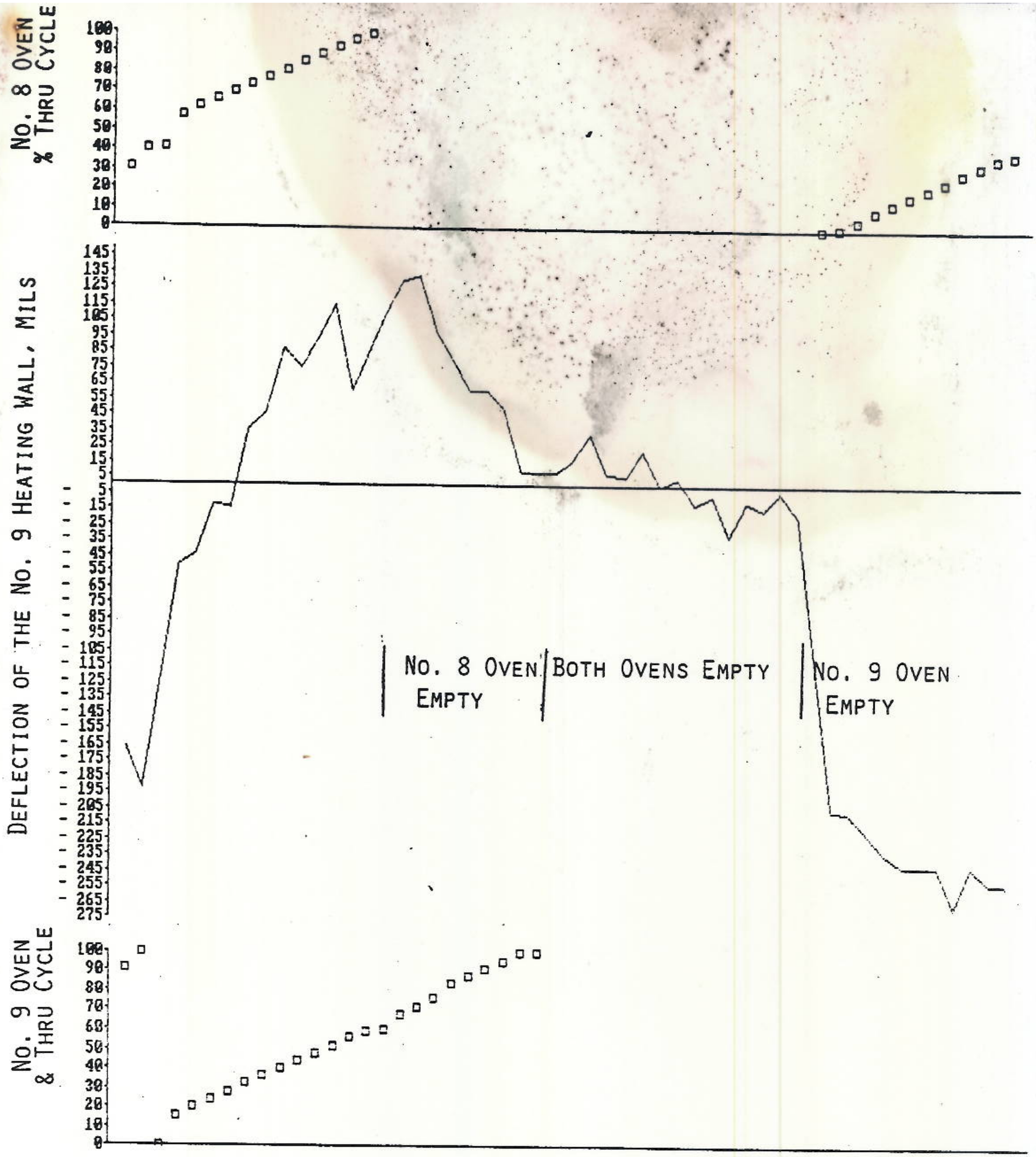
THE MOVEMENT OF HEATING WALLS IS INFLUENCED BY THE STRUCTURAL CONDITION OF THE WALL.



USS - GARY NO. 3 COKE BATTERY

DAMAGED WALL - LOW DIFFERENTIAL PRESSURE

AVERAGE COKING TIME - 12:44
AVERAGE PRIMARY DEFLECTION - 91 MILS
AVERAGE TOTAL DEFLECTION - 327 MILS



USS - GARY NO. 3 COKE BATTERY

DAMAGED WALL - HIGH DIFFERENTIAL PRESSURE

AVERAGE COKING TIME - 12:40
AVERAGE PRIMARY DEFLECTION - 164 MILS
AVERAGE TOTAL DEFLECTION - 362 MILS

PHASE II

No. 1 COKE BATTERY, NO. 3 COKE PLANT

ARMCO, INC., MIDDLETOWN, OHIO

FIVE TEST SERIES CONDUCTED

- * FOUR WALL SERIES
- * LOW BULK DENSITY CHARGES
- * HIGH BULK DENSITY CHARGES
- * SHORT OVEN CHARGES
- * DELAY CHARGE TIME

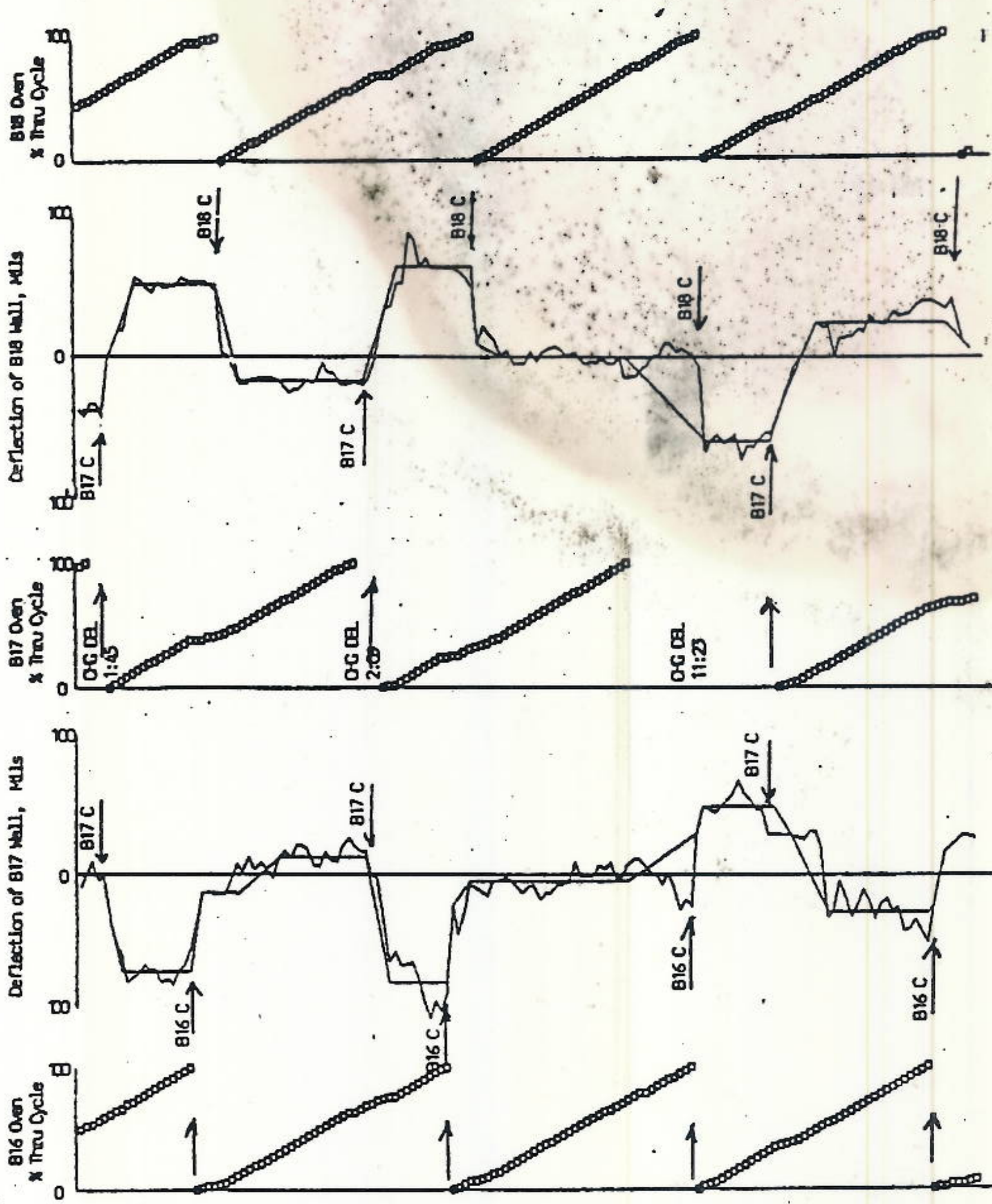
ON LINE SENSOR USED FOR ALL SERIES

OBJECTIVE

IS THE AMOUNT A WALL MOVES RELATED TO ITS LOCATION IN THE BATTERY.

EFFECT OF COAL MOISTURE (BULK DENSITY) AND/OR CHARGE WEIGHT ON WALL MOVEMENT.

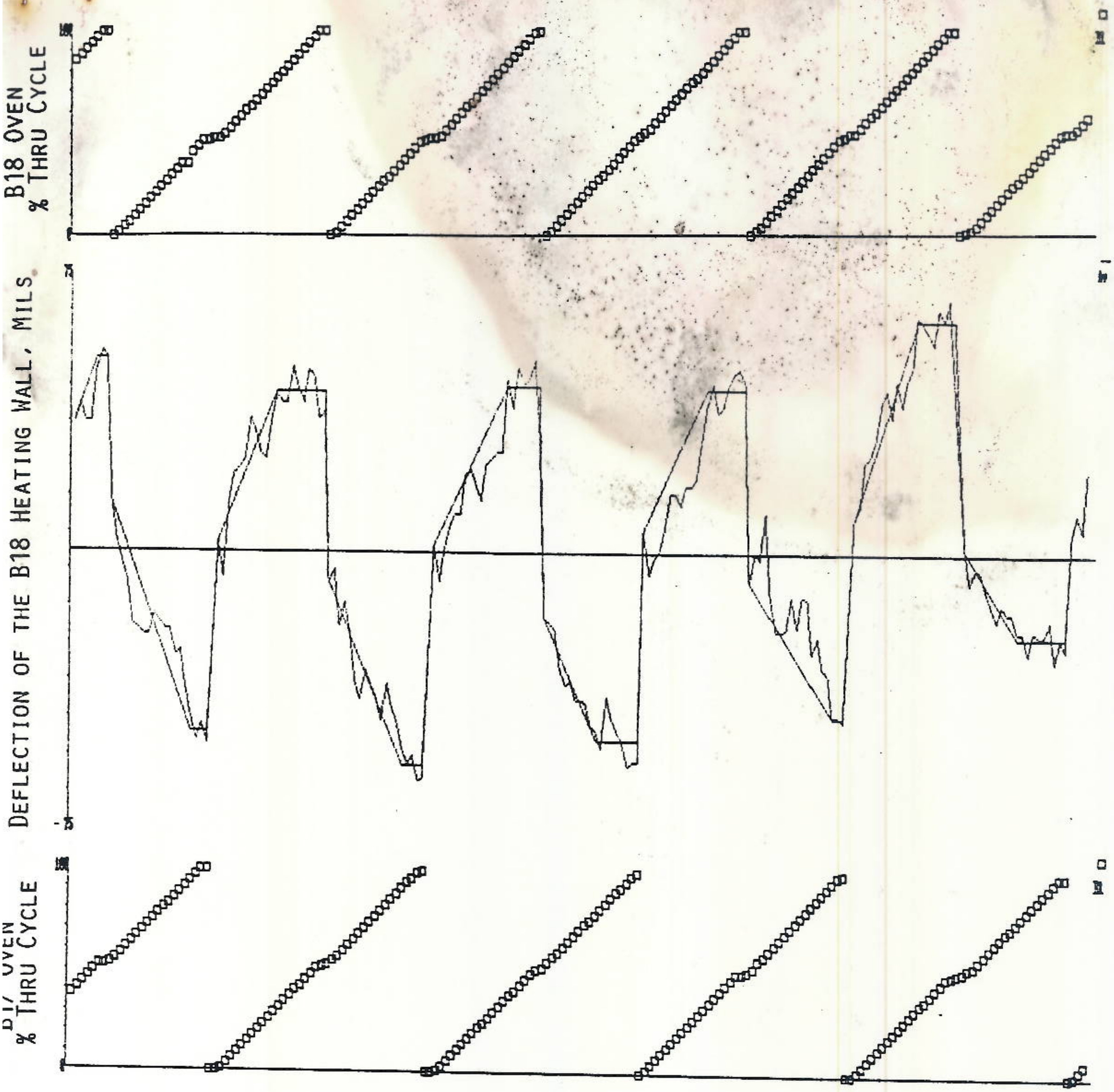
WHAT EFFECT DOES PUSHING AND CHARGING OFF SCHEDULE HAVE ON WALL MOVEMENT



ARMCO - NO. 1 COKE BATTERY, NO. 3 COKE PLANT

DELAY CHARGE TEST SERIES

	B17 WALL	B18 WALL
AVERAGE WET BULK DENSITY	44.7 PCF	44.4 PCF
AVERAGE CALCULATED CHARGE WEIGHT	29.3 TONS	29.3 TONS
AVERAGE COKING TIME	18:21	18:20
AVERAGE PRIMARY DEFLECTION	54 MILS	36 MILS
AVERAGE TOTAL DEFLECTION	88 MILS	73 MILS



ARMCO - NO. 1 COKE BATTERY, NO. 3 COKE PLANT

HIGH BULK DENSITY SERIES

AVERAGE WET BULK DENSITY	46.6 PCF
AVERAGE CALCULATED CHARGE WEIGHT	31.0 TONS
AVERAGE COKING TIME	18:02
AVERAGE PRIMARY DEFLECTION	53 MILS
AVERAGE TOTAL DEFLECTION	97 MILS

PHASE III

NO. 10 COKE BATTERY

INLAND STEEL COMPANY, EAST CHICAGO, INDIANA

FOUR TEST SERIES CONDUCTED

* FIVE WALL SERIES
* LOW BULK DENSITY CHARGES
* HIGH BULK DENSITY CHARGES
* SHORT OVEN CHARGES

ON LINE SENSOR USED FOR ALL SERIES

INTERNAL FLUE TARGETS HAD TO BE INSTALLED

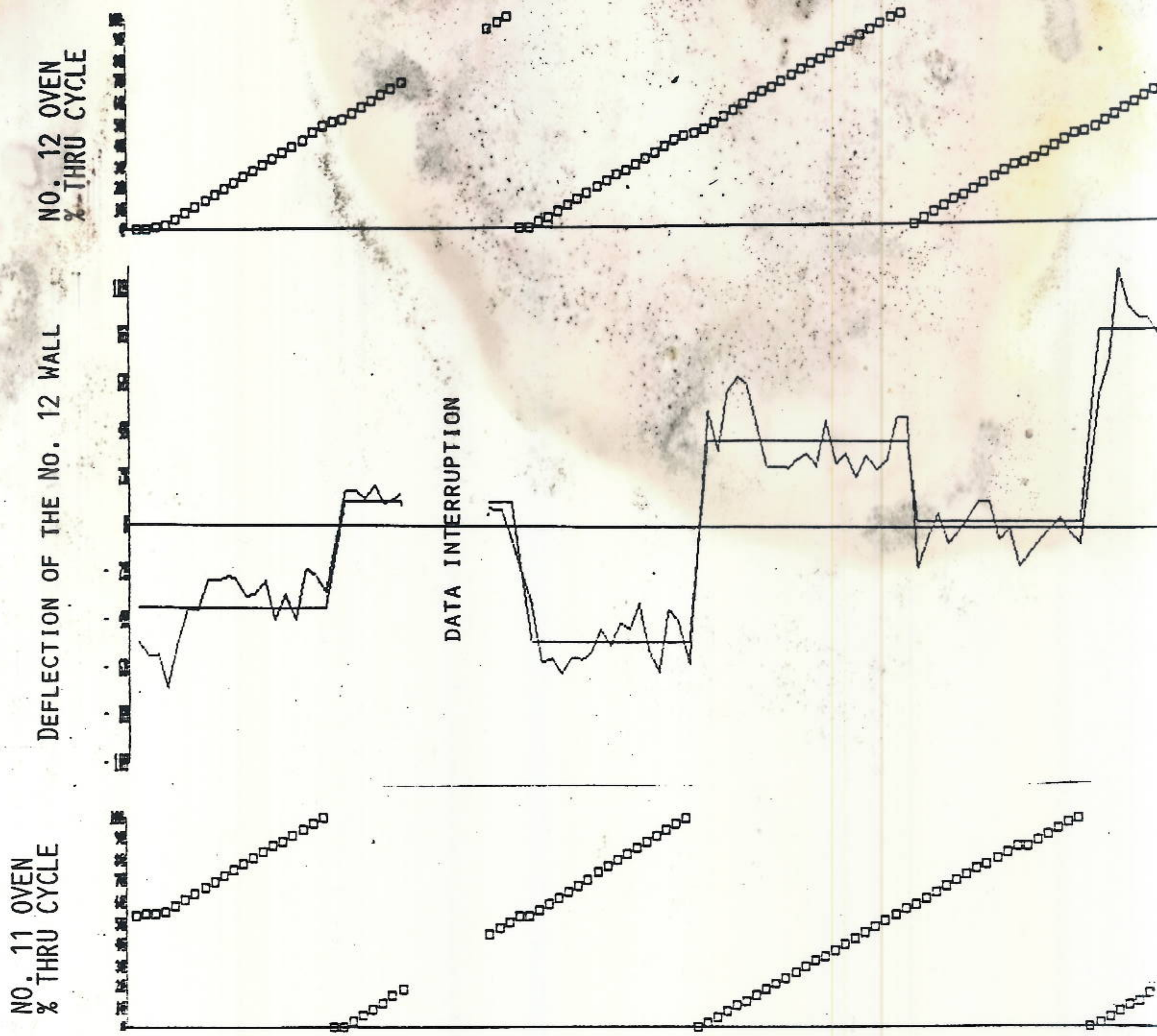
OBJECTIVE

CORROBORATE THE TEST RESULTS OF PHASE II

INLAND - NO. 10 COKE BATTERY

5 - WALL TEST SERIES

WALL NUMBER	WET BULK DENSITY, PCF	CHARGE WEIGHT, TONS	AVERAGE TOTAL DEFLECTION, MILS
2	46.2	26.5	52
7	44.6	25.1	60
12	45.4	25.7	85
17	44.5	25.4	47
22	45.0	25.3	56



INLAND - NO. 10 COKE BATTERY

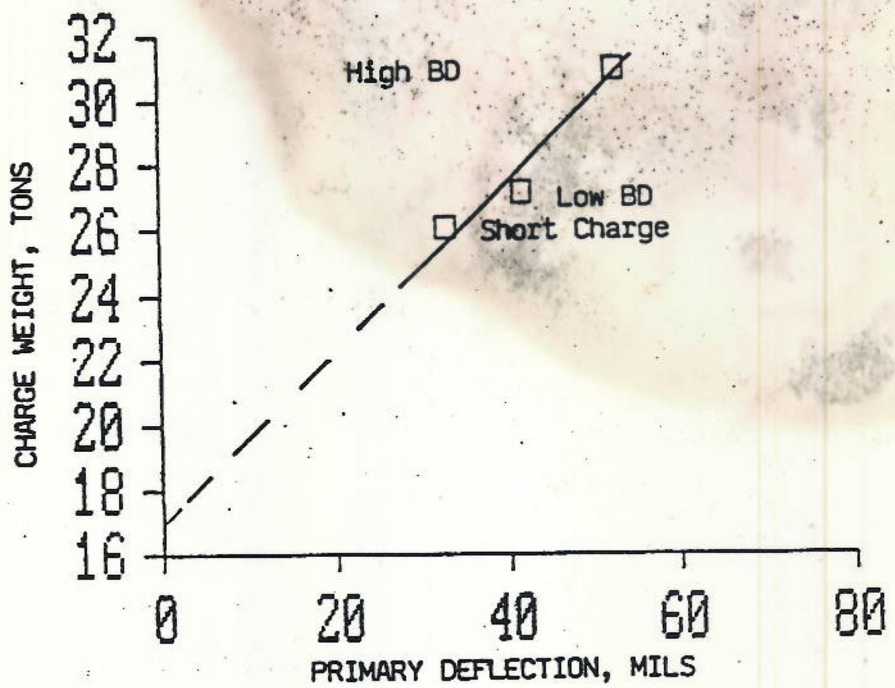
LOW BULK DENSITY TEST SERIES

AVERAGE WET BULK DENSITY	41.9 PCF
AVERAGE CALCULATED CHARGE WEIGHT	23.2 TONS
AVERAGE COKING TIME	17:53
AVERAGE PRIMARY DEFLECTION	62 MILS
AVERAGE TOTAL DEFLECTION	62 MILS

ARMCO - NO. 1 COKE BATTERY, NO. 3 COKE PLANT
MIDDLETOWN (OHIO) WORKS

DATA SUMMARY

TEST SERIES	WET BULK DENSITY, PCF	CHARGE WEIGHT, TONS	DEFLECTION, MILS PRIMARY	DEFLECTION, MILS TOTAL	TIME FOR SECONDARY MOVEMENT, HOURS
Lo BD	42.6	27.2	42	78	1:46
Hi BD	46.6	31.0	53	97	6:10
Sh Ch	44.3	26.1	33	60	2:50



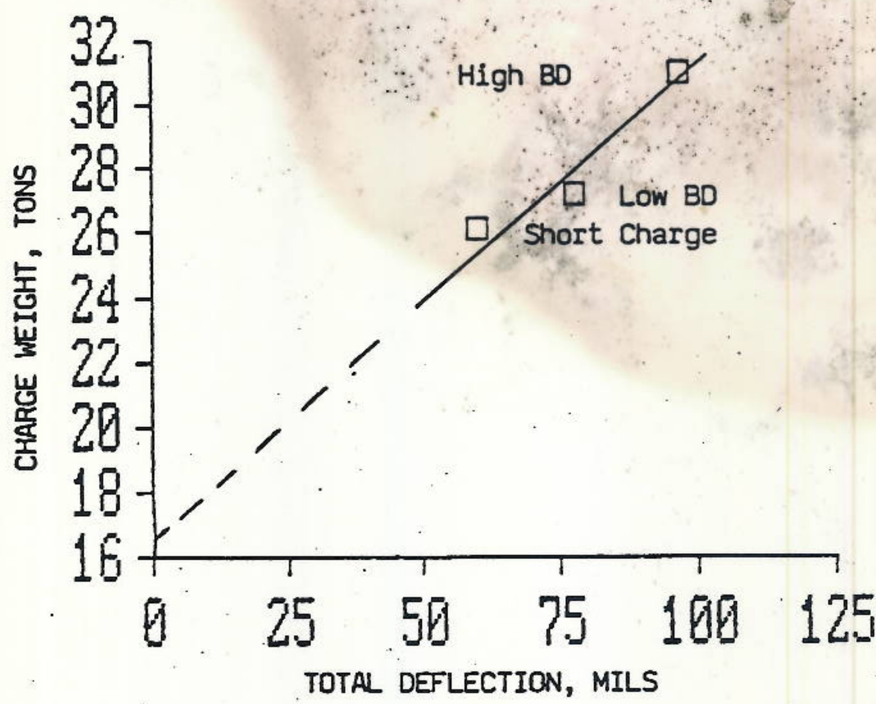
ARMCO DATA SUMMARY

PRIMARY DEFLECTION VS. CHARGE WEIGHT

TEST SERIES	PRIMARY DEFLECTION, MILS	CHARGE WEIGHT, TONS
LOW BULK DENSITY	42	27.2
HIGH BULK DENSITY	53	31.0
SHORT CHARGE	33	26.1

PRIMARY DEFLECTION, MILS = (CHARGE WEIGHT, TONS X 3.77) - 63.4

R = 0.9693



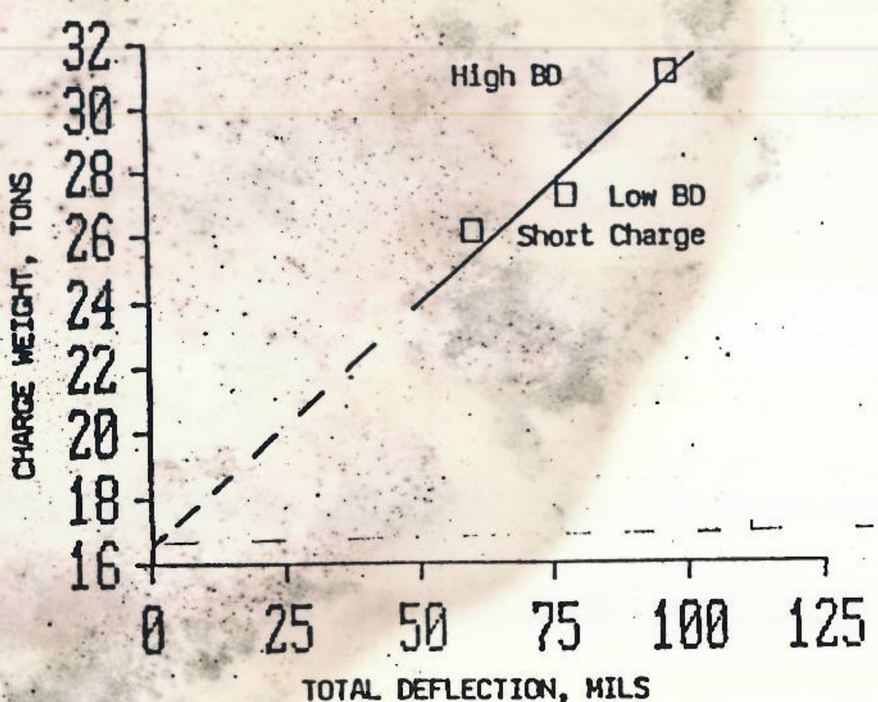
ARMCO DATA SUMMARY

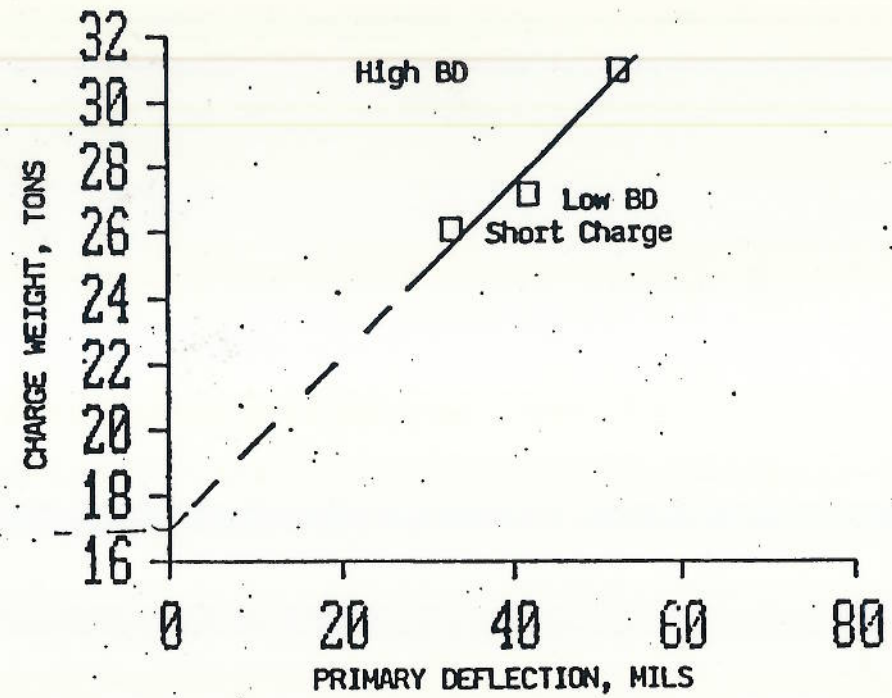
TOTAL DEFLECTION VS. CHARGE WEIGHT

TEST SERIES	TOTAL DEFLECTION, MILS	CHARGE WEIGHT, TONS
Low Bulk Density	78	27.2
High Bulk Density	97	31.0
Short Charge	60	26.1

Total Deflection, Mils = (Charge Weight, Tons X 6.89) - 115.3

R = 0.9575


CHARGE WEIGHT, TONS
32
30
28
26
24
22
20
18
16
0
25
50
75
100
125
TOTAL DEFLECTION, MILS
High BD
Low BD
Short Charge

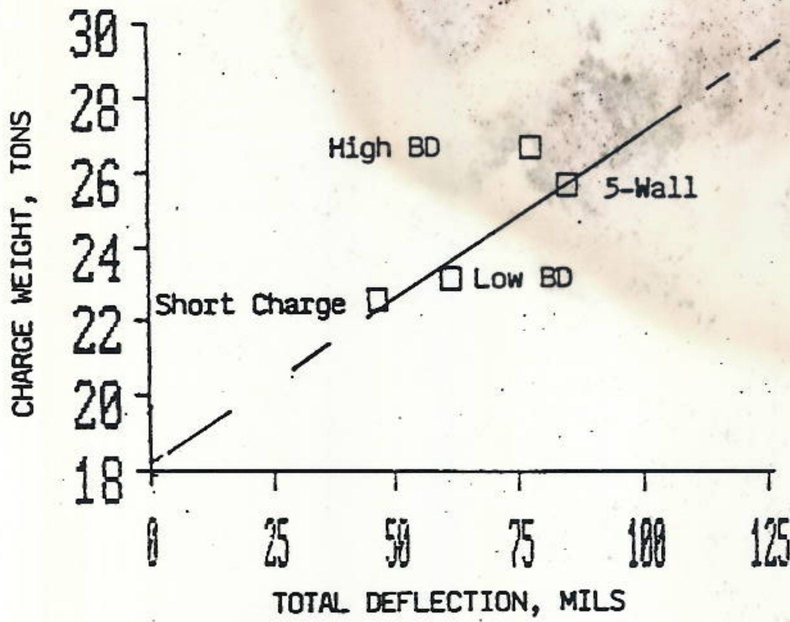

CHARGE WEIGHT, TONS
32
30
28
26
24
22
20
18
16
0
20
40
60
80
PRIMARY DEFLECTION, MILS
High BD
Low BD
Short Charge

OH-9A

INLAND - NO. 10 COKE BATTERY
EAST CHICAGO, INDIANA

DATA SUMMARY
NO. 12 HEATING WALL

TEST SERIES	WET BULK DENSITY, PCF	CALCULATED CHARGE WEIGHT, TONS	PRIMARY & TOTAL DEFLECTION, MILS
LO BD	41.9	23.2	62
HI BD	47.7	26.7	78
SH CH	42.6	22.6	47
5-WALL	45.4	25.7	85



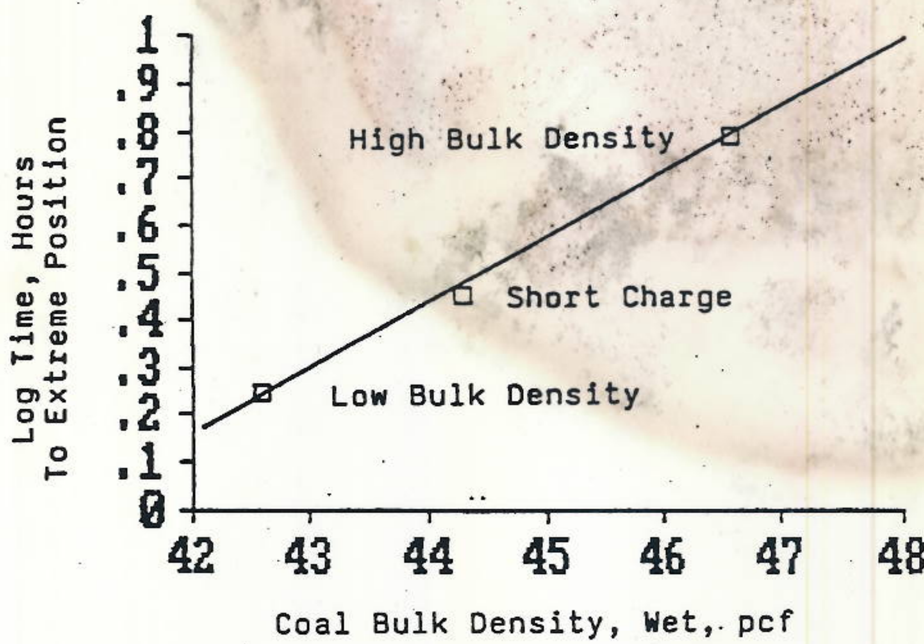
INLAND DATA SUMMARY

TOTAL DEFLECTION VS. CHARGE WEIGHT

TEST SERIES	TOTAL DEFLECTION, MILS	CHARGE WEIGHT, TONS
LOW BULK DENSITY	62	23.2
HIGH BULK DENSITY	78	26.7
SHORT CHARGE	47	22.6
5-WALL	85	25.7

DEFLECTION, MILS = (CHARGE WEIGHT, TONS X 11.36) - 206.14

R =).9761



ARMCO DATA SUMMARY

BULK DENSITY VS. LOG TIME OF SECONDARY MOVEMENT

TEST SERIES	BULK DENSITY, PCF	TIME FOR SECONDARY MOVEMENT, HOURS	LOG TIME
LOW BULK DENSITY	42.6	1:46 (1.767)	.2472
HIGH BULK DENSITY	46.6	6:10 (6.167)	.7901
SHORT CHARGE	44.3	2:50 (2.833)	.4523

WET BULK DENSITY, PCF = (LOG TIME, HOURS X 7.312) + 40.869

R = 0.9986

JENICKE & JOHANSON TESTS

ARMCO BLEND USED

1. COAL LOAD DURING CHARGING COULD REACH A MAXIMUM OF 0.6 PSI

2. CHARGING RATE COULD PLAY A SIGNIFICANT ROLE - HIGHER CHARGING RATES WOULD RESULT IN HIGHER WALL PRESSURES

3. GAS ENTRAPMENT DURING CHARGING COULD RESULT IN MAXIMUM PRESSURES OF 1.5 PSI IF SEVERE PARTICLE SIZE SEGREGATION TAKES PLACE

4. THIS FIRST STUDY DID NOT TAKE INTO ACCOUNT THE EFFECTS OF TEMPERATURE, BUT J&J CONCLUDED THAT STEAM FORMATION COULD PLAY A SIGNIFICANT ROLE IN THE GENERATION OF WALL PRESSURE

SUMMARY

* THE MAJOR MOVEMENT OF A HEATING WALL TAKES PLACE AT AND IMMEDIATELY FOLLOWING CHARGING OF AN OVEN ADJACENT TO THE WALL.

* THE MAGNITUDE OF WALL MOVEMENT INCREASES WITH INCREASES IN THE WEIGHT OF THE COAL CHARGE

* THE STRUCTURAL CONDITION OF A HEATING WALL IS REFLECTED IN ITS DEFLECTION RESPONSE.

* DIFFERENCES IN THE FORM OF A DEFLECTION RESPONSE MAY BE INDICATIVE OF ONE MECHANISM THROUGH WHICH WALL PRESSURE IS GENERATED.

* CHARGING AN OVEN BY AS MUCH AS + OR - 3 HOURS FROM NORMAL SCHEDULE DOES NOT ADVERSELY AFFECT WALL MOVEMENT.

* THE LOCATION OF A WALL WITHIN A BATTERY STRUCTURE DOES NOT AFFECT ITS MOVEMENT, AND THEREFORE ITS STRUCTURAL CONDITION.

* CARBONIZATION GAS PRESSURE WAS NOT FOUND TO HAVE ANY RELATIONSHIP TO WALL MOVEMENT.

FUTURE IMPACT

MEASUREMENT OF HEATING WALL DEFLECTION CAN IMPACT COKE BATTERY OPERATIONS IN TWO SIGNIFICANT WAYS

A TOOL FOR THE BATTERY OPERATOR

THE RELATIONSHIP BETWEEN CHARGE WEIGHT AND DEFLECTION CAN DEFINE STRUCTURAL CONDITION

THIS DEFINITION WOULD PERMIT EVALUATION OF OPERATING CHANGES IN TERMS OF THEIR EFFECT ON PREDICTABLE WALL MOVEMENT

PERIODIC EVALUATION OF SELECTED WALLS WOULD DEFINE CHANGES IN BATTERY CONDITION

A BETTER UNDERSTANDING OF THE SOURCES OF WALL PRESSURE

WHAT IS THE INFLUENCE OF THE VARIABLES ASSOCIATED WITH OVEN CHARGING

HOW DO VARIATIONS IN THE PARTICULATE NATURE OF THE COAL AFFECT WALL MOVEMENT

COULD CONTROL OVER DEFINED SIGNIFICANT VARIABLES BE USED TO CONTROL WALL MOVEMENT AND STRESS