TRANSLATION
from: GERMAN WB:dm

ORIGINAL SIGNED
R. J. ZUNKLEY

R.J.Z.

APR 15 1968

Deutscher Kokereiausschuss
(German Coke Oven Committee)

Report No. 114 April 1959

LIMIT LOAD OF COKE OVEN WALLS

by Walter Ahlers of Mulheim(Ruhr)

(Report No. 114 of the German Coke Oven Committee)

I. DETERMINATION OF THE LIMIT LOAD OF A COKE OVEN WALL

Compressive stress in a coke oven wall due to the weight of the wall, to anchoring and to the charge of the chamber. Flexural stress in a section of a vertical coke oven wall. Composite compressive flexural stress. Calculation of the limit load of a section of a vertical coke oven wall. Comparison of the calculated limit load with experimental results. Calculation of the limit load of a section of a horizontal coke oven wall. Limit load of a coke oven wall. Shear stress.

The life of a coke oven block depends to a large amount on to what extent the coke oven walls can withstand the pressure of the charge of the chamber. Exact data as to the load-carrying capacity of the coke oven walls is unfortunately scarcely available. In the following investigations, the load-carrying capacity and the limit load of coke oven walls will therefore be determined mathematically. In this connection, in the first part of this report the individual types of stress will be taken up and the highest possible lateral loading (limit load) of a coke oven wall determined, while in the second part of the report there will first of all be indicated the influence of the dimensions of the oven on the maximum possible loading. Thereupon what dimensions should be advisedly selected for the oven wall will be discussed in further detail.

In order to avoid misunderstandings, the most important expressions used are defined below.

Stress:

The strain in the bricks caused by pressure, tension flexure or shear in kg/cm^2.

Strength:

The highest permissible stress of the bricks shortly before the destruction (rupture or softening) in kg/cm^2.

Permissible stress:

The stress permissible in operation without danger to the bricks in kg/cm^2.

Load:

The lateral pressure on the coke oven wall in kg/cm^2.

Limit load:

The highest possible loading of the coke oven wall with (theoretically) infinitely high compressive strength of the bricks just before the breaking of the wall in kg/cm^2.

Load carrying capacity:

The loading of the coke oven wall possible in operation without endangering the wall upon finite stressing of the bricks in kg/cm^2.

Stress value:

The quotient $\frac{\text{load carrying capacity}}{\text{limit load}}$

Limit flexural moment:

The highest possible flexural moment which can be transferred by a coke oven wall at the limit load of the wall in cm-kg.

Fundamentally the following stresses occur in a coke oven wall: 1. pressure, 2. flexure, and 3. shear. These stresses will be examined further, taking as example an oven having an inside height of chamber of 4.5 m and the dimenions shown in Fig. 1.

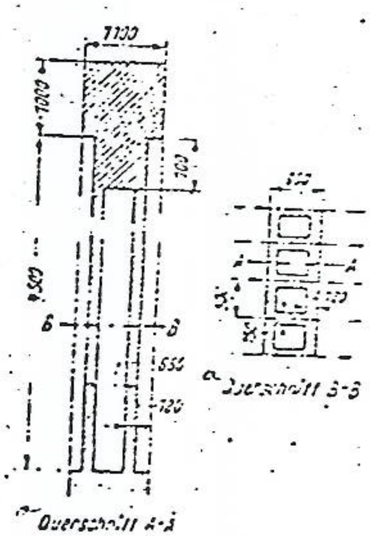


Fig. 1
Dimensions of a coke oven wall
a. cross-section

Stressing in tension in general does not occur in a coke oven wall. It would be possible if the mortar in the joints were firmly connected with the bricks. Such a firm connection between mortar and brick at every point of the wall and for the entire life of the oven block can, however - as shown by experience - scarcely be expected. It is therefore assumed that no tension can occur in a coke oven wall, which assumption is furthermore also made in all construction work in connection with strength calculations for brickwork.

Compressive Stress in a Coke Oven Wall

A coke oven wall can be stressed in compression:

a. by its own weight,

b. by its anchoring, and

c. by the charge of the chamber.

Compressive stress by the weight of the wall itself is shown in Fig. 2. The weight of the wall is indicated in the figure by the arrows G_A, G_B and G_C, in which connection the increase in weight from top to bottom can be noted from the fact that the arrow lengths become longer towards the bottom.

The compressive stress is found to be $p = \frac{G}{F}$ in which G is the weight of the wall itself in kg and F is the area in cm^2 in the corresponding cross-section. For the coke oven wall considered, of a height of 4.5 m, the compressive stress p the cross-section AA is found to be 0.322. in the cross-section BB 1.08, and in the cross-section CC 1.48 kg/cm^2. In Fig. 2 these stresses are indicated by the vertically hatched fields, the hollow space in the region of the heating flues being characterized by the thinner hatching.

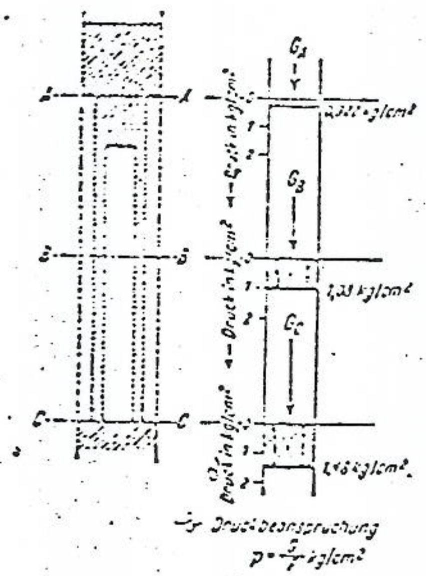


Fig. 2. Compressive stress of a
coke oven wall by the dead weight.
a. pressure in kg/cm^2
b. compressive stress

The weight per unit of volume of the roof of the furnace (fireclay bricks) was taken as 1.9 t/m^3 in the above as well as the following calculations and the weight per unit of volume for the wall itself (silica bricks) was taken as 1.8 t/m^3. The weight of the anchoring lying on the furnace roof, the frame and cover of the filling holes, as well as of the filling car rail was, on the other hand, neglected due to their slight influence on the calculation. The weight of the riser pipes, buckstays, doorframes and doors was also not taken into consideration, since these parts act only on the ends of the coke oven wall and due to the stronger and colder tie rods cannot lead there to a compressive stress which constitutes a danger for the buckstays.

The weight of the filling car with its charge of coal can, to be sure, not be neglected. When the full filling car stands on or travels over the corresponding oven with a part of its wheels - generally two out of eight present - a higher compressive stress occurs which, however, even in the most unfavorable case as, for instance, in the case of a heavy four-wheel filling car with point transfer of the wheel pressures to the oven roof, does not exceed 5.0 kg/cm^2.

The compressive stress by the anchoring depends on the pressure with which the buckstays are pressed against the wall (Fig. 3). This pressure should, on the one hand, not be so great that the wall bricks are overstressed, while, on the other hand, it should not be so slight that vertical joints can be produced within the bond of the wall.

The compressive stress by the anchoring in an amount of $p = 1.0\ kg/cm^2$ shown in Fig. 3 corresponds approximately to the compressive stress by the weight of the wall itself at half the height of the chamber (cross-section BB in Fig. 2). In the case of the oven under consideration having stretchers of a thickness of 120 mm, the buckstays must be pressed against the wall with a pressure of

TRANSLATION

from:

A = 100 x 2 x 12 x 1.0 = 2400 kg/m of height if the indicated compressive stress of 1.0 kg/cm^2 is to be reached. A prerequisite for this is that the pressure of the buckstays be distributed uniformly over the entire height, which result can be obtained by various measures.

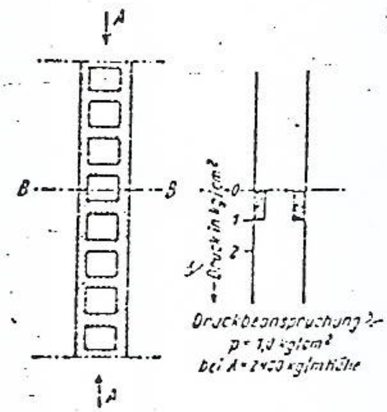
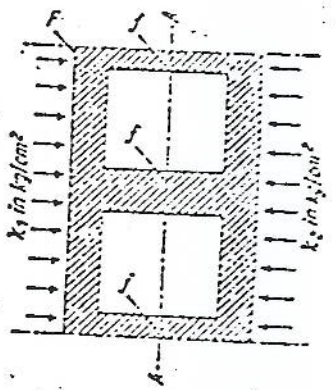


Fig. 3. Compressive stress of a coke oven wall by the anchoring.
a. pressure in kg/cm^2
b. compressive stress
p = 1.0 kg/cm^2
with A = 2400 kg/m of height

The compressive stress upon loading by the charge of the chamber can be noted from Fig. 4. If the loading of the wall of the coke oven by the chamber charge of the lefthand chamber is exactly equal to that produced by the chamber charge of the righthand chamber (case 1: $k_1 = k_2$), then the load will be taken up solely by the headers. The compressive stress in the headers is then $p = k_1 \cdot \frac{F}{f}$

in which F is the area of the chamber wall acted on and f is the header cross-section devolving upon F. In the case of the customarily occurring loadings of the coke oven walls by the charge of the chambers and the customary header dimensions, the compressive stress in the headers of a coke oven wall is p = 0.1 to 0.5 kg/cm^2.



Compressive stressing in the headers:
Case 1 ($k_1 = k_2$): $p = k_1 \cdot \frac{F}{f}$ in kg/cm^2
Case 2 ($k_1 > k_2$): $p = k_2 \cdot \frac{F}{f}$ in kg/cm^2
$p_{normal} = 0.1$ to 0.5 kg/cm^2
Flexural stressing in the coke oven wall in case 2 ($k_1 > k_2$) by:
$k = k_1 - k_2$ in kg/cm^2

Fig. 4. Compressive stressing of a coke oven wall upon loading by the chamber charge.

Flexural Stress in a Coke Oven Wall

Flexural Stress in a Vertical Section of the Wall

If the loading of the coke oven wall by the chamber charge of the lefthand chamber is greater than that produced by the chamber charge of the righthand chamber (Fig. 4, case 2: $k_1 > k_2$), then the compressive stress of the headers is $p = k_2 \cdot \frac{F}{f}$. The difference in pressure $k = k_1 - k_2$ is not a[illegible] up by the headers but leads to a flexural and shearing stress in the coke oven wall. First of all, the flexural stress will be taken up in detail, at first on a vertical section of a coke oven wall of a length of 1 m from the center of the 4.5 m high chamber wall.

Before going further into this, the three cases of loading entering into question here pursuant to the theory of strength of material should be again pointed out. In Fig. 5, case 1 shows a beam resting loosely on both ends, case 2 a beam which is firmly fixed at the left end and resting loosely on the right end, and case 3 a beam which is firmly fixed at both sides, the beam in all three cases having a length l and a width b and being loaded with the uniformly distributed load k in kg/cm^2. The bend of the beam is represented on a greatly exaggerated scale, which is the same for all three cases, by the elastic curve.

For the determination of the flexural stress of the beam, the bending-moment curve is in particular to be considered. It indicates the moment of flexure M_x which must be taken up by the beam at a distance x from the support point A, in which connection x may have any desired value between 0 and l. The greatest bending moment M_{max} is, for cases 1 and 2, $M_{max} = \frac{k \cdot b \cdot l^2}{8}$. In case 1 it lies in the center and in case 2 at the fixed end of the beam. Furthermore, the signs in the two cases are different, which, however, is unimportant for the present considerations.

In case 2 with $x = 5/8\ l$, there is still present a relative maximum $M'_{max} = \frac{9 \cdot k \cdot h \cdot l^2}{128}$. In case 3, the largest bending moment $M_{max} = \frac{k \cdot b \cdot l^2}{12}$ is present at the two fixed ends, while the relative maximum in the center of the beam is only half as great, namely $M'_{max} = \frac{k \cdot b \cdot l^2}{24}$.

The maximum bending moments indicated in cases 2 and 3 for the fixed ends can occur only if the moments can be taken up in their entirety by the clamping. The clamping must therefore be sufficiently firm and secured against turning. If the clamping can take up only a part of the bending moment, as has been assumed in case 3, for the clamping B with the partial bending moment M_T, then the bending-moment curve is shifted in the manner indicated by the dashed line

The transverse-force curve shown in Fig. 5 indicates the force Q_x with which the beam is stressed in shear at a distance x from the supporting point A. We have $Q_x = A - x \cdot b \cdot k$. The dashed-line transverse-force curve of case 3 applies when the clamping B can take up only the partial bending moment M_T.

After considering the three loading cases, one can now return to the vertical section of a length of 1 m from the center of the 4.5 m high coke oven wall (Fig. 6). The wall section is loaded in the same manner as the beam if one disregards the turning by 90° and the unloaded part in the region of the gas collection space. The turning by 90°

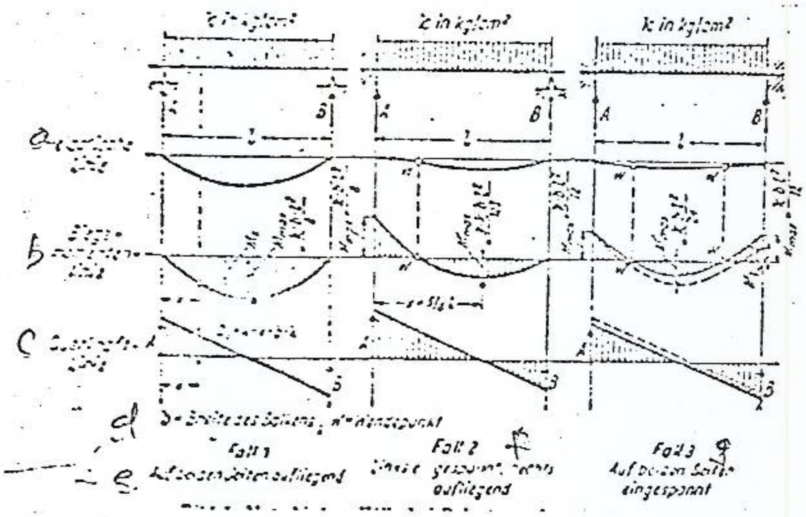


Fig. 5. Different cases upon the loading of a beam.

a. elastic curve
b. bending-moment curve
c. transverse-force curve
d. b = width of beam; w = point of inflection
e. case 1
   freely supported on both sides
f. case 2
   fixed at left, freely supported on right
g. case 3
   fixed on both sides

has no influence on the analyses made in this connection. Due to the difference in the load, the bending-moment curve, however, is shifted somewhat, which has been taken into consideration in Fig. 6 and in all the following descriptions. At the ends A and C, the section of the coke oven wall can first of all be considered as fixed, so that we are concerned with case 3 of the beam. For the cross-sections AA, BB and CC, there then result, with a given loading by the charge of the chamber (here and in the following remarks, unless otherwise stated, there is meant in all cases the difference between th load from the chamber charge of the lefthand chamber and that of the righthand chamber $(k = k_1 - k_2)$) the bending moments M_A, M_B and M_C, in which connection M_A, due to the non-loaded part of the wall in the region of the gas collecting space is not exactly equal to M_C and the relative maximum M_B is not exactly in the center. The deviations are, to be sure, only very slight and are unimportant. Whether the fixed clamping at A and C which has been provisionally assumed is actually present or not will become evident later on.

The bending stress is equal to $\sigma = \frac{M}{W}$ in which M is the bending moment in the cross-section under consideration

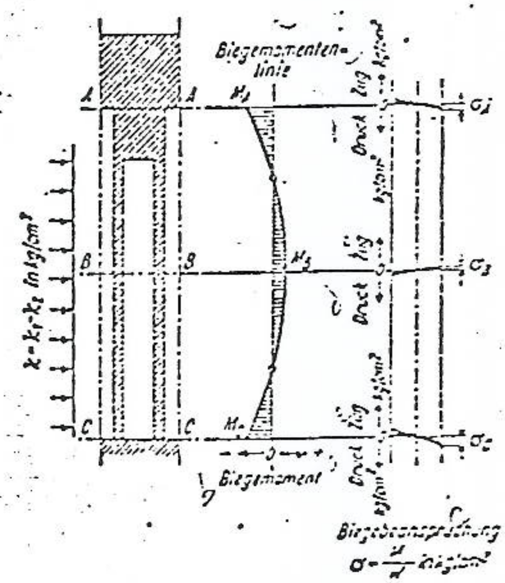


Fig. 6. Flexural stress in a vertical section of a coke oven wall upon loading by the chamber charge.
a. bending-moment curve
b. bending moment
c. flexural stress
d. compression
e. tension

in cm-kg, and W is the moment of resistance in cm^3 in this cross-section. In principle, the bending stress constitutes a tensile stress on the one side of the cross-section and a compressive stress on the other side of the cross-section. The tensile stress drops in this connection from a maximum value in the outer fiber on the one side down to zero in the neutral fiber and then increases on the other side of the cross-section as compressive stress from zero in the neutral fiber to a maximum value in the outer fiber. In Fig. 6 these relationships are entered for the cross-sections AA, BB and CC. In the case of the symmetrical cross-section of the coke oven wall, the neutral fiber lies in the center and the tensile stressing on the one side of the cross-section is equal to the compressive stressing on the other side of the cross-section.

Combined Stress of Compression and Bending
In a Vertical Wall Section

The bending stress, to be sure, does not merely occur in the vertical section of the coke oven wall, but, together with the aforementioned compressive stressing by the dead weight, it produces a combined stress consisting of compression and bending. In Fig. 7 under a there is again shown the compressive stressing by the dead weight and under b there is again shown the bending stress upon loading by the chamber charge. The combined compressive and bending stress plotted under c results from the sum of the two individual stresses. It is seen that in the present case, the tensile stress occurring in the case of the flexure under b on the one side of the cross-section is no longer present in the case of the composite stress under c but rather only compression is still present. In the upper cross-section AA the hatched area represents the sum of the pressures on the individual parts of the surface of the cross-section. It must correspond to the weight G_A of the oven roof acting on the wall at the center of the gravity S of the hatched area. For the middle and lower cross-sections BB and CC, the same applies by analogy. From an area standpoint, however, there ta[illegible] place here a distortion due to the influence of the hollow space in the heating flue, as is indicated by the thinner hatching.

Calculation of the Limit Load of a Vertical Wall Section

If the loading of the section of the coke oven wall is increased, the bending moment also becomes larger and thus also the flexural stress $\sigma = \frac{M}{W}$. The oblique lines entered under b in Fig. 7 will become steeper as σ becomes larger. The same applies to the composite compression and bending stress under c which results from the sum of the compressive stress and of the bending stress.

In Fig. 8, the change of the composite stressing

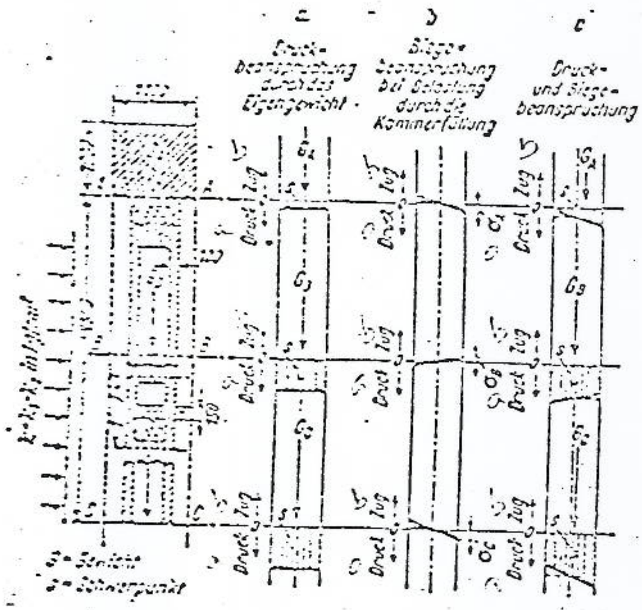


Fig. 7. Composite stress in a vertical section of a coke oven wall caused by the dead weight and upon loading by the charge of the chamber.

G = weight
S = center of gravity
a. compressive stress by the dead weight
b. bending stress upon loading by the charge of the chamber
c. compressive and bending stress
a. compression
b. tension

upon increasing the bending moment due to increase of the loading of the section of the coke oven wall for the upper cross-section AA is shown on a somewhat larger scale. Under c there is again shown the composite stress of Fig. 7. At d the bending moment has become so great that the compressive stress of the left outer fiber is just equal to zero. However, compression still occurs over the entire surface, it increasing from zero in the lefthand outer fiber up to a maximum value

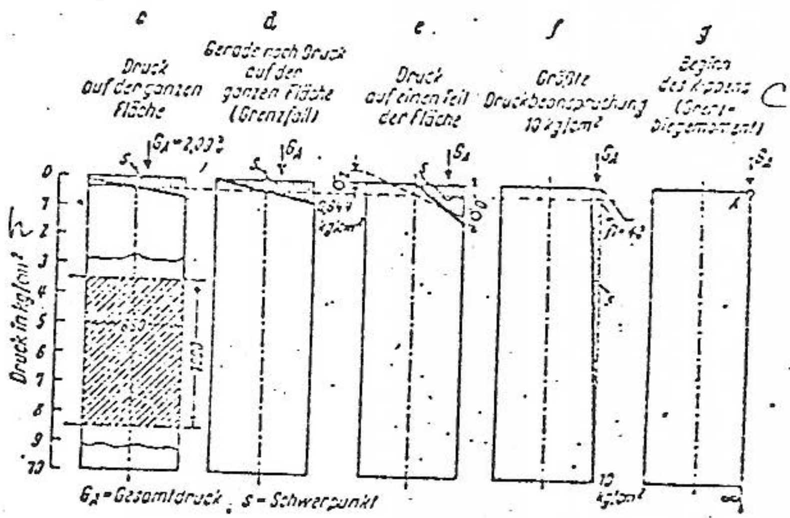


Fig. 8. Change of the composite stress in the upper part of a vertical section of a coke oven wall upon increasing the load by the chamber charge.

G_A = total pressure, S = center of gravity
c. compression on the entire area
d. compression still just on the entire area (limit case)
e. compression on a part of the area
f. maximum compressive stress 10 kg/cm^2
g. start of tipping (limit bending moment)
h. compression in kg/cm^2

of 0.644 kg/cm^2 in the righthand outer fiber. The center of gravity S of the hatched area at which the weight G_A of the oven roof acts is in this case somewhat further towards the right than in the case of c. The area itself, which, after all, represents the sum of the individual pressures, and must correspond to the weight G_A, is the same as under c.

If the bending moment is increased further by increasing the loading of the section of the coke oven wall, then actually a tensile stress would have to occur in the lefthand outer fiber, as indicated under e by the dot-dash line. The tensile stress of the left outer fiber would then be σ_Z. Since the tension cannot be transmitted by the brickwork, the bending moment must be taken up by the fact that the compressive stress is shifted correspondingly further towards the right, as shown by the hatched area under e. The highest compressive stress σ_D in the righthand outer fiber has thereby increased further.

At f, the bending moment has become so great by the increase of the load on the section of the coke oven wall that the maximum compressive stress of the righthand outer fiber just amounts to 10 kg/cm^2. Only the small area of the width fl = 42 mm of the entire cross-section still participates in the transmission of the pressure, the compressive stress increasing from the inside towards the outside from 0 to 10 kg/cm^2.

If the bending moment is still further increased by increasing the load on the section of the coke oven wall, then the compressive stress of the righthand outer fiber will theoretically increase infinitely, as indicated under g. The compressive strength of the bricks must in this case - at least theoretically - be infinitely high. The weight G_A of the oven roof is in this connection transmitted at point A from the outermost righthand fiber to the coke oven wall.

From this moment on, a still further increase of the load on the section of the coke oven wall does not lead to any change in the vertical stressing in this cross-section. The wall, to be sure, begins to tip around the point A. In this way the outermost limit of the theoretically transferable bending moment, namely the limit bending moment, is reached. This means that in the case of the beam fixed at both sides of Fig. 5, case 3, the righthand (or lefthand) clamping point is not sufficiently firm to take up a greater bending moment, so that the bending-moment curve will, upon further increase of the load, assume a shape such as indicated by the dashed line in Fig. 5.

The conditions in the central cross-section BB are also similar to what they are in the upper cross-section AA which has been considered, as can be noted from Fig. 9. Since the bending moment here has a different sign (Fig. 6), the compressive stress, upon an increase of the load on the section of the coke oven wall, instead of moving to the righthand side of the cross-section, moves to the lefthand side. Due to the greater load by weight and the smaller cross-section, the compressive stresses here are, to be sure, considerably higher than in the case of the upper cross-section.

In Fig. 10, the same can be noted for the lower cross-section CC. The compressive stress in this case [illegible]ls towards the right: it is still higher than in the

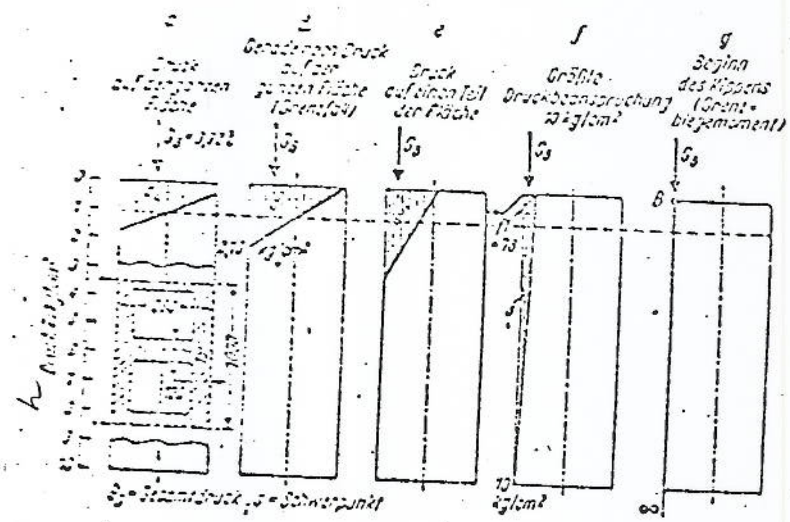


Fig. 9. Change in the composite stress in the central part of a vertical section of a coke oven wall upon increase of the load by the chamber charge.
G_B = total pressure; S = center of gravity
c. compression on the entire area
d. compression just still present over the entire area (limit case)
e. compression on a part of the area
f. maximum compressive stress 10 kg/cm^2
g. commencement of tipping (limit bending moment)
h. compression in kg/cm^2

central cross-section. Under f it can be noted that at the maximum compressive stress in the righthand outer fiber of 10 kg/cm^2 there still participates in the transmission of the pressure an area of the width fl = 108 mm, the compressive stress increasing from the inside to the outside from 0 to 10 kg/cm^2. Since the wall stretchers in the example in question are more than 108 mm thick, namely 120 mm, the headers do not, in this connection, participate in the transmission of the pressure.

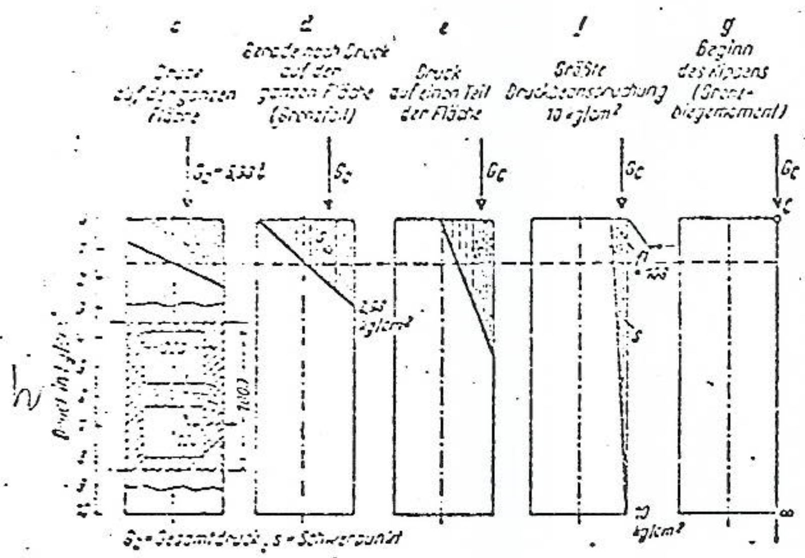


Fig. 10. Change in the composite stress in the lower part of a vertical section of a coke oven wall upon increase of the load by the chamber charge.

G_C = total pressure; S = center of gravity
c. compression on the entire area
d. compression just still present over the entire area (limit case)
e. compression on one part of the area
f. maximum compressive stress 10 kg/cm^2
g. commencement of tipping (limit bending moment)
h. compression in kg/cm^2

In Figs. 8, 9 and 10, the compressive stresses for given bending moments caused by the loading resulting from the chamber charge are shown for the upper cross-section AA, the middle cross-section BB and the lower cross-section CC of the vertical section of a coke oven wall. Particularly important cases were in this connection the case d in which pressure still prevailed over the entire area, the case f in which the greatest compressive stress was 10 kg/cm^2 and case g in which the limit bending moment was reached. The bending moment transferable by the wall section was calculated for these special cases and plotted in Fig. 11 as a function of the height of the section.

Customarily for calculation of flexure, there is taken as basis case d in which there is still sufficient pressure on the entire surface of the area. The transferable bending moment would then amount to $M = W \cdot \sigma$, in which connection W is the moment of resistance in cm^3 and σ is the bending stress in kg/cm^2; this would in case d be equal to the pressure stress by the dead weight. Since the pressure stress by the dead weight in the coke oven wall is, however, very small (see pages 397/98), the transmittable bending moment resulting therefrom will also be relatively small. This would lead to very low heights of chambers. Operational experience has shown that in the case of coke oven walls, one need not effect such a careful calculation and that one can readily take as basis case f if certain conditions with respect to the mortar - which conditions will be taken up in further detail in Part II - are maintained. Between the case f having a maximum stress of 10 kg/cm^2 and case g having an infinitely high stress of the bricks, the difference in transmittable bending moment, however, is only relatively slight. Therefore no great error will be made if, for the sake of simplicity, the limit bending moment in accordance with case g is provisionally taken as basis for the further calculations and the result then correspondingly corrected. The limit bending moment is found in simple manner to be $\frac{b \cdot G}{2}$, in which b is the wall thickness and G is the dead weight of the wall including oven roof down to the cross-section under consideration.

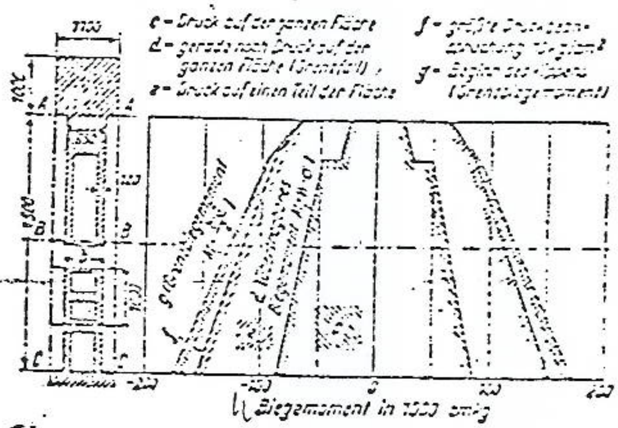


Fig. 11. Bending moment transmittable by a vertical section of a coke oven wall in different stressing cases.

c. pressure on the entire surface
d. pressure just still present over the entire surface (limit case)
e. pressure on a part of the surface
f. maximum compressive stress 10 kg/cm^2
g. start of the tipping (limit bending moment)
h. bending moment in 1000 cm-kg
i. g (limit bending moment $M = \frac{b \cdot G}{2}$)
j. d (transmittable bending moment $M_1 = W \cdot \sigma$)

In Fig. 12 there can again be noted the limit bending moment which represents the extreme limit of the bending moment which can theoretically be transmitted. There are furthermore shown in the figure the bending-moment curves which represent the bending moment which actually occurs for special cases. Curve 1 represents the bending-moment

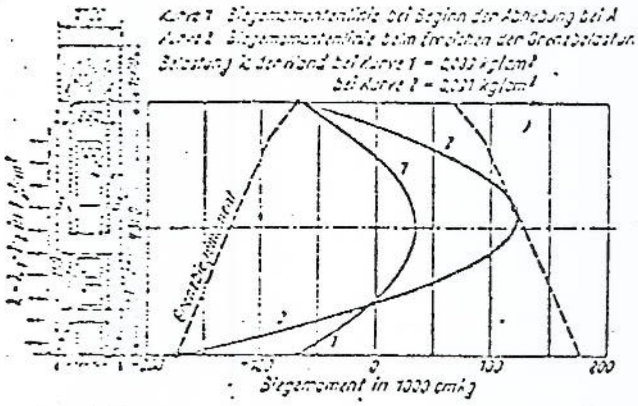


Fig. 12. Change of the bending moments in a vertical section of a coke oven wall upon increasing the loading by the chamber charge.

a. Curve 1: bending moment curve at the start of the lifting at A
b. Curve 2: bending moment curve upon reaching the limit loading
c. Loading k of the wall for curve 1=0.039 kg/cm^2
   for curve 2=0.091 kg/cm^2
d. Bending moment in 1000 cm-kg
e. Limit bending moment

curve for the case that the limit bending moment in the cross-section AA' of the section of the coke oven wall is just reached. It corresponds to case 3 in Fig. 5, which covers beams fixed on both sides. The loading in this case is k = 0.039 kg/cm^2. The weight of the oven roof is - at least theoretically - still transmitted only at the point A to the coke oven wall, so that the compressive stress here is infinitely high. If the loading is further increased by the chamber charge, then the layers lift off at A' and a small crack is necessarily formed.

Curve 2 represents the bending-moment curve in the event that the limit bending moment is reached also in the cross-sections BB' and CC' of the section of the coke oven wall. It corresponds to case 3 of Fig. 5 in which the two clampings can take up only a part of the bending moment (not shown in Fig. 5). The weight of the oven roof is in this case transmitted at point A (as in curve 1), the weight of the oven roof and of the upper part of the chamber wall at point B, and the weight of the oven roof and of the chamber wall at point C. The compressive stresses at points A, B and C are in this connection infinitely high. Upon further increase in the load, the section of the coke oven wall breaks through, in which connection it gapes apart at the points A', B' and C'. The limit loading has been reached. For the wall section under consideration which has a height of 4.5 m, this occurs upon a loading of $k = 0.097$ kg/cm^2

Comparison of the Calculated Limit Load
With the Experimental Results

This limit load of the vertical coke oven wall section in question by the chamber charge was determined purely theoretically to be 0.097 kg/cm^2. Note should be taken of a comparison with experiments on such a vertical wall section which were carried out already a long time ago and on which H. Koppers and A. Jenkner have reported[1]. The experimental set-up is shown schematically in Fig. 13.

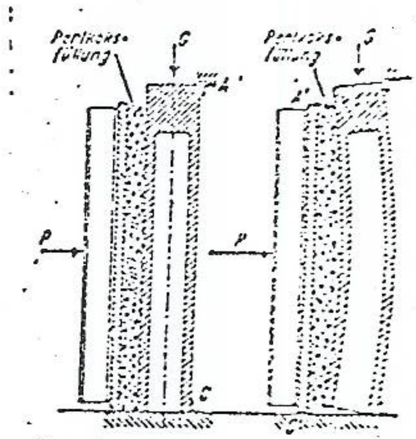
1) Gluckauf 67 (1931), pages 353/62.

The section of the coke oven wall has a height of 4.5 m and a length of 2 m; other dimensions are not indicated. From the picture contained in the report, it can be noted, however, that the outer dimensions do not differ essentially from those of the above-calculated section. The conditions during the experiment, to be sure, did not entirely correspond to conditions in the coke oven for the following reasons:

1. The weight of the oven roof was replaced by weights. Insofar as can be noted from the experimental arrangement indicated in the report of H. Koppers and A. Jenkner, these weights cannot take up any bending moment as the continuous roof of a coke oven can. This means that instead of load case 3 of the beam fixed on both sides shown in Fig. 5, we have load case 2 of a beam which is fixed on one side (bottom) and rests loosely on the other side (top).

2. It is not indicated whether in the tests attention was paid to the accurate position of the center of gravity of the loading weights applied. As will be shown further below, this is of essential importance for the experimental results.

3. The load on the section of the coke oven wall is transmitted by a charge of pea coke. As long as the wall does not flex, the load in this connection may be approximately the same over the entire wall surface. As soon as the wall, however, flexes noticeably under load - the test



- Fig. 13. Diagram of the experimental set-up of H. Koppers for the determination of the lateral limit load of a section of a coke oven wall.
  a. pea coke charge

was carried out with a thickness of a layer of pea coke of approximately 250 mm up to a flexing of more than 50 mm - the loading of the wall surface is no longer uniform, as was

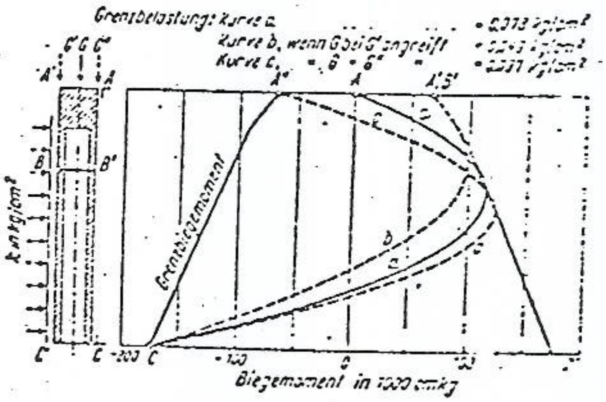


Fig. 14. Theoretical determination of the limit load of a vertical section of a coke oven wall in the experimental set-up of H. Koppers.

a. limit load: curve a =0.078 kg/cm
curve b when G acts at G'=0.049 kg/cm
curve c " G " " =0.097 kg/cm

b. bending moment in 1000 cm-kg

c. limit bending moment

assumed in the calculation, but is greater at the ends A' and C' than in the center.

In Fig. 14 there is shown the theoretical determination of the limit load of the wall section in the experimental set-up of H. Koppers. The fact that no bending moment can be transferred by the oven roof leads to the bending moment in the cross-section AA' being equal to zero. The solid line curve a shows the bending-moment curve for the event that the limit bending moment in the cross-sections BB' and CC' of the section of the coke oven wall is reached. The load k is in this connection 0.078 kg/cm^2.

When the load is increased further, a crack must form at B'. H. Koppers and A. Jenkner in their report state in their test the first crack occurred at a load of 0.09 kg/cm^2.

In Fig. 14 there is shown, in addition to the curve a, also the dashed line curves b and c which apply to the case that the center of gravity of the loading weights applied instead of the roof load lies not over the center of the section of the coke oven wall but over its left or righthand outer corner. In this case, the limit load k is 0.049 or 0.097 kg/cm^2. In the same experimental set-up, H. Koppers checked in the same manner also a solid-wall section as to its limit load. In Fig. 15 there is shown the theoretical determination of the limit load of the section of a solid wall. The curve a shows the bending-moment curve in the event that the limit bending moment is reached in the cross-sections BB' and CC' of the solid wall section. The load k is in this case 0.094 kg/cm². H. Koppers and A. Jenkner in their report state that in the case of the solid wall section, the first crack was noted at a load of 0.09 kg/cm².

Curves b and c of Fig. 15 apply in the event that the center of gravity of the weights applied instead of the roof load does not lie over the center of the solid wall section but rather over the lefthand or righthand outer corner. In this case, the limit load k is 0.050 or 0.117 kg/cm².

The differences between the theoretically and actually determined limit loads k in kg/cm² are relatively

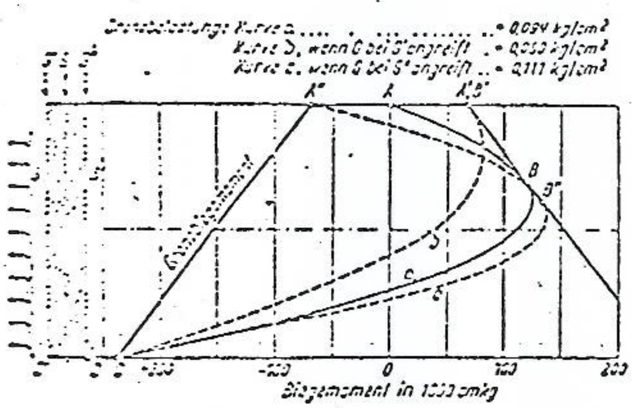


FIGURE 15 - Theoretical determination of the limit load of a solid wall section in the experiments of H. Koppers
a - limit load: Curve a .....
Curve b, when G attacks at G'
Curve c, when G attacks at G"
b - limit bending moment
c - bending moment in 1000 cm-kg

slight. They are set forth below once again, the values within parentheses applying when the center of gravity of the applied loading weights lies above the outermost lefthand or righthand corner of the wall section.

	Coke Oven Wall Section	Solid Wall Section
	Limit Load in kg/cm^2	
theoretical (calculation)	(0.049) 0.078 (0.097)	(0.050) 0.094 (0.117)
Actual (test)	0.09	0.09

The slight differences can be ascribed to a greater or lesser arbitrariness in the position of the center of gravity of the applied loading weights to a not entirely uniform transmission of the load by the pea coke filling on the wall surface or to various accidental occurrences in the test. Perhaps the mortar in the case of the test walls had bonded somewhat to the bricks, so that, in contradistinction to the assumption made in the calculation, a relatively strong tensile stress could be taken up.

Calculation of the Limit Load of a Horizontal Wall Section

It having been found that the theoretical and experimental determination of the limit load of a vertical section of a coke oven wall gives values which show relatively good agreement, there shall now be taken up the case of the limit load in a horizontal 1-m high coke oven wall section. In this case also, in the same way as in the case of the vertical wall section, there occurs a composite stress made up of compression and flexure. The compressive stress is produced by the anchoring and the bending stress as a result of the loading by the chamber charge. If the compressive stress due to the anchoring is to amount, as assumed above, to, for instance, 1.00 kg/cm², then the buckstays in the case of the section of the coke oven wall under consideration having a thickness of stretcher of 120 mm must exert a pressure of A = 2.4 t/m of wall height on the wall. The limit bending moment which can be transmitted by the horizontal 1-m high wall section with a wall thickness of 650 mm results then, in the same manner as employed above in the case of the vertical 1-m long wall section as

$$\frac{b \cdot A}{2} = \frac{65 \cdot 2400}{2} = 78{,}000 \text{ cm-kg.}$$

The limit load of the horizontal 1-m high coke oven wall section is obtained as follows: Corresponding to the three cases of loading shown in Fig. 5, there is concerned in the case of the horizontal wall section a beam lying loose at both sides in accordance with case 1 of the said figure, since no bending moment around their vertical axis can be taken up by the buckstays. For the beam which lies loose on both sides, the maximum bending moment, which occurs in the center of the beam, is:

$$M_{max} = \frac{k \cdot b \cdot l^2}{8} \text{ cm-kg}$$

in which k is the load in kg/cm^2, and b the height and l the length of the coke oven wall section. This maximum bending moment M_{max}, upon increase in the load, becomes in the limit case equal to the above-indicated limit bending moment (78,000 cm-kg). The limit load k can be calculated by solving the equation for k. For the 1-m high coke oven wall section under consideration, it is found to be for a length of l = 13.5 m

$$k = \frac{8M_{max}}{b \cdot l^2} = \frac{8 \cdot 78,000}{100 \cdot 1350^2} = 0.0034 \ kg/cm^2$$

Limit Load of a Coke Oven Wall

It was found that the limit load in the case of the vertical 1-m wide coke oven wall section is 0.097 kg/cm^2 and in the case of the horizontal 1-m high coke oven wall section 0.0034 kg/cm^2. The limit load therefore in the case of the horizontal coke oven wall section is only about 3.5% that of the vertical coke oven wall section, which is due to the fact that the horizontal wall section must be considered as lying loosely at its two ends and the length l the square of which is contained in the equation, is very much greater in the case of the horizontal coke oven wall section.

The limit load of the horizontal coke oven wall section could in itself be increased by increasing the pressure of the buckstays. Upon an increase to twice the amount, the limit load would also be doubled. However, even with this very high pressure of the buckstays, the limit load of the horizontal coke oven wall section is only about 7% that of the vertical wall section. It is therefore still extremely small.

The flexure, under the same load, is several times greater in the case of the horizontal wall section due to the lack of the clamping at the ends and the greater length than in the case of the vertical wall section (compare in Fig. 5 the elastic curve of case 1 with that of case 3). If the vertical and horizontal wall sections are not considered individually, but if the entire coke oven wall is considered as a single unit, then the flexure must be the same in both cases. This means that the greatest flexure and thus also the limit load is not reached by far in the case of the horizontal coke oven wall section, so that within the coke oven wall it has to withstand, as compared with the vertical wall section, even substantially less than 3.5 or 7% of the load. The limit load of the entire coke oven wall is therefore approximately as great as that of the vertical coke oven wall section.

In the above comments, to be sure, a vertical wall section was considered from the center of the chamber wall. Due to the taper of the chambers, the chamber walls, however, are thicker on the machine side and thinner on the coke side than in the center. The limit load is accordingly greater on the machine side and smaller on the coke side than in the center. With a taper of 60 mm, the limit load of the coke oven wall in question of a height of 4.5 m would be

on the machine side	0.102 kg/cm^2
in the center	0.097 kg/cm^2 and
on the coke side	0.090 kg/cm^2

Shear Stress in a Coke Oven Wall

It has already been mentioned that the difference from the loading of the coke oven wall by the lefthand and righthand chamber fillings ($k = k_1 - k_2$) leads not only to the flexural stressing discussed, but also to a shear stressing in the coke oven wall. The shear stress is brought about by the transverse force which results from the lateral loading by the chamber charge and the lateral bearing pressures on top and on bott m. In Fig. 16 this has been shown for the case of the limit load on the above-mentioned vertical 1-m long coke oven wall section of a height of 4.5 m. The lateral load k is counter-balanced by the lateral bearing pressures A and C.

The transverse force in any desired cross-section at a distance x from the floor of the oven in the case of a width b of the wall section is $Q_x = C - x \cdot b \cdot k$. The dependence of the transverse force on the height is represented by the transverse force curve. It may be pointed out in this connection that the upper bearing pressure A, as a result of the lack of load k in the region of the gas

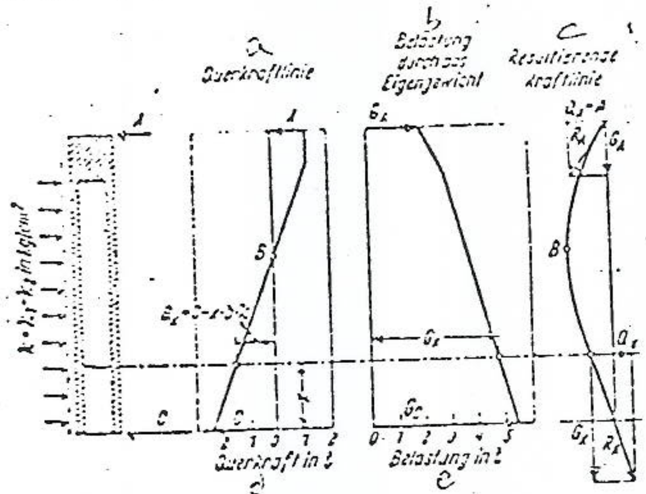


Fig. 16. Transverse force, dead weight, and resultant force curve in a ʿvertical section of a coke oven wall upon limit loading.

a. transverse force curve
b. loading by the dead weight
c. resultant force force
d. transverse force in tons
e. load in tons

collecting space and in particular as a result of the lower bending moment transmitted at A (cf. dotted transverse force curve in Fig. 5; case 3) is less than the lower lateral bearing pressure C.

From the transverse force, the shear stress can be calculated in accordance with the equation

$$\tau = \frac{Q}{F}$$

For the limit load in the cross-section it amounts to 0.2 kg/cm^2 at A, 0 kg/cm^2 at B and 0.7 kg/cm^2 at C.

... In Fig. 16, in addition to the transverse-force curve, there is also shown the dead weight as a function of the height. The direction of loading has, in this connection, to be sure, been plotted towards the right rather than downwards. The transverse force together with the dead weight forms a resultant force whose direction results from the parallelogram of forces. For the upper cross-section at A, it can be noted to the top right in the figure. G_A is the dead weight, $Q_A = A$ is the transverse force, and R_A is the resultant force in value and direction. If the resultant forces R_x are placed one alongside the other, there is then obtained the resultant force curve which can be noted to the right in Fig. 16.

Summary

For a coke oven wall of a height of 4.5 m, the compressive stresses due to the dead weight, the anchoring and the chamber charge were first of all calculated. Thereupon the flexural stress caused by the chamber charge and the composite stressing by pressure and flexure were discussed with resp to a vertical coke oven wall section. From this, the limit load - i.e., the highest possible lateral loading of the coke oven wall section - was derived. This calculated limit load was compared with values determined experimentally by H. Koppers and A. Jenkner, good agreement being found. From the limit load of the vertical coke oven wall section, the limit load of the coke oven wall itself was then derived. Finally the shear stress in the coke oven wall was also calculated.

The stresses and loads determined are compiled once again below:

TRANSLATION

from:

1. Compressive stress in the bricks

a. by the deadweight

top	0.32 kg/cm^2
center	1.08 kg/cm^2
bottom	1.48 kg/cm^2

greatest compressive stress
(with full charging cars) 5.0 kg/cm^2

b. by the anchoring about 1.00 kg/cm^2

c. by the chamber charge

minimum	0.1 kg/cm^2
maximum	0.5 kg/cm^2

2. Limit load on the wall by the chamber charge 0.09 kg/cm^3

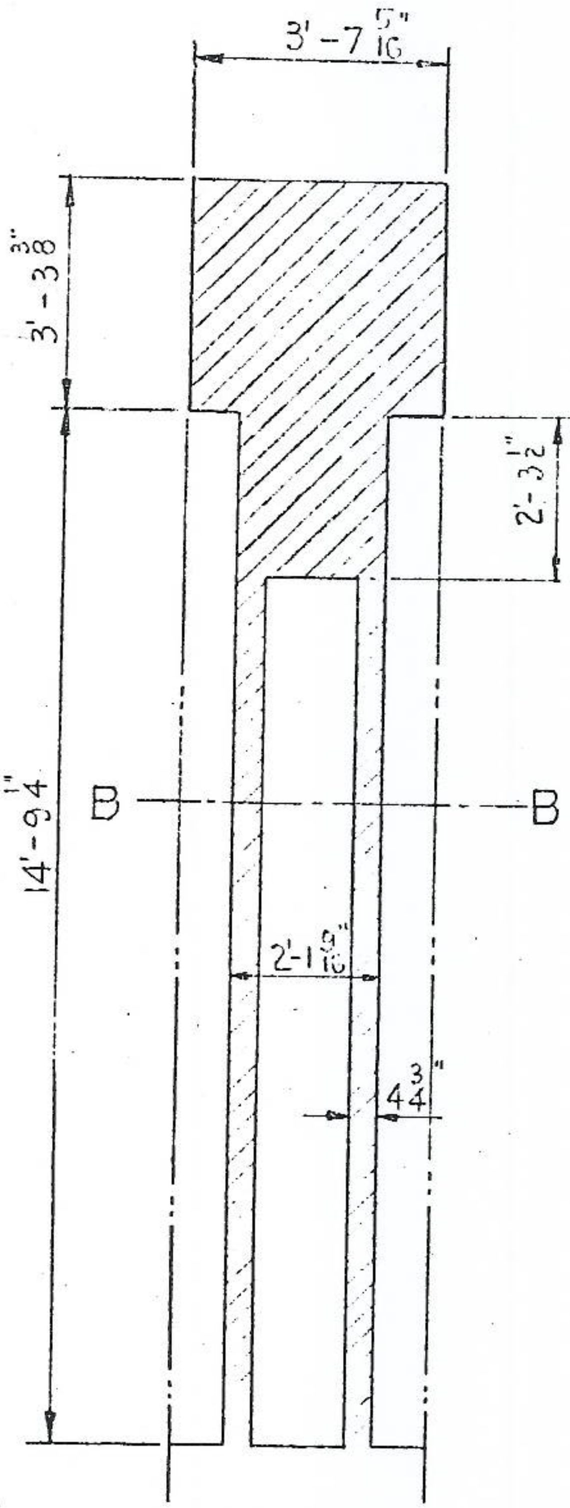
3. Shear stress in the bricks (upon limit loading by the chamber charge)

top	0.2 kg/cm^2
center	0.0 kg/cm^2
bottom	0.7 kg/cm^2

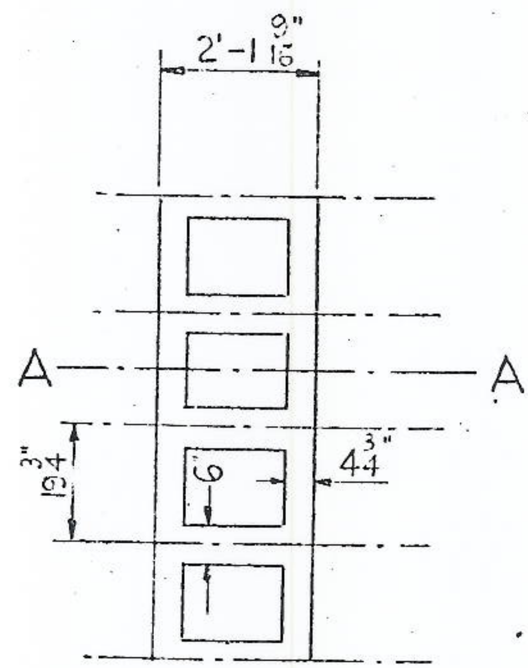
From this compilation, it can be noted that the pure compressive stresses due to the dead weight, the anchoring and the chamber charge are relatively low. They cannot by themselves lead to any endangering of the coke oven walls. The maximum compressive stress indicated of 5.0 kg/cm^2 applies in case of additional loading by a heavy four-wheel coal-filled charging car with point transfer of the wheel pressures to the oven roof. It is substantially less in the case of a filling charging car having eight wheels which are distributed as uniformly as possible and with sufficiently stable rails.

In contradistinction to the compressive stressing, the flexural stressing coming from the lateral pressure of the chamber charge on the coke oven wall can easily reach very high values - up to infinitely high. The wall then breaks through even if the bricks could withstand the infinitely high stresses occurring at points A, B and C (Fig. 12). It cracks in this connection at the points A', B' and C' (Fig. 12). This destruction occurs, in the case of the coke oven wall of a height of 4.5 m under consideration, already with a limit load of 0.09 kg/cm^2.

The shear stress which - in the same way as the flexural stress - comes from the lateral pressure of the chamber charge on the coke oven wall is relatively small even when the limit loading by the chamber charge has already been reached, and it is not dangerous for the coke oven wall.



SECTION A-A



SECTION B-B

DIMENSIONS OF A COKE OVEN WALL

REVISION		DRAWN	DATE
BY	DATE	A. Z	5-3-68
		C'HK'D	SCALE

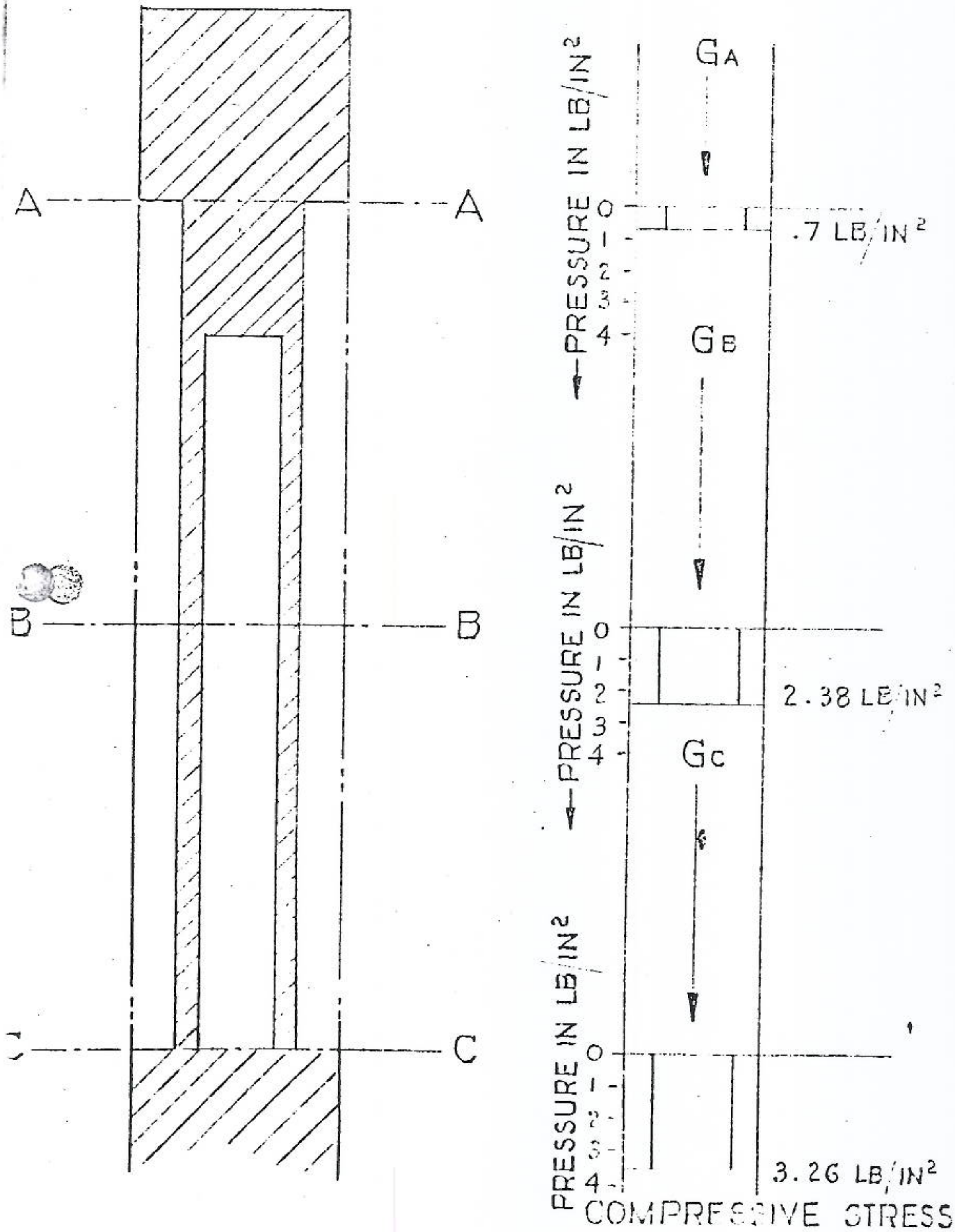
WILPUTTE COKE OVEN DIVISION

Allied Chemical Corporation

COKE OVENS AND COAL CHEMICALS PLANTS

LIMIT LOAD OF COKE OVEN WALLS

SK-9051-L



$$P = \frac{G}{F} \ LB/IN^2$$

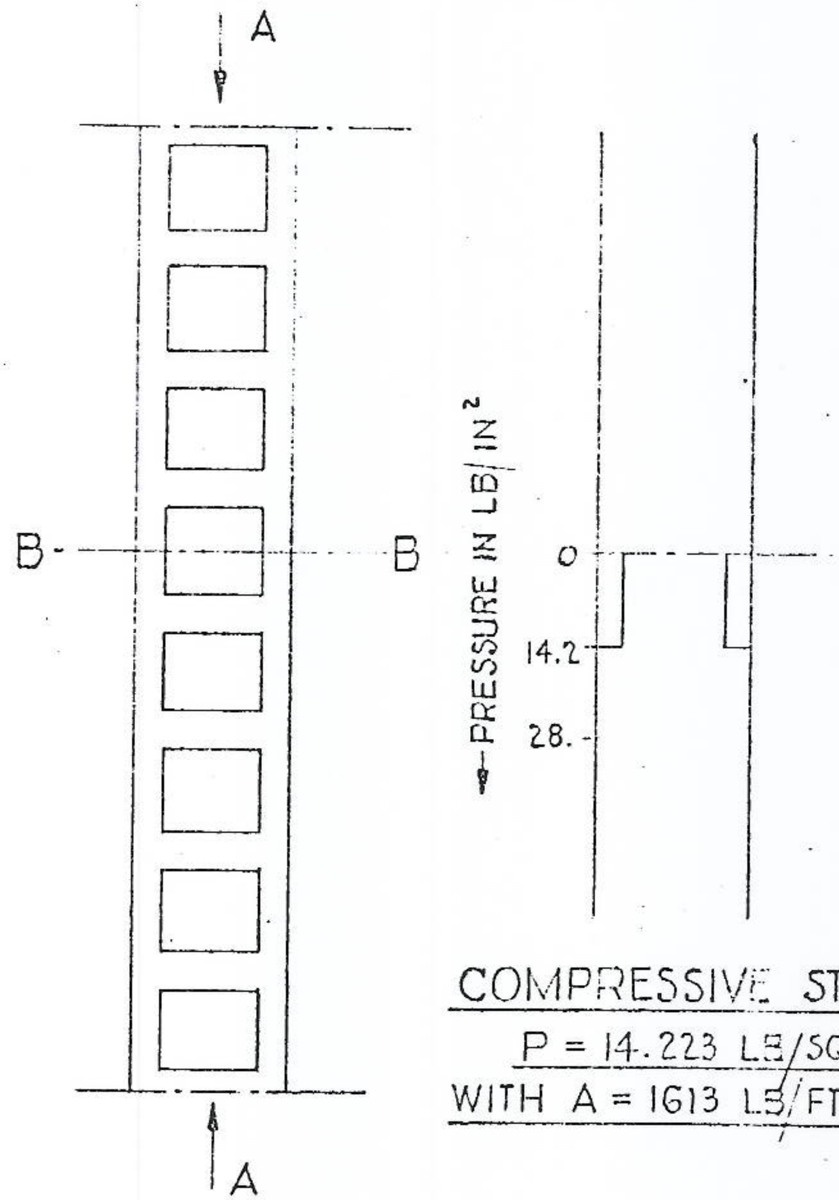
COMPRESSIVE STRESS OF A COKE OVEN WALL BY THE DEAD WEIGHT

WILPUTTE COKE OVEN DIVISION
CORE OVENS AND COAL CHEMICALS PLANTS

REVISION			DRAWN	DATE
	BY	DATE	A.Z.	5-3-68
1			C'HK'D	SCALE
2				NONE

LIMIT LOAD OF COKE OVEN WALLS
FIG. 2

SK-9052-L



COMPRESSIVE STRESS

P = 14.223 LB/SQ.IN.

WITH A = 1613 LB/FT. OF HEIGHT

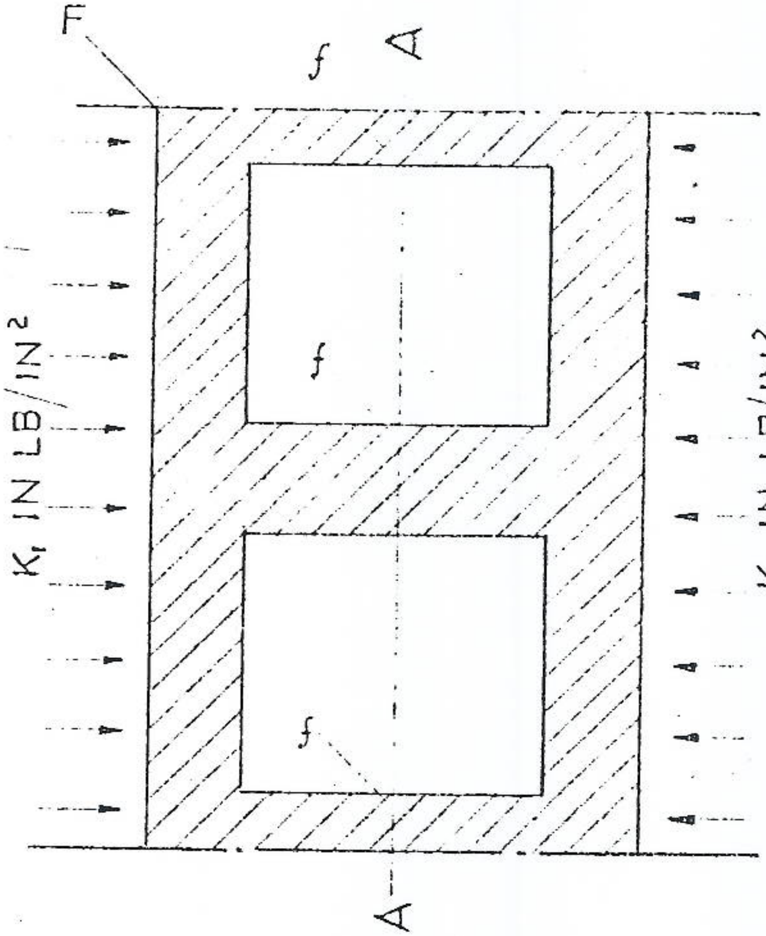
COMPRESSIVE STRESS OF A COKE OVEN WALL BY THE ANCHORING

LIMIT LOAD OF COKE OVEN WALLS

DRAWN A.Z. DATE 5-3-68

REVISION BY DATE

WILPUTTE COKE OVEN DIVISION



COMPRESSIVE STRESSING IN THE HEADERS:

CASE 1 $(K_1 = K_2)$: $P = K_1 \cdot \frac{F}{f}$ IN LB/IN²

CASE 2 $(K_1 > K_2)$: $P = K_2 \cdot \frac{F}{f}$ IN LB/IN²

P NORMAL = 1.42 TO 6.45 LB IN²

FLEXURAL STRESSING IN THE COKE OVEN WALL IN CASE 2 $(K_1 > K_2)$ BY:

$K = K_1 - K_2$ IN LB/IN²

COMPRESSIVE STRESSING OF A COKE OVEN WALL UPON LOADING BY THE CHAMBER CHARGE

LIMIT LOAD OF COKE OVEN WALLS

FIG. 4

SK-9054-L

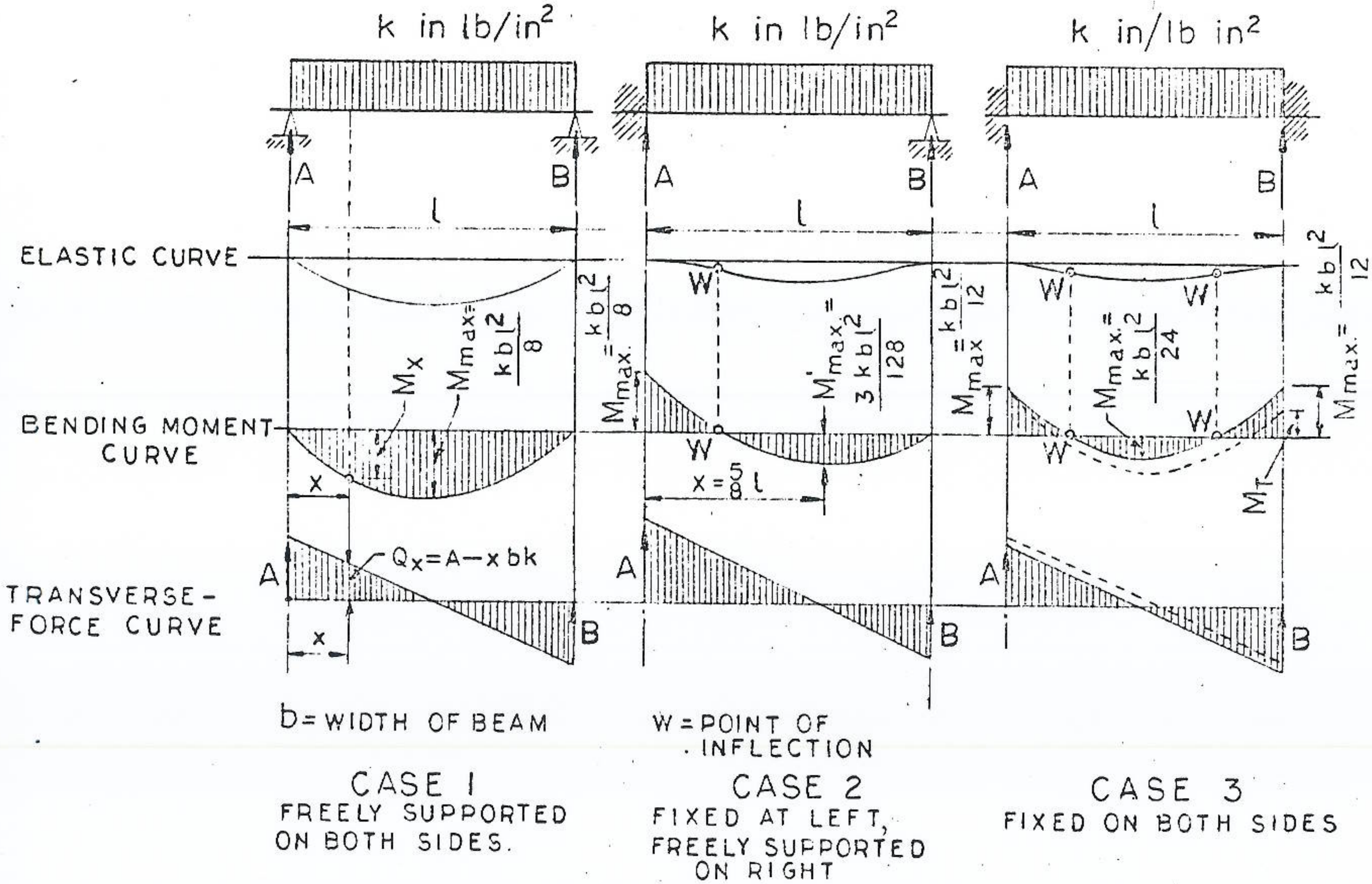
DRAWN	DATE
A.Z.	5-3-68
C'HK'D	SCALE
	NONE

REVISION	BY	DATE
1		
2		

WILPUTTE Corporation

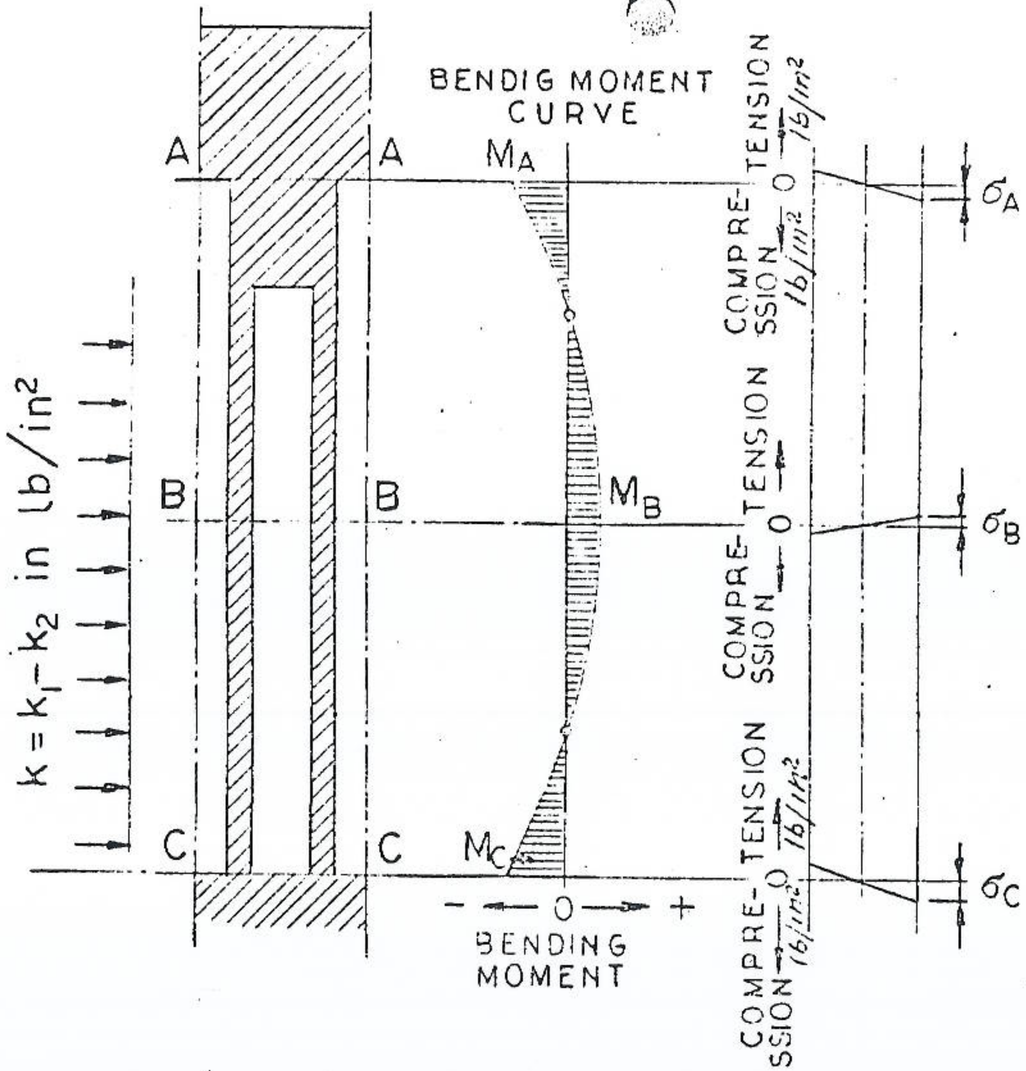
COKE OVEN DIVISION

COKE OVENS AND COAL CHEMICALS PLANTS



DIFFERENT CASES UPON THE LOADING OF A BEAM.

WILPUTTE COKE OVEN DIVISION Allied Chemical Corporation COKE OVENS AND COAL CHEMICALS PLANTS	REVISION		DRAWN	DATE		
	BY	DATE	WEL	5-3-63	LIMIT LOAD OF COKE OVEN WALLS	SK-9055 I
	1		C'HK'D	SCALE NONE		



FLEXURAL STRESS IN A VERTICAL SECTION OF A COKE OVEN WALL UPON LOADING BY THE CHAMBER CHARGE

WILPUTTE COKE OVEN DIVISION — Allied Chemical Corporation — COKE OVENS AND COAL CHEMICALS PLANTS, 40 RECTOR STREET, NEW YORK 6 N.Y.	REVISION		DRAWN	DATE	LIMIT LOAD OF COKE OVEN WALLS FIG. 6	SK-9056 L
	BY	DATE	WEL	5-3-68		
	1		C'HK'D	SCALE		
	2			NONE		

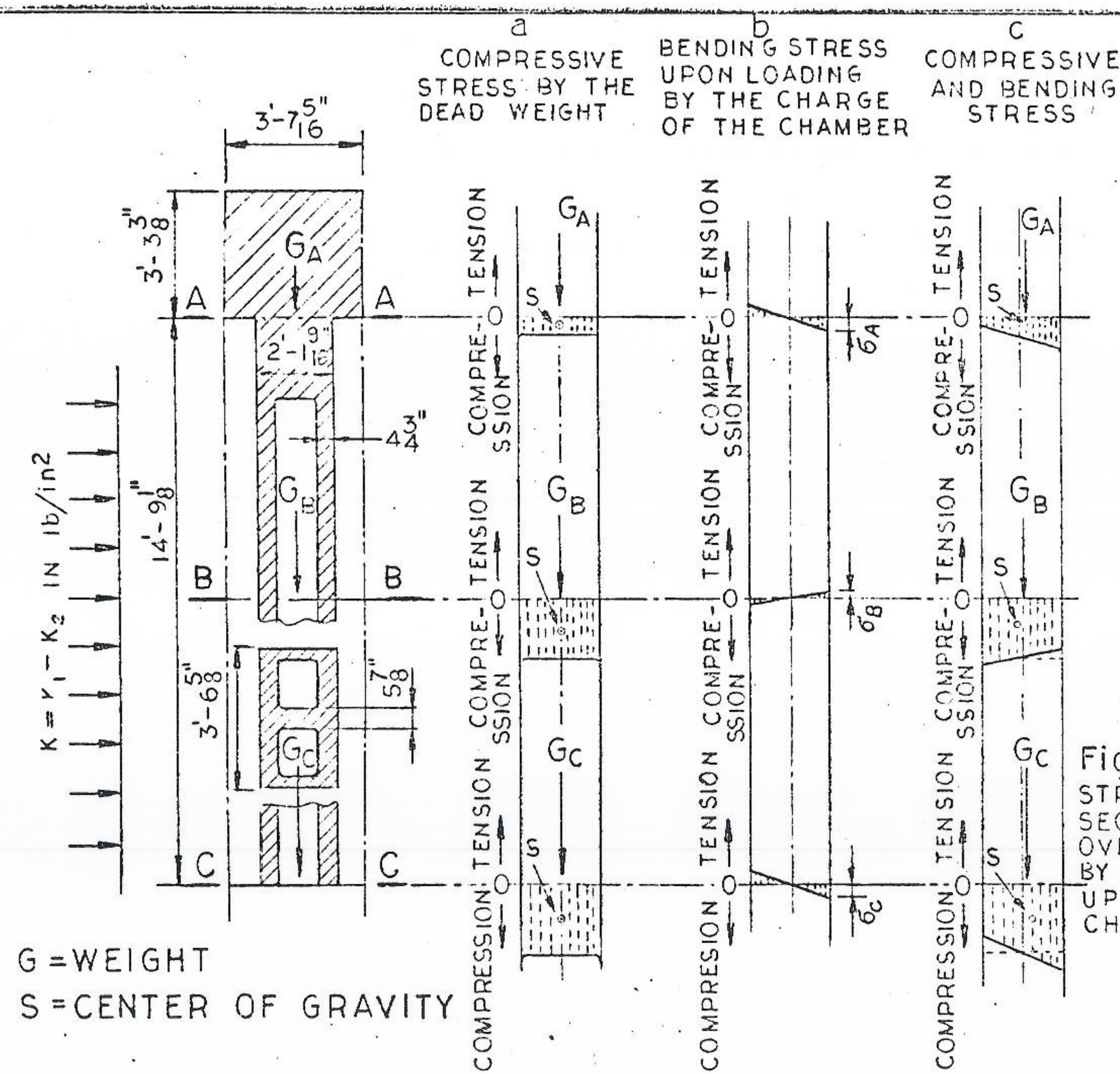
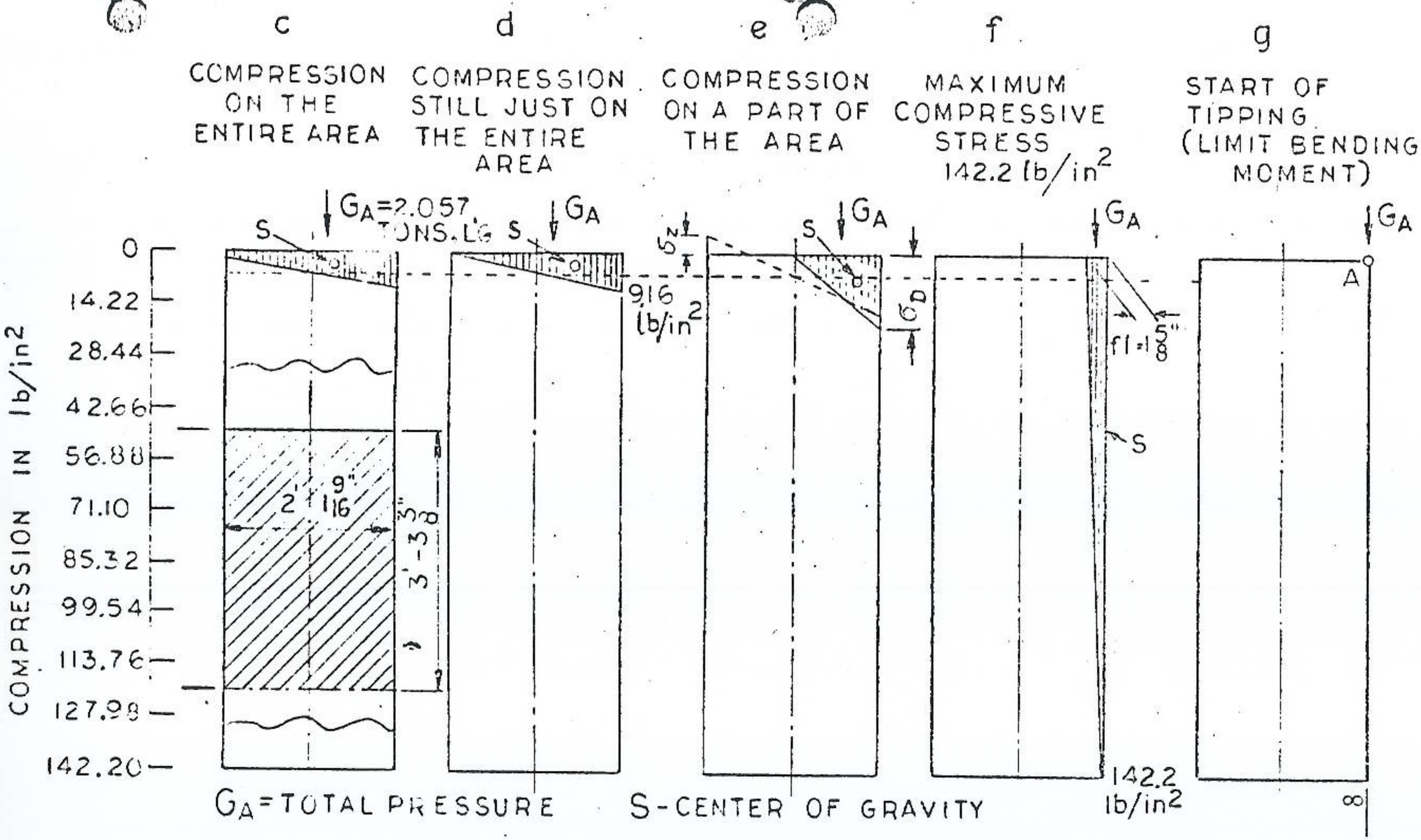


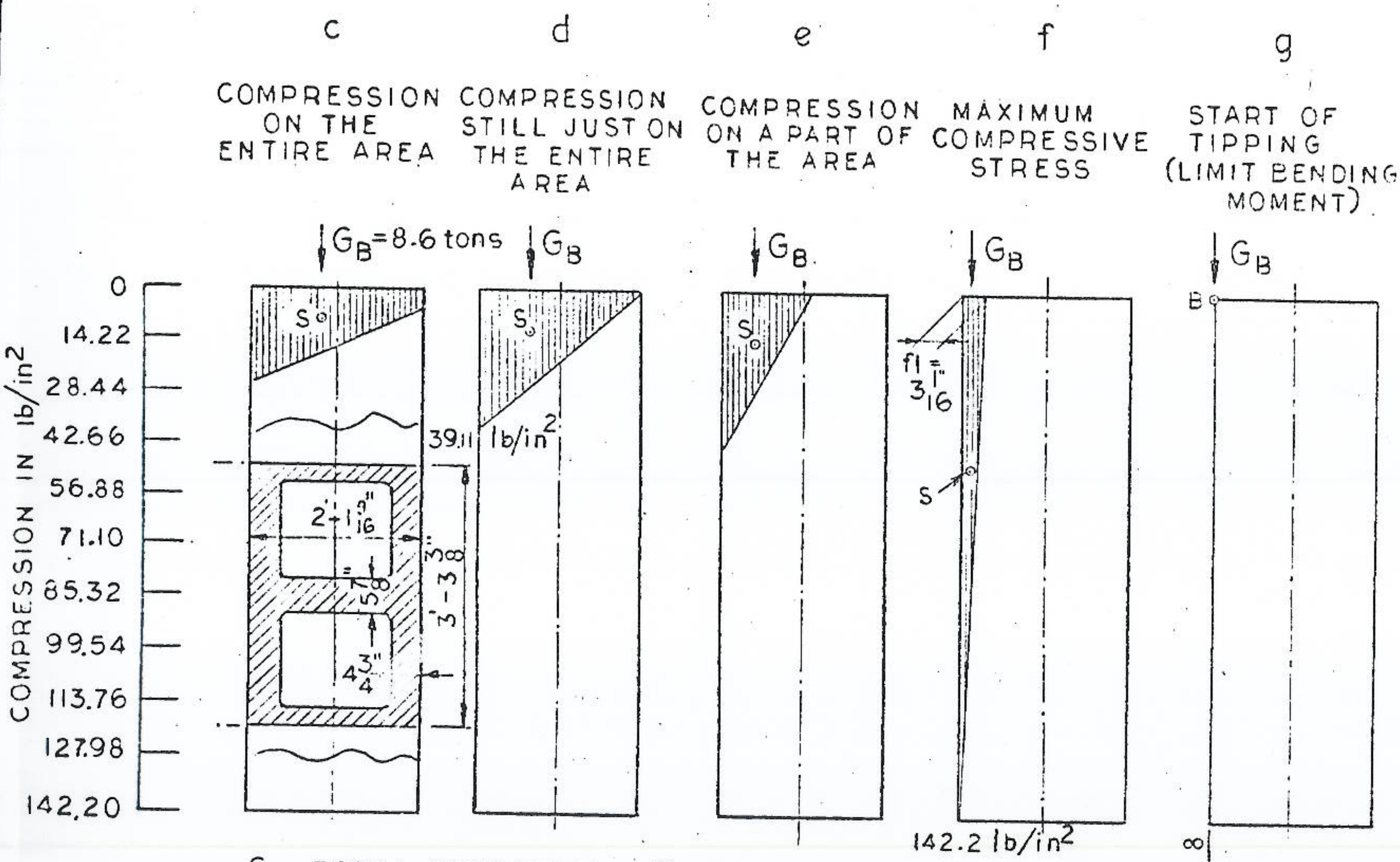
Fig. 7 COMPOSITE STRESS IN A VERTICAL SECTION OF A COKE OVEN WALL CAUSED BY THE DEAD WEIGHT AND UPON LOADING BY THE CHARGE OF THE CHAMBER

WILPUTTE COKE OVEN DIVISION — Allied Chemical Corporation — COKE OVENS AND COAL CHEMICALS PLANTS	REVISION: BY / DATE: 1	DRAWN: WEL	DATE: 5-3-68	LIMIT LOAD OF COKE OVEN WALLS FIG. 7	SK-9057 L
		C'HK'D	SCALE		



CHANGE OF THE COMPOSITE STRESS IN THE UPPER PART OF A VERTICAL SECTION OF A COKE OVEN WALL UPON INCREASING THE LOAD BY THE CHAMBER CHARGE.

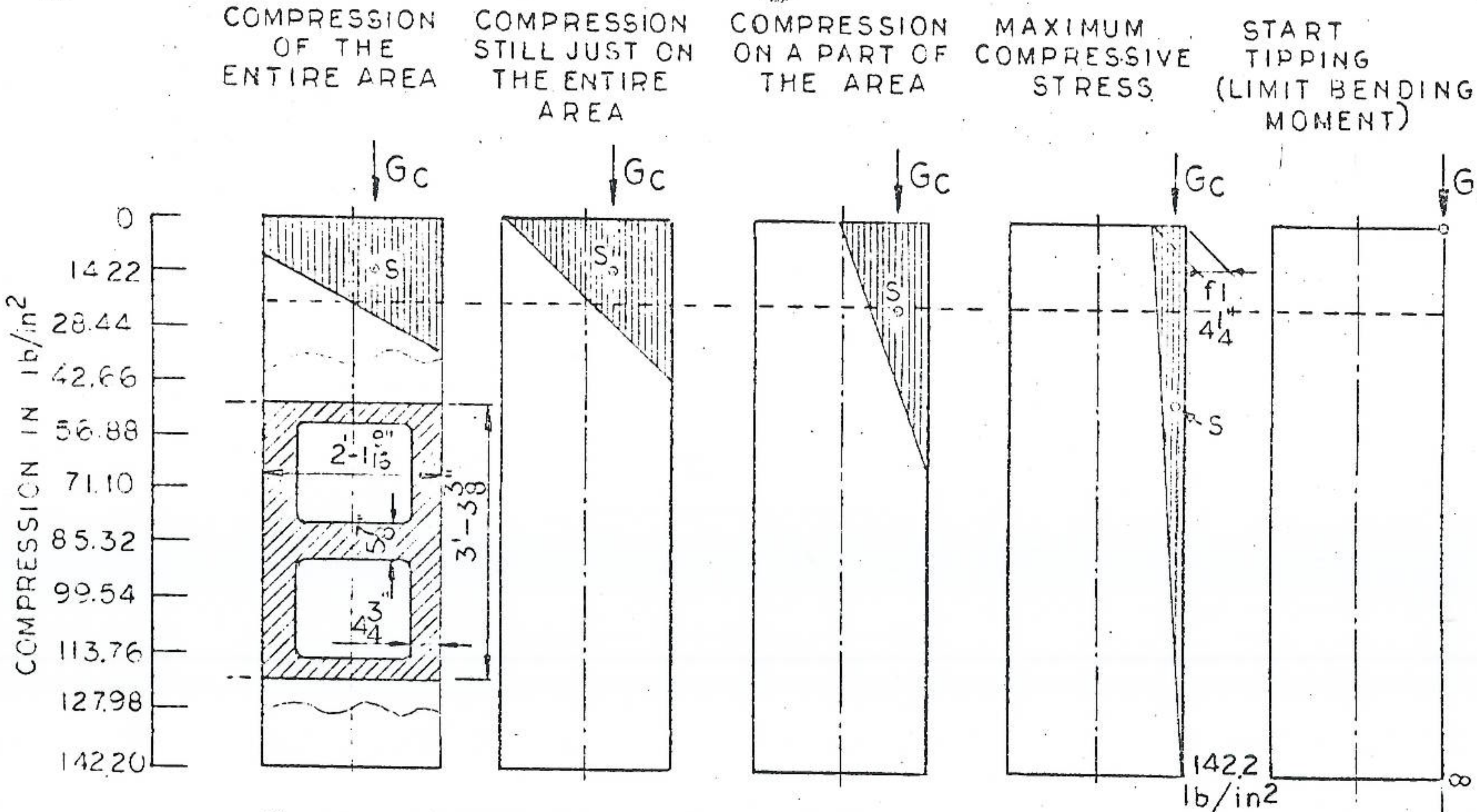
WILPUTTE COKE OVEN DIVISION, Allied Chemical Corporation — COKE OVENS AND COAL CHEMICALS PLANTS, NEW YORK N.Y.	REVISION		DRAWN	DATE	LIMIT LOAD OF COKE OVEN WALLS FIG. 8	SK-9058 L
	BY	DATE	WEL	5-3-68		
1			C'HK'D	SCALE 1/2"=1'-0"		
2						



G_A = TOTAL PRESSURE; S = CENTER OF GRAVITY

CHANGE IN THE COMPOSITE STRESS IN THE CENTRAL PART OF A VERTICAL SECTION OF A COKE OVEN WALL UPON INCREASE OF THE LOAD BY THE CHAMBER CHARGE.

WILPUTTE COKE OVEN DIVISION — Allied Chemical Corporation — COKE OVENS AND COAL CHEMICALS PLANTS	REVISION BY	DATE	DRAWN WEL	DATE 5-3-68	LIMIT LOAD OF COKE OVEN WALLS	SK-9059L
	1		C'HK'D	SCALE		

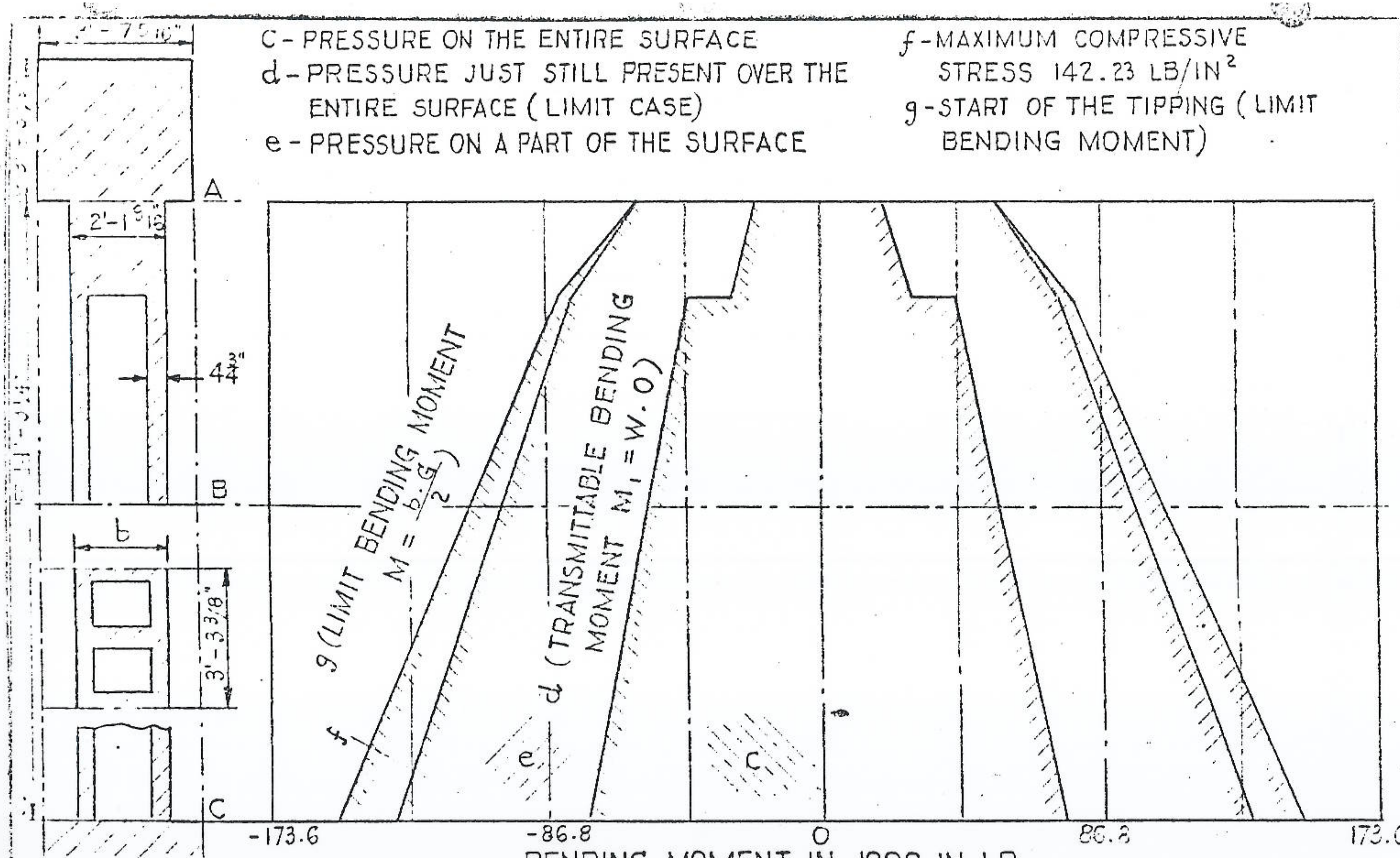


G_C = TOTAL PRESSURE   S = CENTER OF GRAVITY

CHANGE IN THE COMPOSITE STRESS IN THE CENTRAL PART OF A VERTICAL SECTION OF A COKE OVEN WALL UPON INCREASE OF THE LOAD BY THE CHAMBER CHARGE.

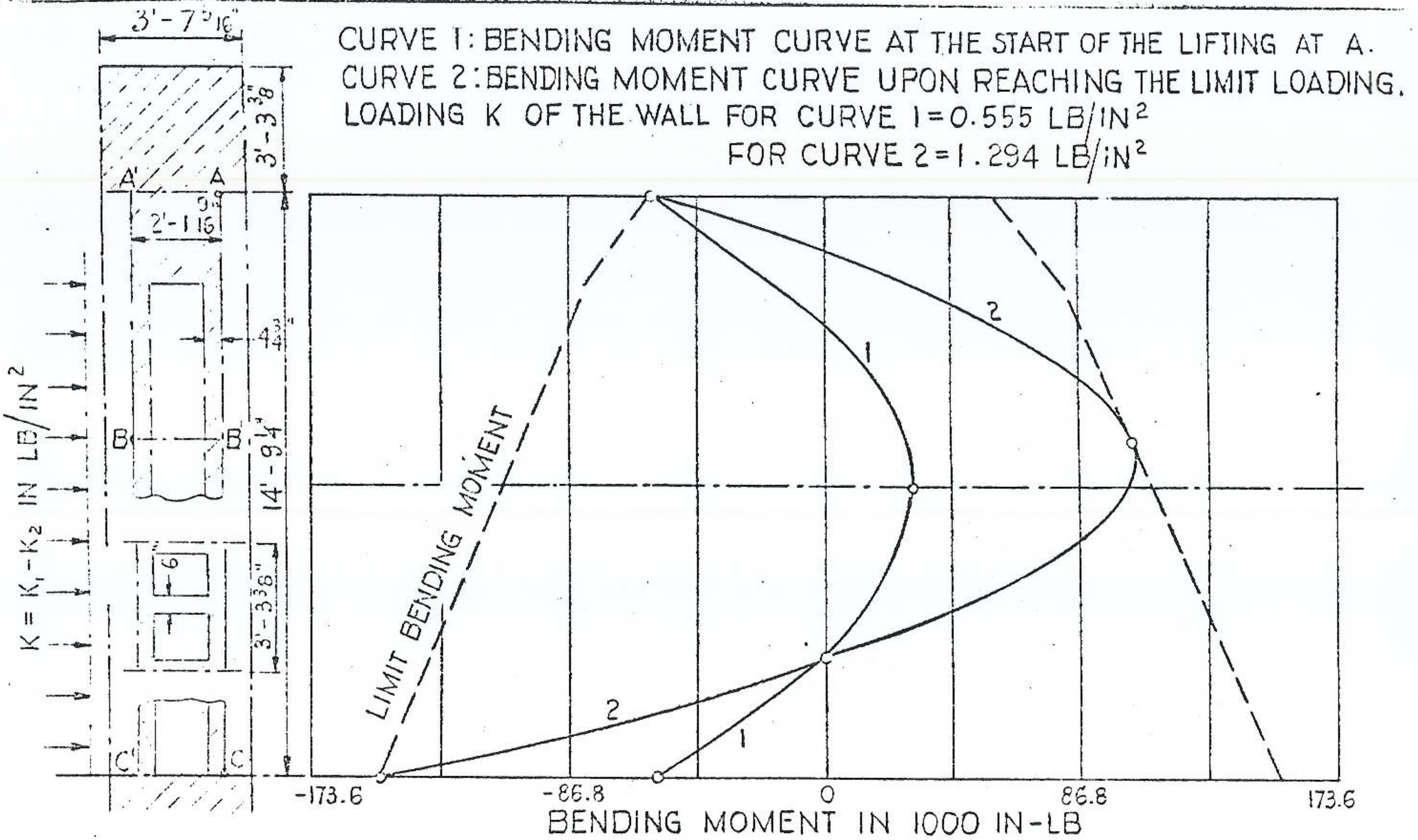
WILPUTTE COKE OVEN DIVISION, Allied Chemical Corporation — COKE OVENS AND COAL CHEMICALS PLANTS, 40 RECTOR STREET, NEW YORK 6, N.Y.	REVISION: BY / DATE (1, 2)	DRAWN: WEL	DATE: 5-3-68.	LIMIT LOAD OF COKE OVEN WALLS	SK-9060 L
		C'HK'D	SCALE: 1/2" = 1'-0"	FIG. 10	

C - PRESSURE ON THE ENTIRE SURFACE
d - PRESSURE JUST STILL PRESENT OVER THE ENTIRE SURFACE (LIMIT CASE)
e - PRESSURE ON A PART OF THE SURFACE
f - MAXIMUM COMPRESSIVE STRESS 142.23 LB/IN^2
g - START OF THE TIPPING (LIMIT BENDING MOMENT)



BENDING MOMENT TRANSMITTABLE BY A VERTICAL SECTION OF A COKE OVEN WALL IN DIFFERENT STRESSING CASES

WILPUTTE COKE OVEN DIVISION, Allied Chemical Corporation, COKE OVENS AND COAL CHEMICALS PLANTS, NEW YORK	REVISION		DRAWN A.Z.	DATE 5-3-68	LIMIT LOAD OF COKE OVEN WALLS FIG. 11	SK-9061-L
	BY	DATE	C'HK'D	SCALE NONE		
	1					
	2					



CHANGE OF THE BENDING MOMENTS IN A VERTICAL SECTION OF A COKE OVEN WALL UPON INCREASING THE LOADING BY THE CHAMBER CHARGE

WILPUTTE COKE OVEN DIVISION — Allied Chemical Corporation — COKE OVENS AND COAL CHEMICALS PLANTS, NEW YORK, N.Y.	REVISION		DRAWN A. Z.	DATE 5-3-68	LIMIT LOAD OF COKE OVEN WALLS FIG. 12	SK-9062-L
	BY	DATE	C'HK'D	SCALE NONE		
	1					
	2					

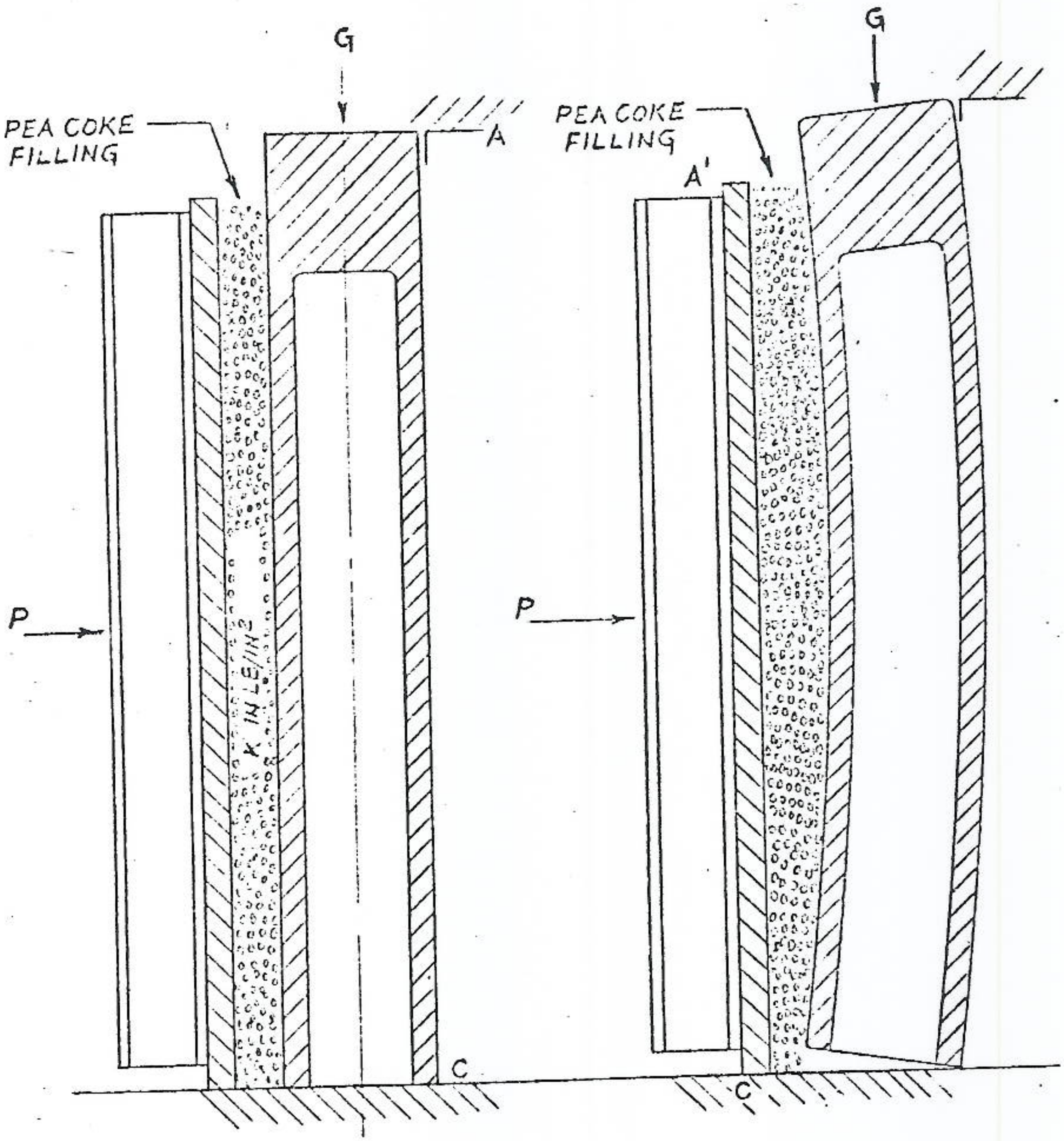


DIAGRAM OF THE EXPERIMENTAL SET-UP OF H. KOPFERS FOR THE DETERMINATION OF THE LATERAL LIMIT LOAD OF A SECTION OF A COKE OVEN WALL.

SK-9063-L

LIMIT LOAD OF COKE OVEN WALLS

FIG. 13

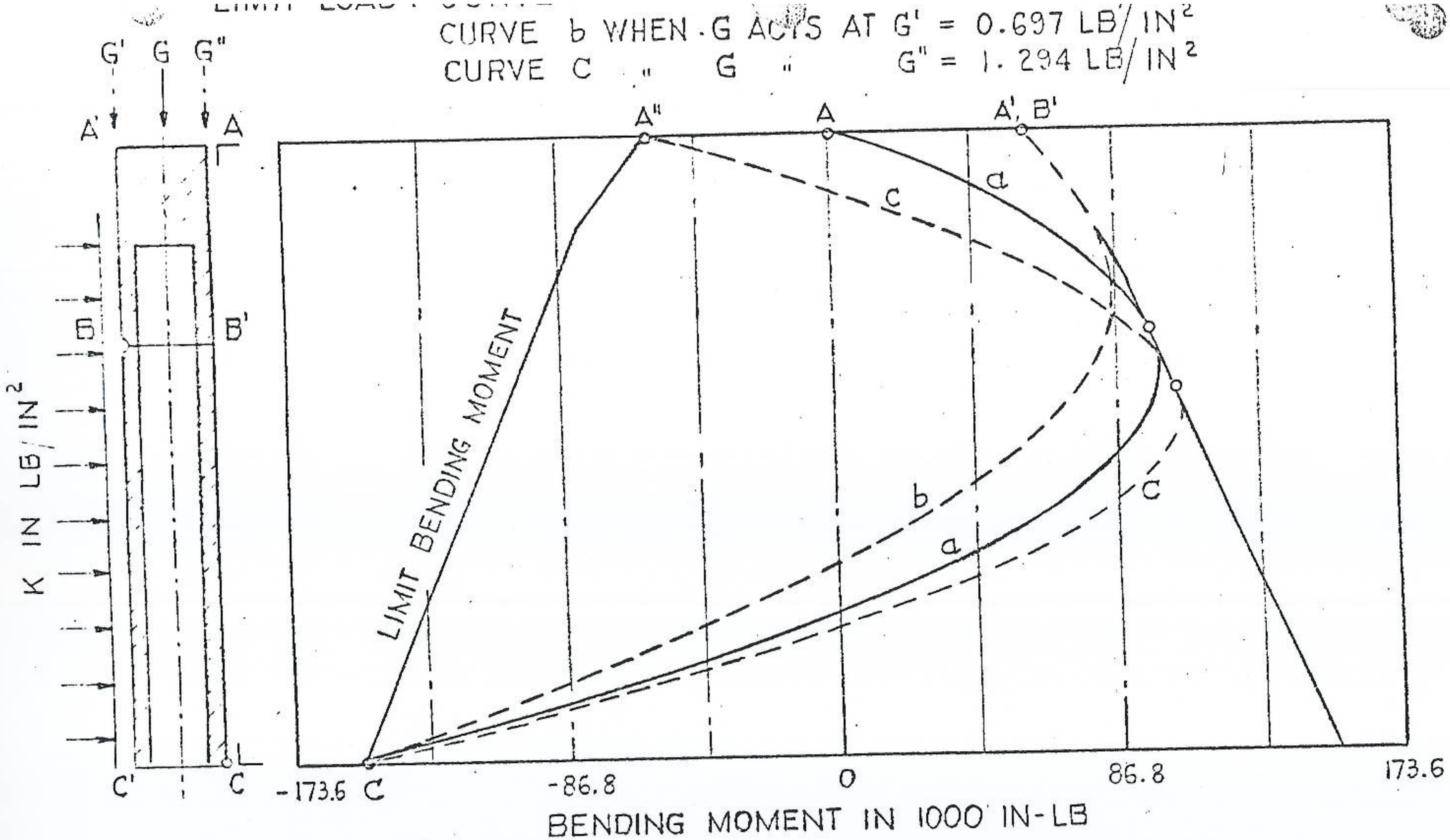
DRAWN	DATE
J.K.	5-3-68
C'HK'D	SCALE
	NONE

REVISION	BY	DATE
1		
2		

WILPUTTE COKE OVEN DIVISION

Corporation

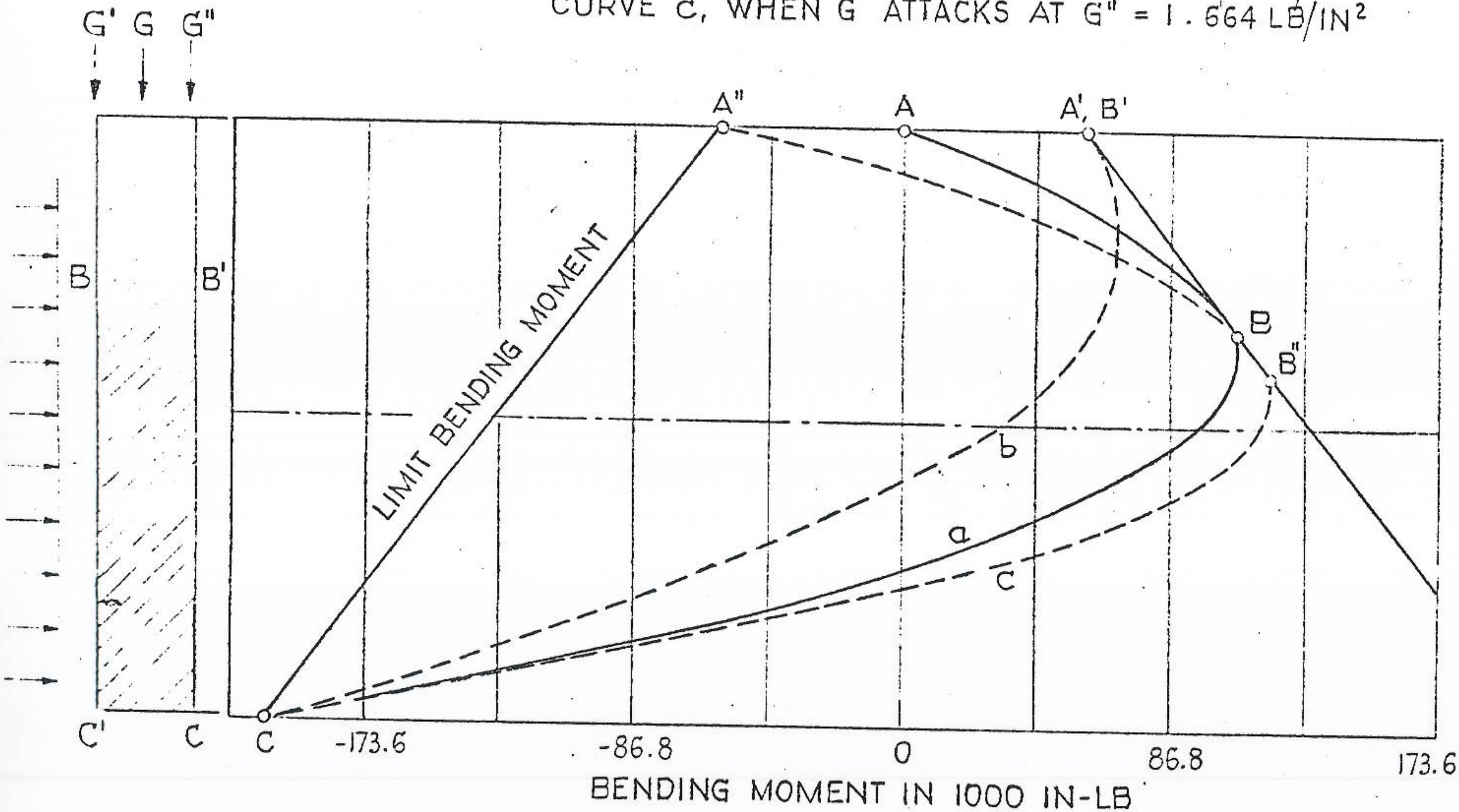
COKE OVENS AND COAL CHEMICALS PLANTS



THEORETICAL DETERMINATION OF THE LIMIT LOAD OF A VERTICAL SECTION OF A COKE OVEN WALL IN THE EXPERIMENTAL SET-UP OF H.KOPPERS.

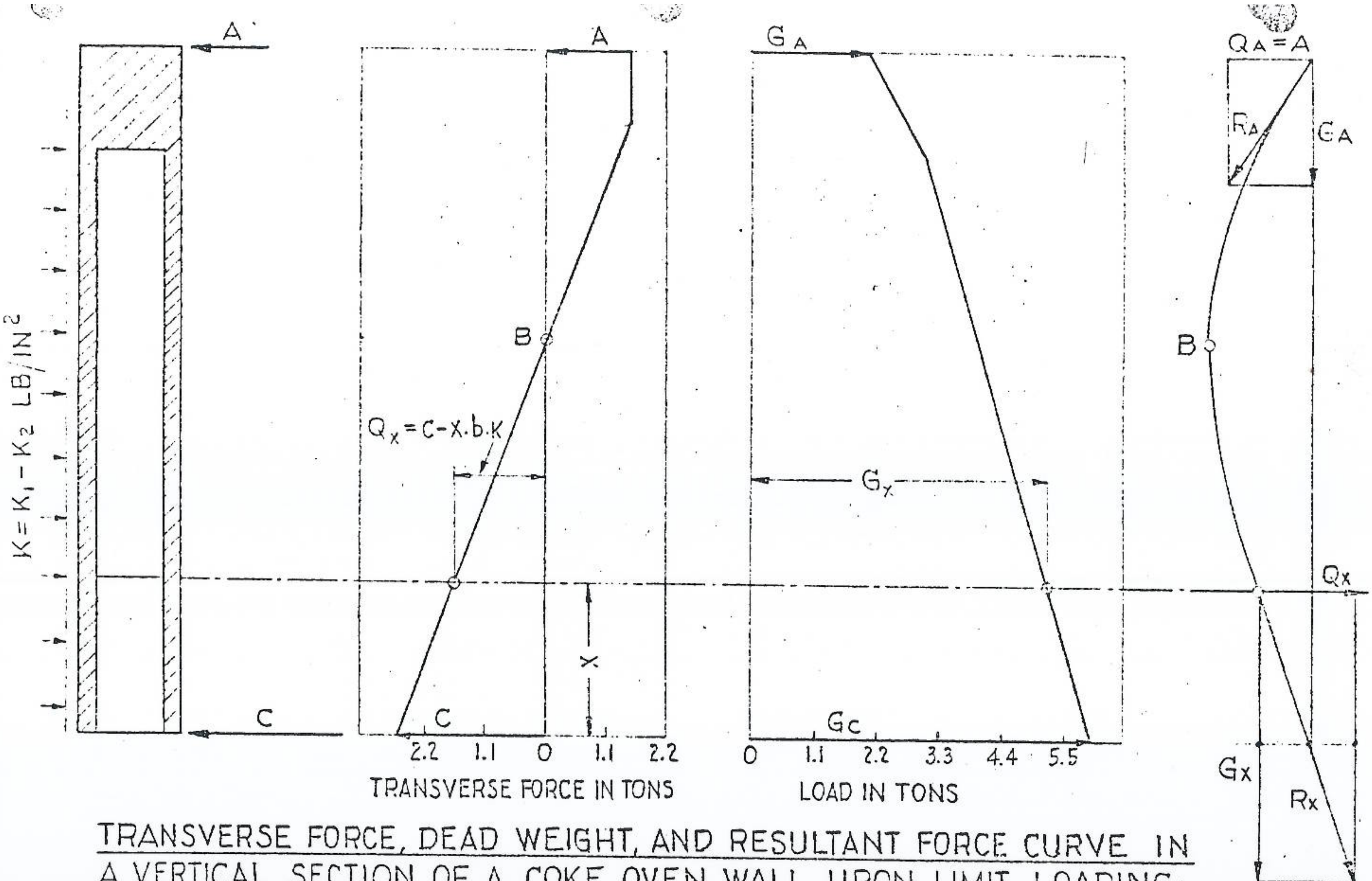
WILPUTTE COKE OVEN DIVISION — Corporation — COKE OVENS AND COAL CHEMICALS PLANTS	REVISION		DRAWN A. E.	DATE 5-3-68.	LIMIT LOAD OF COKE OVEN WALLS FIG. 14	SK-9064-L
	BY	DATE	C'HK'D	SCALE NONE		
	1					
	2					

LIMIT LOAD : CURVE a _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ = 1.337 LB/IN²
CURVE b, WHEN G ATTACKS AT G' = 0.711 LB/IN²
CURVE c, WHEN G ATTACKS AT G" = 1.664 LB/IN²



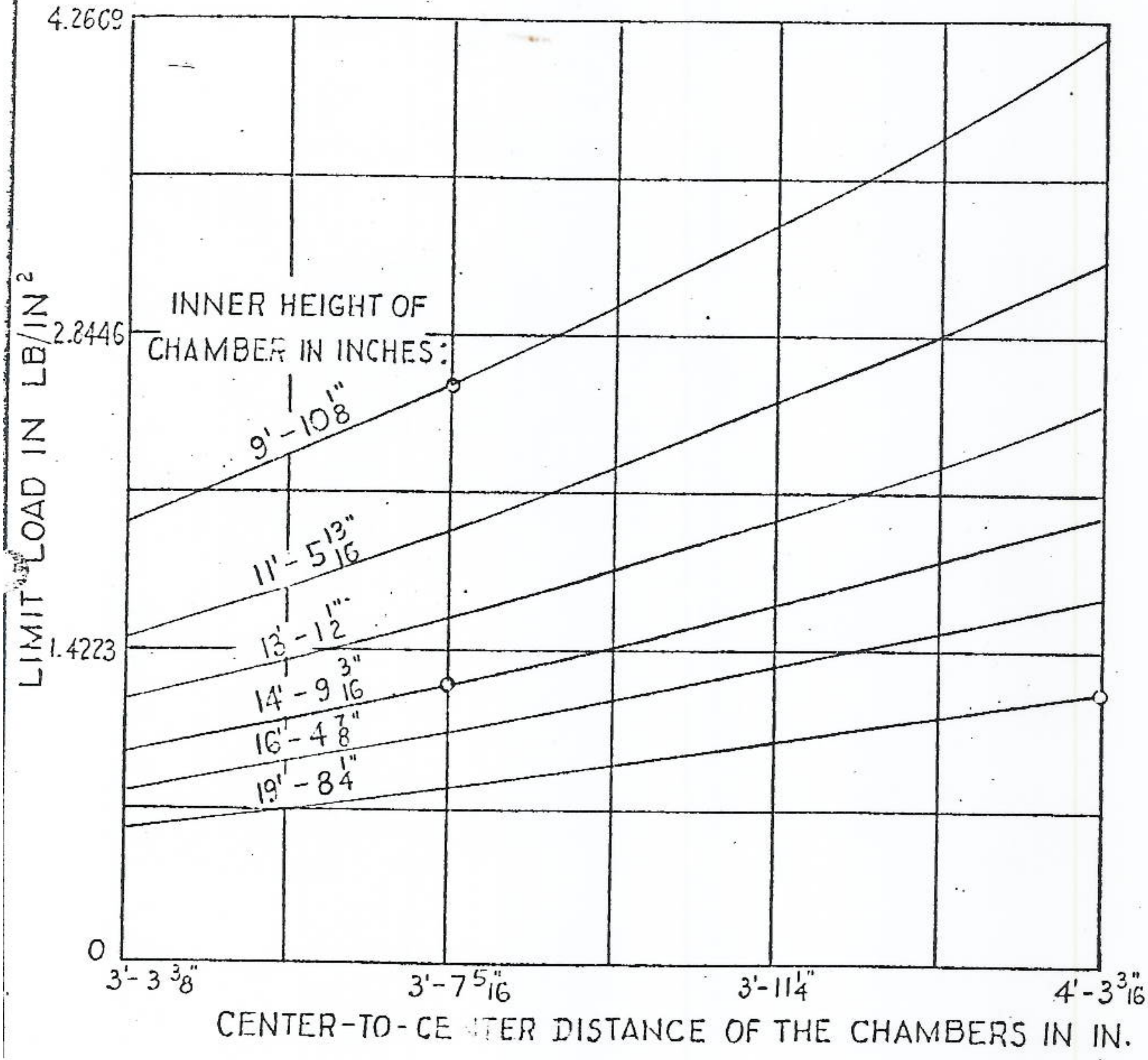
THEORETICAL DETERMINATION OF THE LIMIT LOAD OF A SOLID WALL SECTION IN THE EXPERIMENTS OF H. KOPPERS

WILPUTTE COKE OVEN DIVISION, Allied Chemical Corporation, COKE OVENS AND COAL CHEMICALS PLANTS, 40 RECTOR STREET, NEW YORK 6, N.Y.	REVISION: BY / DATE (1, 2)	DRAWN A.Z.	DATE 5-3-68	LIMIT LOAD OF COKE OVEN WALLS	SK-9065-L
		C'HK'D	SCALE NONE	FIG. 15	



TRANSVERSE FORCE, DEAD WEIGHT, AND RESULTANT FORCE CURVE IN A VERTICAL SECTION OF A COKE OVEN WALL UPON LIMIT LOADING

WILPUTTE COKE OVEN DIVISION — Corporation — COKE OVENS AND COAL CHEMICALS PLANTS — NEW YORK	REVISION		DRAWN A.Z.	DATE 5-3-68.	LIMIT LOAD OF COKE OVEN WALLS FIG. 16.	SK-9066-L
	BY	DATE	C'HK'D	SCALE NONE		
	1					
	2					



LIMIT LOAD OF COKE OVEN WALLS (ON THE COKE SIDE)
DIMENSIONS ASSUMED: AVERAGE WIDTH OF CHAMBER 17 3/4"; TAPER 2 3/8"; ROOF THICKNESS 3'-3 3/8"; STRETCHER THICKNESS 4 3/4"; HEADER THICKNESS PER FT. OF WALL LENGTH 11 13/16".

SK-9067 - L

LIMIT LOAD OF COKE OVEN WALLS
FIG. 17

DRAWN	DATE
A.Z.	5-3-68
C'HK'D	SCALE
	NONE

REVISION		
	BY	DATE
1		
2		

WILPUTTE Corporation
COKE OVEN DIVISION
COKE OVENS AND COAL CHEMICALS PLANTS