AN ANALYSIS OF THE DESIGN, AND A STUDY OF THE POWER DEVELOPMENT OF THE MOORE'S PARK POWER DAM.

A THESIS SUBMITTED TO THE FACULTY
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-BY-
C.L. DIETRICH AND C.J. HENSHAW
CANDIDATES FOR THE DEGREE OF
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THESIS

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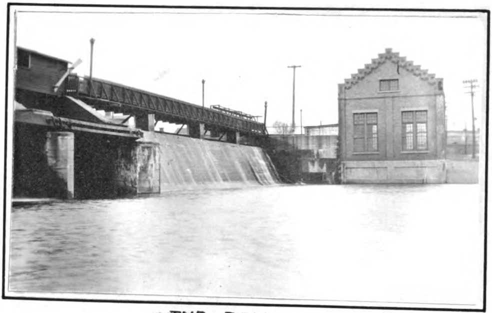
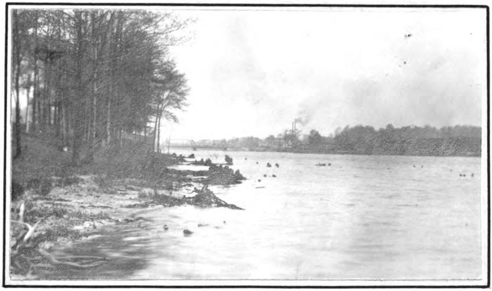


THE DAM



THE RESERVOIR

INTRODUCTION.

The object of this introduction is to briefly outline the course followed, in gathering and computing data and drawing such plans or maps, as have been included in the Subject matter.

In this work, on the Moore's Park Dam and Reservoir, (owned by the "Mich. Power Co." of Lansing) no attempt has been made to analyze the power possibilities of the water after it passes the sluice gates. The efforts put forth have been entirely confined to a study of the prime factors which must be determined and provided for before the actual work of construction can begin. As the dam has been constructed some years, the actual construction of the dam has been omitted from the consideration. The concrete and masonry is assumed to have been properly laid, the finished dam impounding sufficient water to produce a 14 foot head. A large part of the balance of the study, has been taken up in a survey of this reservoir, including drainage and rainfall conditions over the supply basin.

In accordance with the above, it has been found convenient to deal with the complete subject under the following heads;

I. Location of Dam.
II. Analysis of Design.
III. Present Power Conditions.
IV. Power Possibilities. (If any)

In concluding the authors wish to thank Mr. Benedict, Chief Engineer of the Michigan Power Company, for assistance which he has given them, regarding blueprints and plans of the Mich. Power Co's. dam at Moore's Park, Lansing.

C.L. Dietrich.
G.J. Henshaw.

East Lansing, Mich., May 25, 1917.

ANALYSIS OF THE DESIGN, AND STUDY OF THE POWER DEVELOPMENT OF THE MOORE'S PARK POWER DAM.

LOCATION.

This thesis is intended to cover the points of a hydroelectric plant which are of interest to one of the Civil Engineering profession. Obviously this does not include the changing of the water head into electrical enegy, nor the latter's transmission to the consumer. But what is of importance is the investigation of the dam, (especially it's design), the reservoir, and its drainage area or basin.

The Michigan Power Co's Dam of which we have written, in this thesis, is located within the city of Lansing, Mich. It is on Grand River in the S.W. part of the city, in Moore's Park, 4 blocks west of S. Washington Ave. at the beginning of the Moore's River Drive.

The General direction of the river, going up stream, at this point is westerly. The river bed keeps a westerly direction to a distance of about 1 mile west of Waverly Park, (3½ mi. from Lansing). Here it assumes a south westerly direction and keeps this direction as far as the back water of the dam extends.

The dam is a masonry dam, with height of 19' from crest to river bed, and 14' from tail water to crest. It is 170' long and has a retaining wall to south bank 215' embanked on the down stream face to within 2½' of the top. The dam itself has 3 typical sections, viz, (1) Thru Spill way 105' long, (2) Section thru flood gate, and(3) Section between flood gates (conbined are 65'). These three sections are shown on Plate 1 . The up stream face of dam, on flood gate sections has an embankment, up 5 3/4, so as to conform to the shape of the dam. This embankment is gravel fill.

The Power Station is located on the north bank of the river, taking water thru gates 50' long, two turbines being used. Beyond the Power house a retaining wall extends up the bank, making a °45∠

with the dam and is so placed as to pervent damage to the earth embanks, in case of over flow at high water. Its length is 110'.

ANALYSIS OF THE DAM.

The Analysis of the dam structure consists in determination of the factors used in its construction Beardsley in his text "Hydro-electric Plants", on pp. 236-265 (Chap. V) gives the things which are to be found in order to determine the safety of the dam.

We have found the dam can be sufficiently examined by considering under these heads:-

1. Safety against over-training, -2 condition - reservoir full and res. empty.

2. Safety against sliding -2 cases - sliding on itself or shear, and against its rock or earth foundations.

3. Crushing strength, especially at heel and toe.

Other factors than can be considered, are (4) see page underneath dam, with its bouyant and underming effect, (5) effect of ice expansion (6) weakness of green concrete, etc. (7) and effect of vacuums

We have checked these factors thru, making no corrections or alterations on the design of the dam itself, as the dam is now in service but to find the factors as used by the Fargo people. The orignal dam only give a 15' head, but was latter added to (original design make provision for this) to produce the present 14' head. All calculations are based on the dam as it now stands.

On examination of the section on Plate 1 it can be seen that the section thru the rollway is the one to be considered as here stresses are greatest.

Following Fig. 1 Plate 1 the calculations are as follows.

I. To find Overturing moment.
Determination of Center of Gravity.

This section has been figured as composed of 2 sections. Set abcd (Fig. 1 -Plate 1)= section I and defg = section II. It will be seen that this has excluded a small amount of masonry at e, and also the two lugs beneath line gc. These do not increase the base however and hence do not effect the analysis, except they tend to increase the facter of safety.

Area of section A = (19 x 9½) ÷ 2 = 175.72/2 or 87.86sq.ft.

" " " B = (19 x 9/2) = 171/2 or 85.50sq.ft.

Total Area of Sec. I = 173.36sq.ft.

85.50 x 2¼ = 192.38) Note: For finding C.G. Sec.
87.86 x 7.58 = 665.98) I is subdivided into a rectangle
858.36) B and a triangle A.

858.36 ÷ 173. 36 = 4.96' which is $\bar{x}$
$\bar{x}$ being the distance horizontally from the yy axis to the center of gravity of Sec. I.

For this section (I) be = the yy' axis and gc the xx' axis.

Total area = 173.36 sq. ft. (A + B)
87.86 x 6.332 = 556.88
85.50 x 9.50 = 811.28
1368.16

Then 1368.16 ÷ 173.36 = 7.88 ft. which is $\bar{y}$ for I.

Then C.G. of Sec. I is at 4.96', 7.88'

Sec. II has also been subdivided into a triangle and rectangle for ease in finding C.G. The right triangle whose long side is de is B and the rest is the rectangle A.

Area of A = 6 x 3.25 = 19.5 sq. ft.
" " B = (3 x 6) ÷ 2 = 9.0 " "
Total area of II = 28.5 " "

19.5 x 1.625 = 31.69
9 x 4.25 = 38.25
69.94

69.94 ÷ 28.5 = 2.45 ft. = $\bar{x}$

9 x 4 = 36
19.5 x 3 = 58.5
94.5

94.5 ÷ = 3.31 ft. = $\bar{x}$

Then C.G. of Sec. II is at 2.45', 3.31' where the xx' axis as dg and the yy' axis is gf.

Then next step is to combine the centers of gravity of the two parts I and II and thus get

the C.G. of the whole section shown in Fig. I.

Area I = 173.36
" II = 28.50
201.86

173.2 x 4.96 = 859.0
28.5 x (17.0-2.45) = 414.9
1273.9

1273.9 ÷ 201.86 = 6.33 Ft. = $\bar{y}$ gc being xx' axis

86.60 x 7.88' = 1366.0
28.5 x 3.31 = 94.3
1460.3

1460.3 ÷ 2017 = 7.26 ft. = $\bar{x}$ where bc is the yy' axis. Thus the C.G. of the total section is at 7.26, 6.33.

OVERTURNING MOMENT OF DAM.

Assuming the dam is unable to slide (as it must be), the pressure of the water against the up-stream face tends to rotate the dam about the point g, in a counter-clockwise direction. The weight of the dam, acts downward thru its center of gravity andtends to hold the dam in place, that is, it exerts a clockwise direction, moment

Let P = total water pressure on upstream face. $P = w\bar{z}f$
where W = the wt. of water per cu. ft.
" Z = distance to the C.G. of the area.
" F = the area which water is against.
In this case 1' along the dam is taken.
Thus:

$P = w\bar{z}f$
$= 64.5 \times 9.5 \times 19$
$= 11,642.25$ lbs

To take the most extreme case, no counter-acting tail water pressure has been used.

Let W = the weight of a portion of the dam 1' along its length. Assuming masonry as weighing 150#s / cu.ft.; W = 201.86 x 1x 150 = 30,255#s.

W_e = the effective wt. of the dam. If the footings under the line gc do not cut off all see page the dam will be bouyed up by the amount of the water displaced, which will extend up to the height of the tail water. This amount must be subtracted

from the wt. of the dam, to give the force effective to prevent or counteract overturning.

Then W_c = 30,255 -(5 x 17 + 3.25 + 5.75)150
= 30,255-5,483 = 24,772 #s.

Then taking moments about g; Resisting moment = W_c x 17-7.26
= 24,772 x 9.74
= 240,500 ft. pounds.

Overturning mom. = P x 6.333
=11,642 x 6.333
=73,700 foot pounds.

Thus in the most extreme case, as taken, the moment to prevent overturning, is more than 3 times the moment which would tend to cause overturning.

Then Factor of Safety = $\frac{240,500}{73,700}$ or 3.26 (3¼)

Obviously the dam is amply safe against overturning

SAFETY AGAINST SLIDING.

Case I. At some horizontal plane between the base and the crest. It can be seen from Fig.1 that below elevation 85' the tail water would tend to keep the dam from shearing off, so evidently somewhere above here lies the most dangerous section. 1 above here at elevation 86' the dam has a much smaller horizontal cross section, while the pressure is nearly as great as at 85'.

Let S = the shearing stress, caused by water pressure down to elev. 86'.

P = WZF
= 5452.2#s = S.

Let R = the force which will tend to prevent horizontal shear. R = U(W_c) Where U= the coefficient of friction. With masonry on masonry U= .65

With masonry on rock U = .50

Then R = .65($\frac{10.83 + 4.5}{2}$ x 13)150 x 1
= 9,810

To prevent failure by shear R must be greater than S.

9,810 is greater than 5452.2

Hence the dam is safe at this most precarious

section.

SAFETY AGAINST SLIDING

Case II. At the base.

The extreme case has been used, that the footings below gc have already been shear, or at least not in the same integral mass as the rest of the dam. Also no tail pressure has been figured, which makes it the rare case, where no water has been allowed to escape by the dam for some time. (Never has occured).

$S = P = 11,642$

$R = W_c \times u$

$= 24,772 \times .5$

12,386 #s.

R is greater than s, hence dam will not slide. However in this extreme case the dam has a factor of safety of only a little over 1, which is not sufficient. However the footings should never become injured in so small a dam.

CRUSHING STRENGTH.

To get the resistance ti crushing at the downstream toe of the dam.

Base of dam gc = 17'

$W_c = 24,772$ #s. Taking moments about the upstream edge c, we have; $(11,642 \times 6.33)+(24,772 \times 7.26) = 16\frac{1}{2} F_c$.

Where F_c = the crushing force exerted on the last square ft. of concrete to the left.

$253,189.3 = 16.5\ F_c$ or $F_c = 15,345$

According to Ketchum, in his "Structural Engineer's Handbook," the allowable crushing strength of gravel aggregate concrete is 2000 #s/sq." or 288,000 #s/Sq.' (on a 1:2:4:mix) Thus this dam is way safe as regards danger of concrete being crushed.

This completes the investigation of the section no.1 for the 3 main factors. There are severalminor ones however, as mentioned before, which are worthy of investigation.

Seepage.

The dam is safe as regards seepage under the dam. We have already allowed for seepage in computing for overturning moment hence the only thing yet to investigate, is danger of seepage becoming excessive underneath the dam and undermining it, This has been guarded against in 3 ways;

(1) The dam is brot down to the rock which is but, about 2' below river bed. This will prevent

wearing away, by water action, underneath the dam.

(2) A gravel fill, or embankment, has been made on the upstream face. It is 7.75 ft. high next to the dam and has a 2 on 1 slope downward, upstream. This also prevents washing near the toe, as it excludes the water from that vicinity.

(3) At the heel a 1' cut-off arm or sill has been built integral with the dam proper- which is 3' thick at the base. At the toe there is one, having a depth of 2' and 2.25' thick at the base. These two "curtains" prevent any percolation of water thru the rock at the base. These projections beneath the base of the dam also make the dam safer against sliding off, its base.

The factor of safety against overturning is large enuf to take care of the effect of ice expansion.

The dam being only 19' from crest to base, the consideration of the green concrete being crushed, at the bottom, by the addition of the top layers, while it was in process of construction, need not be made.

This dam is provided with flood-gates (Fig. 2.- Plate 1) and hence in flood time, the flow over the crest is not much greater than ordinary times. The slight vacuum effect that the sucking of the water as it leaves the rollways, produces, need not be considered.

GRAPHICAL SOLUTION
FOR
OVERTURNING MOMENT.

This solution is given on Fig. 1, Plate 1.

To find the Center of Gravity of Sec. I (abcd) lay off db' to the left of d = ab
" " ce' " " right " c = dc
Connect e' with b'
Next connect the middle of the dc with the middle point of ab. Where this line intersects b'e', there is the C.G. of section I.

Section II is worked in the same manner gf' being laid off horizontally to the left of g,=

ef and ed' = gd. These two centers of gravity are then combined as in the previous solution. It is found that this center of gravity occurs 1/3 of the distance from the bottom, that is 19 ÷ 3 or 6.33. Also, the center of pressure, of any submerged area, is 1/3 the distance from the bottom. Hence P (the water pressure) acts thru the C.G. of the dam as does also the weight. This is the best possible place for P to act as it thus produces no secondary stresses.

Then using the scale: 5000 #s = 1"P was laid off to the left thru the C.G. and W vertically downward thru the C.G. Then the resultant of P and W was drawn. This cuts the base g.c., 7.9' from g.

If this resultant falls within the middle third of the base, no overturning moment will be produced by the conditions, relating to the resultant. In other words, no tension has been placed in the concrete, in the right hand 1/3 of the base Daugherty Hydrau (pp.32 and 33) 17 ÷ 3 = 5.66 Thus this dam is very safe and is really not the most economical dam that could have been built, for the Resultant falls 2.2 inside the middle third.

Thus have found the following things concerning the dam; That the C.G. has been made on the line of application of the total water pressure, P; that the resultant of P and W_e falls well within the middle third (shown by graphical solution); and that the factor of safety against over-turning is ample, being 3.25 for section which is the most perilous. The dam is also safe against sliding in the most extreme cases. Also the allowable crushing strength of concrete is many times, what the outside sections of this dam are called upon to stand. The downstream face of the dam however should have been given a greater horizontal pitch as in flood season the water leaves the face of the dam at the crest and encounters it again about 6' lower.

As this analysis does not attempt to go into the economical side of construction, or shape, of this dam, it has not been considered necessary to further analyze the other two sections. Their bases are the same and of the same demension. Certainly the flood gate section shown in fig. 2 will not over-turn as the

height is much less, and hence P is applied much lower down, relative to the C.G.

The section between the flood gates is shown in Fig. 4, plate 1. This section will be more safe than the spillway section, as to overturning, as we will be much greater. Also will be safer against shear.

PRESENT POWER CONDITIONS.

The condition of the dam, as it is at present has been given in the foregoing matter. The dam furnishes water enuf to satisfy the capacity of the turbines for 9 months in the year. Direct-connected to the 2, impluse turbines are 2 A.C. current 500 K.W. generators which deliner current to consumers, in the city of Lansing. Thus when the dam is furnishing a nomial amount of water, 800 horsepower is produced.

On the 26th. of April (1917) the authors of this thesis, took current readings, and obtained a cross section of the river at the Logan Street bridge. This is 4 blocks upstream from the dam.

The cross section was made in the following manner; The river was 195' wide at this point. (narrowed about 110' by bridge approach). From the south bank 5' intervals were laid off to the north on the bridge. At these points the depth of the river was obtained by lead line measurements. This data was used in plotting the cross-section of Plate 2.

Then starting 10' from the south bank current readings were made every 10' with a Electrical contact current meter. The current meter was placed on river bottom and drawn up as evenly as possible so that 10 "tielso" of the instrument would bring it to the surface. (The rapidity of the tieks depending on the velocity of the water). The time taken for these 10 ticks was recorded in seconds. Then from the table compiled for this instrument the velocity of the water was found. The table on Plate 2 gives all results as obtained.

After readings were taken every 10' across the first time, the alternate 10' were taken the second time. Table on Plate 2 gives the two combined.

On the day mentioned approximately 800 H. P. was being generated by the turbines and the amount of water passing the dam was 693.5 cu. ft. per second. As this was well past the spring Freshet the flow was not more than 10% above normal.

693.5 -.1(693.5) = 624.1 cu.ft. of water for the normal flow. According to reports of power house employees at this time, probably 5% of the flow was wasted over the dam, the water being 4 inches above the crest.

624.1-.05(624.1) = 592.9 cu.ft. of water, which is the amount (approx) flowing thru the sluice gates.

Theoretically this should produce the H.P. computed;

592.9 x 14 x 64.5 = 535,388.7 foot pounds per second.

535,389 ÷ 550 = 955.3 theoretical H.P.

Real app. H.P. = 2(500 x .746 x V3)
" " " = 746 x V3
" " " = 1290.58 or 1300 H.P.
Probably max. production is 2/3 of capacity.
.66 x 1300 = 858 Actual H.P.

Efficiency = 858 ÷ 955 = 89.8%

This effieiency being figured from the water conditions at present and is really only the efficiency of the Power house machinery. To get efficiency of the whole power project it would be; 858 ÷ (694 x 14 x 64.5) ÷ 550 = 76.5 %

Now assuming that 693.5 cu.ft. per sec. was the normal flow we can figure, run off, percolation and evaporation for the drainage basin. The area of the drainage basin between the Moore's Park dam and the Dimondale Dam is 11.699 Sq. miles. This area is the mean obtained from 9 planimeters readings of the area as given on the Topographical May of the Lansing Quadrangle, as made by the U.S. Geological Survey. (Board of Geological Survey, R.C. Allen- State geologist).

From figures taken from the Annual Meteorological Summary and Comparative Data of Lansing Mich, for the year ending Dec. 31, 1916, the mean rainfall for April, covering a period of 53 years, is <u>2.41</u> inches. This year (1917) no snow was on the ground at April 1. Hence all drainage water, whether underground or surface, was caused by the months precipitation.

From table 14, p. 68, of Turneaure's and

Russel's, "Public Water Supplies" we find that a depth of rainfall of 1" produces a volume of 2,232,200 cu.ft. per square mile. Then 2,232,200 x 2.41 x 11.7 = the total volume of precipitation over the basin mentioned above = 62,948,040 cu.ft. As most of this land is under cultivation, or in wood lots (at least 75 %) the evaporation is not large, especially in April. Also the crops are not in the growing season and hence take but very little water. According to table No.11, pp.58 and 59 of Turneaure and Russel, give in the Lower Lake Region, at Detroit, the evaporation of April as 3 ÷ 36 that of the whole year, or 1/12. As the soil in this basin is also not heavy, the yearly evaporation probably does not exceed 25" 25 ÷ 12 = 2+"
2 x 2,232,200 x 11.7 = cu.ft. of evaporation = 52,333,480. 62,948,040-52,333,480 = 10,614,560.
Allowing 10% as taken up by the plant life;
10,614,560-1,061,456 = 9,553,104.

9,553,104 cu.ft. of water is what percolates into the ground, and run over the surface, into the river. 9,533,104 ÷ (30 x 24) = the flow in the river per hr.

= 13268 cu.ft./hr.
or 221.1 " /hr.

This shows that only a very small amount of the flowage comes from this area, practically the same ammount of water flows over the Dimondale Dam as does the one at Moores Park.

POWER POSSIBILITIES.

In order to ascertain whether it would be feasible, if possible, to produce more power at the Moore's Park Dam, a line of levels was run from this dam, upstream. The object of this was two-fold; first, to determine the fall of the river, and second, to find the extent of the back-water.

There were two in the level party, (the authors of this thesis) and a direct reading instrument was used (A Deitzgen, from the M.A.C. Civil Engineering Dep't.) which was of good power, the average length of shots being 150 yards. An ordinary "high,low" level rod, with a target was employed. The leveling was started April 4. There being no bench marks in the vicinity, the height of the south wing wall of the dam was assumed as 22.00 feet. The water on this day then had an elevation of 18.28'. The levels were then run upstream, B.M.s being set at convenient intervals.

On account of the raising and lowering of the water level, caused by the opening and partial closing of the sluice gates, on different days, the exact extent of the back water could not be determined. But 2 miles north of Dimondale at the bridge on the Township line the elevation of the water was 19.51' (From B.M. No. 14). Back down the river $1\frac{1}{4}$ miles on the same day the water elevation was 19.50' (B.M. Noll) On this day (4/5/17) the water was about 1.1 higher at the dam, than the day when first levels were taken.

From Dam to B.M. 14 is a distance of 6.8 miles. $14' \div 6.8 = 2.05'$ fall per miles.

The elevation of the Dimondale Dam tail-water is 21.77'. The elev. above Dimondale Dam is 28.57'.

From B.M. 14 to tail-water at Dimondale is 1.5 miles. $21.77 - 19.51 = 2.26'$ fall.
$2.26 \div 1.5 = 1.5+$. which shows assuming river has uniform fall, that the back water extends somewhat beyond B.M. #14.

21.77 (T.W.elev. at Dimondale)$-18.22+1.1-14$ (elev. of T.W. at Moore's Park) $= 16.45$
$16.45 \div (6.8 + 1.5) = 1.98'$ which is the actual fall per mile.

14 ÷ 1.98 = 7.07 miles. This shows that the back-water extents 7.07 - 6.8 or 0.27 of a mile beyond the Township line bridge (B.M. No 14). After leveling was completed a transit line was run as shown on plate 3. A Keuffel & Esser Transit from the M.A.C., C.E. Dep't. was used. The object of this line was also two fold. First, it was meant to serne as a "backbone" line for the map of river basin (Plate 3) and second, to plot contours from. Three contours were located, the 22', 24' and 26'.

After studying the map as drawn it can plainly be seen that the land west of Lansing on the north bank of the river is quite generally, low. This is along the Grand Trunk Railroad and will eventually, under present conditions, be valuable factory sites.

Therefore in covelusion of this study, the following facts, we think, should be emphasized:

The Grand River is by no means an ideal power stream, it having slightly less than 2 feet per mile fall thru this region, and its banks being being very sloping and any increase in height of present dam, would necessitate a much longer span, in order to reach the bounding banks at a sufficient elevation. This would incur and enormous expense.

The present dam could not be made higher as its foundation is not sufficient (from part I) and also its crest has now only a width of 4½'.

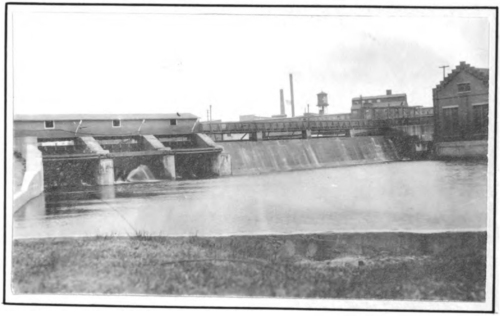
It also could only be made a fort higher because of the Dimondale Dam. The mill rights at Dimondale would have to be purchased to go above this, and upon inquiry it appears the owners are not in favor of selling.

Also as conditions are at present there are 3 months of the year when the dam cannot run at capacity because of the swiftness of runoff on the drainage basin. This would, to a large extend, be the same with a higher head and a proportionately larger reservoir.

But most important of all, if the head was increased 8', which would be about the maximum increase, the new reservoir would have the shape of the 26' contour (Plate 3) which would cover much valuable land between Lansing and Waverly Park and even be-

yond. This land would command a high price. The Grand Trunk Railway would also undoubtedly enter a protest.

In view of these facts we think it inadvisable to attempt to increase the power production of the Moore's Park Dam, as the capital invested would not produce a sufficient amount of return, because of the possible additional 480 H.P.



Pocket Ms. 5 Plates