THESES

HIGHWAY IMPROVEMENTS

UNIVERSITY OF ILLINOIS.

1883.
FOR
BACHELORATE
DEGREE
BY
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Classification

Water Highways
Marine Highways
Rivers
Canals
Land Highways
Rail Ways
Rail Roads
Street Railways
Elevated Railways
Wagon Ways
Tramways
Streets
Country Roads

Improvement of Road-Bed
Reduction of Grades
Alignment
Highway Improvement

The subject of Highway Improvement has been a question of growing importance since man first recognized the advantages and embraced the opportunity for social and commercial intercourse. It was one of the first questions presented to civilized thinkers and, could its importance have been recognized and its solution, in the several forms which it assumes, have been effected in the outset, one of the greatest obstacles to the advancement of civilization would have been removed.

Notwithstanding the fact that
much attention has been paid to it and vast amounts of money and labor have been expended on it in modern times, its importance is not yet fully appreciated by those in whose hands the matter rests, as the following discussion will show.
Highways
may be divided into Water Highways and Land Highways.

Water Highways
may be again divided into Rivers, Canals and Marine Highways.

The improvement of Rivers
involves the removal of any obstacle to navigation that may be found, dredging out the channel, and building wharves or other means of establishing landing places.

Canals should have their locks, wharves, tow paths and water supply attended to and kept in good repair.
Marine Highways includes oceans, seas, lakes etc. Their improvement consists of building docks and lighthouses anchoring buoys and establishing such other signals of warning as will insure the safe passage of vessels.

Land Highways may be again divided into Rail Ways and Wagon Ways. Rail Ways may be divided into Rail Roads, Street Railways and Elevated Railways. The improvement of Rail Roads consists in reduction of maximum
grades and curves, in perfecting the alignment and in repairing and improving the track and road bed. No expense should be incurred for reduction of grades and curves already below the maximum.

Street Railways should have a smooth and even track to prevent jolting and unnecessary draught.

Elevated Railways must be carefully designed and substantially constructed. The floor system should be such as to prevent a derailed train from cutting through or running off the cross ties.
Wagon Ways may be divided into Tramways, Streets and country roads. Tramways should have their maximum grades as low as possible. Iron plates are now more economical than wood. Streets should be so adjusted as to insure a ready disposal of surface water. The surface should be made perfectly hard and impervious by water. Crossings should be a little higher than the street and sufficient means of illumination should be provided to prevent accidents by night.
Country Roads

A discussion of this subject is the chief object of this Thesis and its details will be more closely examined than those of the preceding subjects. Their improvement may be discussed under the following heads:

Improvement of Road-bed involving the justifiable expenditure to be incurred in obtaining and preserving a smooth hard surface.

Reduction of Grade involving the justifiable expenditure to be incurred in cutting through a hill.

Alignment, treating of Rectilinear alignment, Rectangular or Diagonal.
Improvement of Roadbed

To furnish a basis upon which to build the discussion a series of observations were taken on roads of different character and in different conditions. The result of these observations may be seen in Table 1 page 11. As these shown readings were taken on seven different stations. Station one was on a slab floor, station two in mud two inches deep, with a smooth spongy underpan, station three, four and five were in mud three inches deep, stations six and seven were on a road composed of broken brick and mortar, not yet perma-
<table>
<thead>
<tr>
<th>No.</th>
<th>Mt.</th>
<th>1</th>
<th></th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Sum 6</th>
<th>Remarks</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>1935</td>
<td>50</td>
<td></td>
<td></td>
<td>75</td>
<td>150</td>
<td>180</td>
<td>160</td>
<td>140</td>
<td>140</td>
<td>Dynamometer road to 25 lbs.</td>
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<td></td>
<td>Height of Wagon = 960 lbs.</td>
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<td></td>
<td></td>
<td>125</td>
<td>160</td>
<td>112</td>
<td>125</td>
<td>100</td>
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<td>Draught of Wagon on Station 1 = 25 lbs.</td>
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<td></td>
<td></td>
<td>275</td>
<td>310</td>
<td>172</td>
<td>275</td>
<td>240</td>
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<td></td>
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<td>Reading on Stations 1 and 2 only taken one way.</td>
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<tr>
<td>2</td>
<td>2800</td>
<td>100</td>
<td>125</td>
<td>175</td>
<td>125</td>
<td>75</td>
<td>200</td>
<td>150</td>
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<td>200</td>
<td>225</td>
<td>160</td>
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<td>375</td>
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<td></td>
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<td>125</td>
<td>187.5</td>
<td>175</td>
<td>112.5</td>
<td>187.5</td>
<td>150</td>
<td>186.25</td>
<td>156.25</td>
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</tr>
<tr>
<td>3</td>
<td>4180</td>
<td>150</td>
<td>200</td>
<td>200</td>
<td>150</td>
<td>125</td>
<td>226</td>
<td>226</td>
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<td>325</td>
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<td>525</td>
<td>525</td>
<td>360</td>
<td>450</td>
<td>450</td>
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<td>200</td>
<td>262.5</td>
<td>250</td>
<td>175</td>
<td>225</td>
<td>225</td>
<td>233.7</td>
<td>14859</td>
<td></td>
<td></td>
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</tbody>
</table>

3) $6.0234 \times 16746 = \text{the draught on a soft road in terms of that on a hard road.}$
mently packed. At the five latter stations, as the road was slightly inclined, observations were taken in both directions and the onehalf sum taken as the reading upon a level surface.

From the table we see that the average reading of the six last stations, for a load of 1955 lbs was 118.5 lbs for a load of 2800 lbs it was 156.26 lbs and for a load of 4180 lbs it was 222.917 lbs. The relations of draughts for loads are 118.5
1955
156.26
2800
222.917
4180
or 16 17 and 18 respectively.

Previous observations on good roads have proved that the draught increases as the load. The above
deviation is explained by the fact that the road was improved each time the wagon passed over it.

For a planked road we have the following relation of draught to load: 
\[
\frac{6\frac{3}{10}}{2\frac{1}{10}}, \frac{12\frac{2}{3}}{4\frac{1}{3}} \text{ or } 52, 28, \text{ and } 28 \text{ respectively, the average of which is } 29.
\]

Taking the average draughts for the several loads on soft roads and dividing them by the corresponding draughts on a planked road: 
\[
\frac{15\frac{4}{25} + 2\frac{22}{212}}{1\frac{1}{3}} = 1.975 + 1.625 + 1.4839, \text{ the average third sum of which } = 1.6745 \text{ was the force required to move a load over a soft road in terms of the force required to move it over a hard one, the above being taken as soft and}
hard roads respectively.

Taking into account the disadvantage at which the horsework and the extra wear and tear on the harness and wagon, we may, since the cost increases as the draught, that it costs twice as much to move a load over a soft road as over a hard one.

With a load of one ton of two thousand pounds on good roads, the average team will travel thirty-five miles per day. The usual wage paid for team and driver is $3.00 per day which includes board and horse feed.

At these figures the cost per mile
If moving a load over a hard road is ten cents. Since this cost is doubled on a soft road the cost of a soft road is ten cents per mile per load of one ton. The number of days per year of soft roads is variable and will depend upon the amount of rainfall, the lay of the country, and the nature of the soil. It will be safe to say that two hundred days out of the three hundred and sixty-five the roads will be either rough, rutty or muddy. All of which are the result of soft roads. It would be impossible to determine, by experiment, the
The cost of moving a load over a rough or cutty road we must depend solely upon judgment. The cost of moving a load over a soft road would probably be a nearer approximation. Hence the yearly cost per daily load for mile of soft road is $2.00 x $0.10 = $2.00. Reserving $5.00 of this amount for annual repairs we have remaining $15.00 to be invested in capital to be expended in permanent improvements. At 6 percent we have at our disposal $250.00 as the justifiable amount to be expended in the permanent improvement of a road which is to accommodate one load per day.
For any other number of daily loads these amounts must be multiplied by that number. For example: for ten loads per day we would have $50.00 to be expended in annual repairs and $250.00 to be expended in permanent improvements of one mile of road.
Reduction of Grade.

To determine the justifiable expenditure to be incurred in reduction of grade we observe that when the inclined surface makes an angle with the horizontal equal to the angle of repose the resistance in ascending is doubled and in descending is reduced to zero, hence the energy expended in ascending is nearly restored in descending. This amount of rise is therefore not a serious objection and we will not be justified in an expenditure for its reduction. From these observations we learn
that the draught on a good road equals one twenty-ninth of the load and from the principle of the inclined plane we know that a rise of one foot in twenty-nine, measured along the inclined surface, causes a resistance equal to one twenty-ninth of the load. We would therefore not be justified in making a reduction of grade below one in twenty-nine. This however is only applicable to a short rise and is on the assumption that the normal pressure against the surface is equal to the weight of the load. To determine the justifiable expenditure for reduction of a long rise...
or a rise not followed by a fall we observe that a horse, by being allowed a few moments rest, can pull for a short distance four times his usual load. This is proved by common experience and is confirmed by experiments with the dynamometer. For all small elevations we may use the same approximations as in determining the angle of repose, or a rise of one foot in twentynine causes twice the resistance; a rise of two feet three times the resistance and a rise of three feet four times the resistance of a level road. This is the maximum grade allowable.
under any circumstances for beyond this extra horse power becomes necessary which greatly increases the cost.

An estimate of the cost within the above limit depends largely upon judgment but to say that it increases as the rise per twelve nine feet would come very near the truth. Upon this supposition a rise of one foot in twenty nine would cost 20 cents, a rise of two feet 30 cents and a rise of three feet 40 cents per mile. For example take a rise of three feet per twenty nine on a hill of 528 feet almost height, the cost of moving a load over it would
be \( 4 \times \frac{5 \cdot 2 \times 80}{5 \cdot 2 \cdot 80} = \$0.04 \) or the yearly cost per daily load would be \( 365 \times \$0.04 = \$14.60 \)

At 6\% per cent this is the annual interest on \$243.33 which is the justifiable amount to be expended for one daily load. For any other number of daily loads this amount must be multiplied by that number thus (in daily loads loads would justify the expenditure of \$243.33 in cutting through the hill.)
Alignment:

Rectilinear Alignment.

In determining questions of alignment, we must be governed in part by the same considerations and data as in discussing Reduction of Grade. Suppose, for example, the question of deviation from a straight line to avoid an expensive cut of fill is to be solved. Suppose this distance on a straight line is 1.414 of a mile and on the deviating line is two miles, the difference in distance in favor of the straight line is 0.86 of a mile equal to 187.5 rods, which involves at 60 cents per rod
375 rods of fencing $225.00
4.7 acres of land at $35.00 164.15
Total first cost $389.15

Interest on which at 6% $23.35
Annual repairs, fencing, road bed 10.00
Total yearly cost $33.35

Supposing the cost of earthwork to be $1,000.00 per mile on the straight line and nothing on the diverting line. The straight line will then cost above the cost of the same distance & diverting line 1.414 x $1,000.00 = $1,414.00

Interest at 6% = $84.84

Difference of annual cost in favor of diverting line = $33.35

The yearly cost per one daily load of 5.86 of a mile, as shown above is $51.49
\[0.586 \times 365 \times \$10 = \$21.39\]

The above annual difference in cost in favor of devacation divided by the yearly cost per daily load of 5.86 is a mile will equal the number of daily loads required to justify the expenditure necessary to open the straight line, or

\[\frac{\$51.49}{21.39} = 2.4\]

Therefore if the number of daily loads equals or is expected, within a reasonable time to equal 2.4 loads the straight line should be constructed.

Some of the above amounts are variable and must be adjusted for each particular case.
Diagonal Alignment

For the convenience of local communication the United States Government has adopted what seems to be a very appropriate system of rectangular location of public roads. As shown above a very small amount of travel will justify a restriction to straight lines even at a considerable cost. The question now presents itself as to whether or not, in addition to the rectangular system, there should be a system of diagonal roads established connecting the opposite diagonal corners of the sections in closed by the rectangular system.
Take for example the supposed case of opening a road from the diagonally opposite corners of a section one mile square. Estimating the cost of:

- 2,828 miles of fencing at $0.00
- Right of way at $640.00
- Bridging, road bed, etc. at $100.00

Total cost of construction $1690.00

Interest on which at 6½% = $101.40

Annual repairs at $38.60

Total annual cost $140.00

The yearly cost per daily load over 0.586 of a mile at 10% as above = $21.69

The above total annual cost divided by the yearly cost per daily load over 0.586 of a mile equals the number of daily loads required to justify opening.
a diagonal road through a section of the above conditions under the above circumstances or

\[
140.00 \div 21.39 = 6.5\]

The adoption of the diagonal system in addition to the rectangular in laying out a town site would seem to be justifiable in consideration of the frequent necessity for a quick and easy access to any part of the town, as in case of fire or in time of war etc. and, if the streets are parallel to the roads of the surrounding country, the above discussion proves that they should be extended a considerable distance into the country.
By referring to Plate II we see the disadvantage at which a person would pass, by the rectangular system, between the diagonally opposite corners of the town, as from A to C. Also the extra travel required between the points A and C. The diagonal system removes both these objections.

Though the above discussion is not in harmony throughout with other writers on the subject its conclusions do not differ materially from those of recognized authority. Gillespie arrives at the conclusions that for a road over which 5,000 tons of freight passes yearly to reduce
The friction from 1/20 to 1/50 of the weight of the load would justify an expense of $375,000.00. Also to shorten the length of this road one mile in thirty he would spend $20,830.00, and to avoid a hill one mile long and inclined one in ten on some road he would spend $31,250.00 to open a level road a mile longer around the hill.

Gillmore says: "If the traffic upon 10 miles of good road requires the constant employment of 50 horses and 25 drivers at an aggregate annual cost of $21,750.00, it would cost $87,000.00 per annum to conduct the same amount of traffic upon the same road covered
with deep ruts and thick mud and it would be a wise policy to expend the whole excess of $55,250.00 in improving and maintaining this road in a superior condition of smoothness and hardness were such a large expenditure necessary to secure that result."

For Illinois roads J.M. Osborne of Toledo, Ohio advocates an expenditure of $4,000.00 per mile, just one half what a large portion of Ohio 4-roads have cost. These conclusions indicate that the common roads of the United States are far behind what economy demands they should be.