Assuming that this 4 feet is intended to be measured from the surface of the ordinary low stage of water, and not from the bed of the river, it will be observed that the crest is now 1 foot and 10 inches (actual 1.8 feet) higher than is allowed by law.

Further examinations were prosecuted by Messrs. Richards and Stephan, as I was unable through sickness to render any further practical assistance in the field. These engineers report that they extended the line of levels one-half of a mile above the State line, and found a rise in that distance of $5\frac{3}{4}$ inches in the surface of the water in the river. They also took a cross-section of the river at the State line, which has a sectional area of 543 feet, with a hydraulic mean depth of $4\frac{1}{2}$ feet; this giving the water a velocity of nearly 2.35 feet per second, with a flow of about 1,271 cubic feet per second.

Their next cross-section was taken about 1 mile above Momence, where it is supposed the greatest rock obstruction exists. This section had a wetted perimeter of 420 feet, with a sectional area of 1,026 feet, and the water a velocity of 1.4244 feet, thereby passing 1,457 cubic feet per second.

I understand that it is your intention to construct a ditch in the State of Indiana 42 feet wide on the bottom, 52 feet on the top, and 10 feet in depth, containing an area or cross-section of 470 feet, with an inclination on the bottom of 12 inches to the mile.

Such a ditch when running full of water will give a flow of $1{,}558\frac{1}{2}$ cubic feet of water per second, having a velocity of 3.3166 feet per second. As before stated, the amount of water delivered by the present channel is 1,271 cubic feet per second; it therefore follows that you cannot in any case deliver more than $287\frac{1}{2}$ cubic feet per second at the State line by the construction of your proposed ditch, as this would be its entire capacity ($1271+287\frac{1}{2}=1558\frac{1}{2}$) cubic feet of water. Messrs. Richards and Stephan give the width of the present channel at the State line as being 180 feet, with about the same fall to the first half mile that you propose to give to your ditch, while the latter has only a width of 52 feet on the top.

Practically, this would give but a very slight rise in the water at that point, unworthy in fact of consideration in a proposed work of this character.

Taking the amount of water arriving at the State line by the present channel of the river at 1,271 cubic feet per second, would give a depth of 8.2 feet of water in your ditch when constructed.

But it is to be presumed that your ditch will carry off the water with so much more rapidity than the old channel that its lower portion at least will run with full banks.

From the foregoing it will be seen that you have no engineering difficulties of moment to contend with west of the Indiana State line, and the construction of such a ditch as you contemplate is but a simple problem requiring no great engineering skill, except in careful leveling, that the excavation may be made to the proper grade, and when this is done the water will simply seek its level by running down hill.

I am indebted to Col. D. C. Houston, Corps of Engineers, United States Army, for most of the important calculations embraced in this report, he having kindly taken the notes with him to Washington during his recent trip to that city, and there made the calculations from the latest formulas in the office of the Chief of Engineers.

Respectfully submitted.

ENSIGN BENNETT,
Civil Engineer.

APPENDIX X.

BRIDGING NAVIGABLE WATERS OF THE UNITED STATES.

GRADES AND CURVATURES UPON BRIDGES AND APPROACHES.

Upon the distribution of the report upon bridging the Mississippi River between Saint Paul, Minn., and Saint Louis, Mo., some disappointment was felt that it contained no tabulated statement of the grades used upon the bridges. As a matter of fact, all that could be ascertained about the grades on the bridges was given in the description of each bridge or on the drawings of them. The bridges, excepting those of the wagon-way at Saint Paul and the railway at Saint Louis, were draw-bridges and the grades were level, or nearly so; a table of these grades was of little value.

Such a table, however, has been prepared for the Mississippi River and sent herewith, giving curvature also; and as it is only in high bridges that grade is important, we have taken the table of grades, &c., on the Ohio River bridges from the report of the Board of Engineers, printed in the annual report of the Chief of Engineers for 1871, page 425.

These two tables cover a considerable range of examples. The highest railway grade given is on the bridge at Louisville, Ky., where it reaches 1.49 feet per 100 feet.

The grade on the Saint Louis Bridge is 1 foot in 100 feet, and this grade is also used at the Saint Charles Bridge across the Missouri River. These grades require either special engines or low rates of speed, and there is difficulty in holding the rail to the ties to prevent its *crawling* under the action of the driving wheels of the locomotive and the vibrations of the bridge.

The question of grades has little importance whenever a draw-bridge is allowable to accommodate navigation. But whenever the bridge is for a railroad system requiring constant service for hours at a time, or where the large amount of navigation would require the draws of a draw-bridge to remain open for continuous passage of vessels for many hours at a time, the accommodation of both means of transportation requires high bridges.

On high bridges where the railroad business is large and considerable speed of transit is required, the grade should be kept as low as possible with due regard to economy of construction. Where, in such cases, high grades are used, the strength, and rigidity must be increased with the grade, or special locomotives or stationary power should be employed. The advantages which this latter method presents will permit of much higher grades than can be allowed by traction engines.

*Table giving maximum of grade and curvature on bridges and approaches on the Mississippi River.**

[Data taken from Warren's Report on Bridging the Mississippi River. Annual Report Chief of Engineers, for 1878, Part II, pp. 900–1125.]

Name of bridge.	Grade per 100 feet.		Curvature.			
	Right bank.	Left bank.	On bridge or approach.	Right bank.	Left bank.	On bridge or approach.
	Feet.	*Feet.*				
Saint Paul Railway	0.5	0	Approach	4° curve	5° curve	Approach.
Saint Paul Highway	5.0	0	Bridge	Tangent	Tangent	
Hastings Railway	0.3	0	Approach	2°	Tangent	Approach.
Winona Railway	1.0	0	do	10°	Tangent	do
Do		0.8	do			
La Crosse Railway		0.5	Bridge			
Prairie du Chien Railway. (This is a ponton bridge with two sets of approaches—one for high stages, the other for low.)	0.4	0.5	Approach.	2°	6°	Approach.
Dubuque Railway	0	0		4°	9°	Approaches.
Clinton Railway	0	0		0	0	
Rock Island Rail and Highway				3½°	Tangent	Approach.
Keokuk Rail and Highway	0	0.8		6½°	do	do
Quincy Railway	0	0		Tangent	4°	do
Hannibal Rail and Highway	0	0		9½°	6°	do
Louisiana Railway	0	0		8°	Tangent	do

*The Saint Paul Highway Bridge is the only high bridge on the Mississippi from Saint Louis to Fort Snelling. The channel-span is 63 feet above high-water and 85 feet above low-water. The others are swing draw-bridges, about 10 feet above high-water.

The following is a tabular statement of the principal features of the bridges over the Ohio, together with the cost of each bridge as far as ascertained. Nothing but the actual cost between abutments has been taken, all land damages and connections with main track having been excluded.

Name of bridge.	Length of approach from right bank.	Length of approach from left bank.	Total length, including approaches.	Maximum grade per mile (equated).	Maximum curvature.	Above low-water.	Above highest water.	Maximum local rise.	Width at low-water of channel openings on axis of bridge.	Cost.
	Feet.	*Feet.*	*Feet.*		° ′	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Steubenville Railroad	.....	.....	1,895.4	.....	.....	90	45	45	303¼	$1,000,000
Wheeling (Highway)	.....	.....	980	253	.....	91½	48	43½	980	161,594
Bridgeport (Highway)	.....	.....	638	.....	.....	53	9½	43½	212	68,500
Bellaire Railroad	1,490	864	4,001½	60.3	5	90	40	50	322 / 220	Unfinished.
Parkersburg Railroad	726	1,994	4,262	59.3	4.20	90	40	50	326½ / 326½	1,223,550
*Newport and Cincinnati Railroad (as commenced)	950	230	2,961.5	57.2	10	71½	9	62½	400	†820,394
Newport and Cincinnati Railroad (as altered)	2,400	1,680	5,861.5	66.0	10	100	37½	62½	400	†1,109,089
Covington and Cincinnati (Highway)	.....	.....	1,619	283	.....	103	40½	62½	1,005	1,480,000
Louisville Railroad	.....	.....	5,218⅔	79.1	.....	96½	45½	51	380 / 352½	1,615,120
Paducah Railroad	.....	.....	.....	.....	.....	.....	.....	52¼	.....	Not begun.

NOTE.—The lengths of earthen embankments are not included in the above.

G. K. WARREN,
Lieut. Col. Engineers and Bvt. Maj. Gen.

*This bridge was designed and nearly completed with the following grades and alignment: Commencing at a point 750 from the abutment on the Newport side, the grade was 0.2393 foot per 100 to the end of the first span, or 882 feet, then level over 7 spans, 1457.4 feet; then a grade of 0.465 foot per 100 on the last two spans, and 100 feet of the approach on a curve of 609 feet radius; then 0.8 foot to the 100 for 450 feet on a curve of 573 feet radius; then 0.8 foot per 100 on a tangent until the main line is reached. The Board of Engineers reported that the bridge as being built would prove a serious obstruction to navigation and that it should be raised 28⅓ feet to give 100 feet headway at lowest water, and 37½ feet at highest water. An estimate was made for doing this by lengthening the approaches on the same alignment. In this modification the maximum grade adopted for the approaches was 66 feet per mile, on tangents, for the reason that this was the ruling grade of the railroad on the Kentucky side, which had grades of 60 feet to the mile on 6° curves.

The raising of the bridge as recommended by the Board was ordered by Congress. It is not known what the new grades are as reconstructed, but they are in excess of those in the engineering board's plan, the height being the same while the approaches were not lengthened or the alignment changed.

†Estimated.