Grades and Alignment

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This subject encompasses such a large area that I have taken the liberty of applying it only to the secondary road system. There are two meanings to the word "grades" when associated with "alignment" of a road. The first one is "the rate of rise or fall of the center of the roadway." The other is elevation above ground line which is the meaning upon which major emphasis is placed in this discussion. Its application to the interstate, urban, and primary systems follows the same general principles but on grander scales. In Iowa, the interstate system totals 709 miles, the urban system 1,060 miles, the primary system 9,650 miles and the secondary system 92,164 miles.

The Secondary Road System in Iowa includes all public highways outside of cities and towns, except primary roads and state park and institutional roads. The legal status of the secondary roads in Iowa is that they are under the direct supervision of an elected Board of Supervisors that varies in number from three to five in all, but two of our 99 counties. And in these two the number is seven. These supervisors may be elected by either districts or at large, depending upon the desire of the voters in the county. This jurisdiction over the secondary roads has a few approval limitations as to plans and contracts that require Iowa Highway Commission concurrence. In the case of the Federal Aid Secondary System of some 32,000 miles, there is a joint responsibility of the two road agencies. The statute requirements for all secondary roads are that construction and maintenance work be under the direction of a licensed county engineer.

Modern equipment has lowered the cost of moving earth and rock to such an extent that grading costs usually do not exert a major influence upon grades and alignment. Rather, we give greater thought to the desire of traffic determined by origin and destination studies, road operating costs, value of right of way, and soil studies.

Just as we have streamlined motor vehicles for less resistance to air currents, so we have streamlined sections in road design. If we can design a road that does not materially obstruct the flow of winds and snows and one that is above the surrounding natural ground, there is less likelihood of having to remove snow from the traveled portion of the roadway. We are all familiar with the tendency to deposit airborne snow by the eddies induced by abrupt cut and fill slopes.

The old method of cutting hills to fill hollows had its place when the horse and the slip scraper were in their heyday. Along with this practice there were some headaches as well. These narrow hill cuts were snow traps. They also exposed many unstable areas in the roadbed. Springs and frost boils were prevalent. This generally occurred where the new grade line met the natural terrain grade. These spots were troublesome and costly.

With today's large, self-propelled, earth moving units we have been able to improve upon the laborious and relatively expensive horse drawn excavation methods. We have sloped the banks back on a flat slope, thus producing the excavation necessary, with possible addition of borrow, to fill the hollows. Since measurement is made on "cut" or "excavated" yardage, this has not cost us much more moneywise. Developments in soil science have spotlighted areas likely to cause maintenance trouble. By proper selection of adequate local materials, these trouble spots have been treated.

HIGH LEVEL GRADE LINE

By using a widened and higher section, more yardage is being moved more easily with modern equipment. The indispensable scraper operates most efficiently on flat cut and fill slopes with high yardage per mile. Where these conditions prevail, contractors reduce excavation prices to unbelievably low figures. The highway user and taxpayer benefit doubly from the streamlined cross section in the forms of safer operating conditions and lower maintenance costs, when compared to the old, narrow, and steep sections.

The policy of building higher grades within 80′ to 100′ right of way has had several profound effects upon the economy of Iowa's county road progress. The higher grades and the streamlining of these grades allow for efficiency in snow removal as well as for permitting the wind to sweep the surfaces clear of snow. This preventive measure is much more economical than the actual removal of the snow, which would otherwise constitute a continuing burden.

Although not looked upon with favor at first by some of the traveling public, objections to high grade lines are discounted after a heavy snow when the neighbor on a high grade travels when he pleases, while the neighbors on a low grade wait agonizingly for the road to be opened. Great amounts of money are spent to remove snow from roads,

Figure 1. High level grades are relatively free from snow.

yet there is no actual benefit to the road from this expenditure. By diminishing the amount of snow on the traveled roadway, surfacing materials and flexible pavements are saved in two ways, as shown in Figure 1. First, they are saved because less granular material will be bladed or thrown off while removing the snow. Second, by keeping the road surface dry from melting snow, the roadbed is less likely to become soft.

In the process of building higher grades, deeper ditches are obtained. Thus, when it is necessary to remove snow, we have a larger storage area for it. With this adequate storage area, there is less likelihood of a blocked highway should another storm follow closely on the heels of the first. These items point to a greater service to the traveling public.

EROSION CONTROL

Another factor controlled by adequate grades, along with the development of the "flume outlet," is erosion control. Here I allude to the use of the roadway embankment to serve as a dam to intercept peak run-offs from small drainage areas for relatively short periods of time.

A conventional drop inlet type culvert was first used to release the impounded water in a controlled manner. This is as shown in Figure 2, as a perspective downstream from the project. It is to be noted that the culvert is installed at the original ditch elevation. Maximum height of fill is approximately 15 feet.

However, it was found that it was very difficult to set or establish the grade of the main culvert barrel for all the various rates of discharges

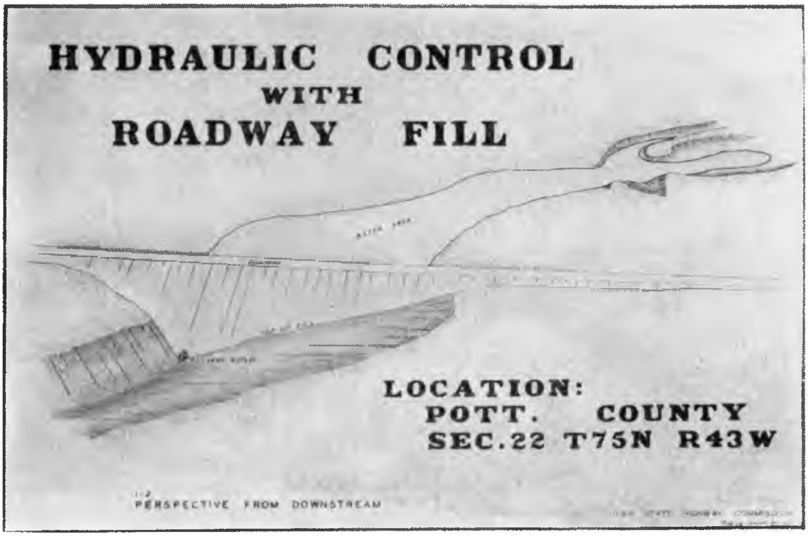

Figure 2. Conventional drop inlet type culvert is used to release impounded water in a controlled manner.

through this structure. Either the velocity was too high or too low. High discharges produced velocities that would erode the outlet streambed. Low discharges produced velocities through the culvert so low that silt would deposit in the barrel and the culvert would fill. In locations where the gully extended across the proposed highway location, a conventional culvert was placed at streambed elevation. It was found that the streambed eroded quite badly off the outlet of these culverts. This was probably due to high velocities generated within the culvert by excessively steep grades of the culvert barrel. However, in most cases this erosion was due to natural degradation of the stream bed which worked upstream to the culvert site.

In desperation to counteract this problem, several highway engineers resorted to bridging the entire gully. This system was found to be quite expensive and not too successful. Excessively long piling was required in pile piers to prevent loss of bearing because the stream had deepened. The gully banks continued to widen until excessive maintenance was required to protect the bridge ends. At some sites, bridge lengths of 150 to 200 feet were required to span the gully formed by runoff from drainage areas of less than 1,000 acres. Replacement of a bridge with a compacted fill and culvert is shown in Figure 3.

To repair the culverts which had eroded at the outlet, several types of structures and methods were used. These varied from simple rock

Figure 3. Replacement of a bridge with a compacted fill and culvert.

rip-rap dumped into the outlet channel to very expensive and elaborate structures, usually of concrete.

From the experience gained by use of these structures, it appeared that a stilling basin which would create a hydraulic jump, to dissipate the hydraulic energy, was required on the outlet end of culverts. To stabilize this hydraulic jump within the basin, it was necessary to place this basin several feet below the existing streambed. Concrete chutes were used to connect the stilling basin to the culvert. Several types of chutes and stilling basins were built and observed. From the exeprience with these various types, the chute and basin now being used was adopted.

In 1950 approximately 100 of these control structures, which had been in place for several years, were inspected in the field. It was found that less than 10 per cent of these structures were in need of any maintenance. It was quite apparent that, in most cases where maintenance was required, the stilling basin had been set too high or the basin was of a type which was no longer being used.

The highway engineers in Iowa generally refer to the chute and stalling basin type of structure as a "flume outlet," a misnomer, but it is still being used.

At sites where the highway crosses a deep gully, the inlet of a flume outlet type structure can be set at about the elevation of the top of the gully banks and the culvert barrel can be carried through the highway embankment at this high elevation.

Figure 4 is a plan view.

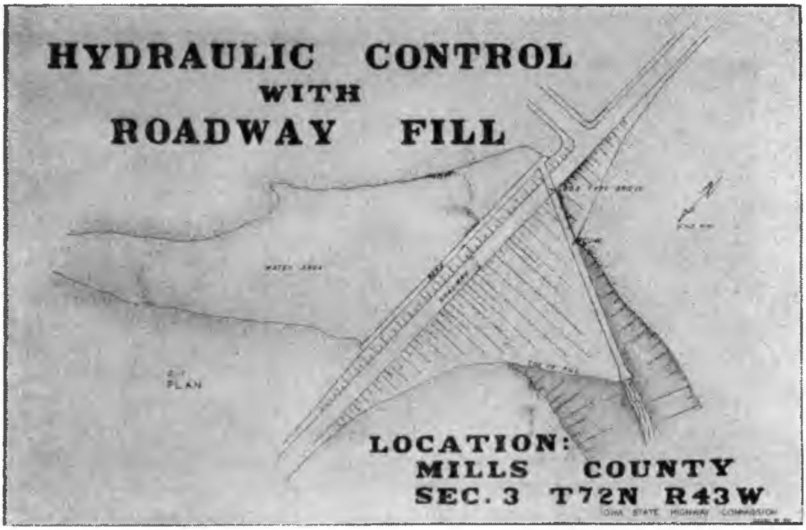

Figure 4. Plan view of flume outlet type structure.

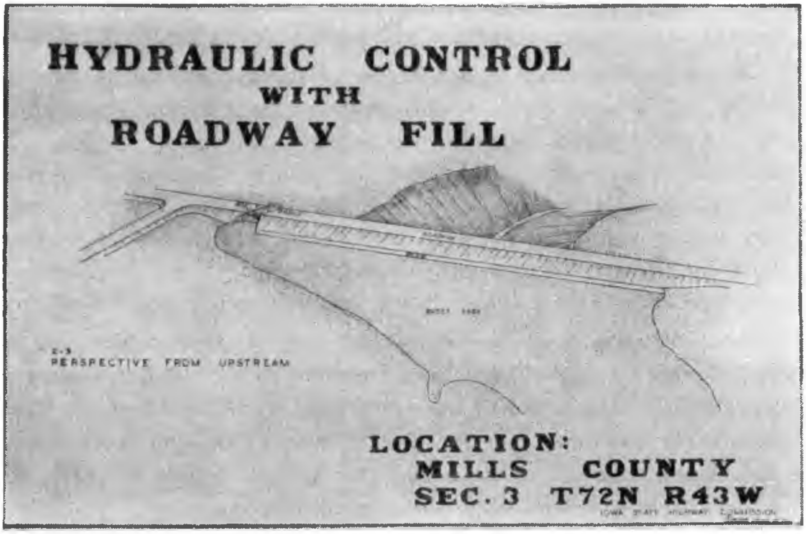

Figure 5. Perspective upstream view of same installation as Figure 4.

Figure 5 is a perspective upstream. Note that the bridge is constructed at the stream edge of the impounded water. This bridge is constructed on solid ground rather than on fill.

Figure 6 is a perspective downstream from project. It is to be noted that this bridge is constructed at an angle or in alignment with the flume. An apron is constructed at the bottom of the flume to prevent erosion. The flume terminates at the original ditch level without any change in

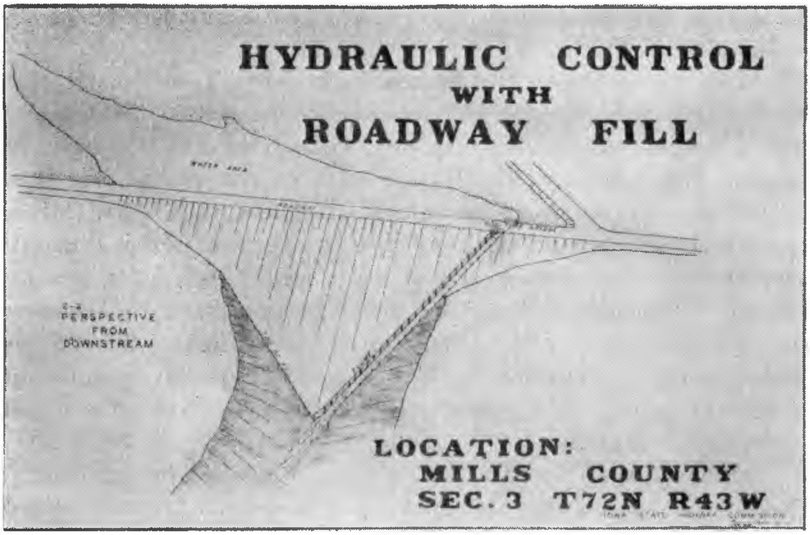

Figure 6. View from downstream of installation shown in Figure 4.

direction of water flow. The maximum height that a fill should be constructed when water is impounded is 30 feet to 35 feet.

A certain amount of water will be impounded in the upstream gully. However, unless very good soil conservation is used in the upstream watershed, the gully will soon fill with silt and the stream will be restored to its natural condition before the gully was formed.

A highway embankment constructed at proper grade under modern highway specifications is a very good hydraulic structure, and a considerable depth of water can be impounded without damage to the embankment.

One of the major problems in the design of high inlet structure on a fill across a gully is the obtaining of all the necessary data required to properly set the inlet flow line and to establish the elevation of the road grade so that the upstream property will not be damaged excessively. The use of high inlet-flume outlet type of structure permits the highway embankment to be used as a gully control structure. At the same time, a direct saving in highway construction can be obtained. For example, the total lineal feet of structure is less than that for the culvert installed in the bottom of the streambed. The load of the highway embankment which the barrel must support is considerably less. This results in a material savings in cost. The difference in cost per foot of barrel for an 8-ft. x 8-ft. concrete box culvert with a 7-ft. fill is about $25 less than one with a 17-ft. fill. Caution should be exercised to arrange with the owner of the upstream land to permit its temporary inundation.

With the revolution that is now going on in Iowa—that is, the change from that of getting the farmer out of the mud to that of giving him a hard, dustless surface—the high, well graded road is showing its worth. When you consider that the earth excavation will cost from $2,000 to $3,000 per mile for an ordinary grade while a 2-ft. higher grade may be built for $4,000 or $5,000, you see that there is little difference in cost between an ordinary and a higher grade. Yes, percentage-wise, it amounts to 50 per cent to 100 per cent more. But, compare this with the cost of a higher type surface that will cost $20,000 per mile or more. The additional $2,000 for grading might save a significant portion of the original pavement or prolong its service life and is a good protection of investment.

Then, let us go one step further. In one of the counties, namely, Kossuth, we are told that high grades have saved from $3,000 to $5,000 per mile in the construction cost of the base and higher type pavements. This has been accomplished by using better types of soils obtained in the grading operations from a lower elevation in the ditches which has permitted replacing a portion of the normal granular bases. Here we have a point where the original extra expenditure has not only insured the future base from failure but has actually produced a savings in the construction of the base.

BENEFITS FROM GOOD SIDE DITCHING

When we excavate material from side borrow pits to raise a roadway somewhat higher than the adjoining natural ground, we have places for run off to collect. In order to grade or raise the traveled way, we must obtain earth. The logical place to obtain this earth is adjacent to the grade, which is the closest possible source. Deeper ditches do help to keep water and frost action out of the roadway. Also, quite often a better type of soil is brought up to finish off the top of fills. The ditches obtained by this excavation then serve the purpose of collecting and disposing of moisture. We have moisture from above which may easily run off and away from the high and well graded traveled portion into these ditches. Likewise, the ditch serves as a drain for sub-grade moisture.

Let's look at this sub-grade moisture problem. In most of Iowa, it is a formidable problem. Years ago, field tile was placed under the shoulder of the road to help dry out the traveled way. This, with a small "V" type ditch which was about the only type easily constructed in those days, served the purpose for awhile. The tiles became broken, were tapped by adjoining farmers, and were not always kept in repair. Also, it was not an easy job to repair these tiles. The exact spot of trouble had to be found. This required exploration by digging and mostly by hand labor.

Then came the larger, heavier and more versatile construction machinery. Why not just deepen the ditches and use them as a means of keeping the sub-grade moisture at a lower level under the traveled portion of the road?

These ditches helped in other matters as well. What the farmer would have done without first the tile and then the deeper ditch in some flat areas is possibly hard to measure in consideration of the benefits. These ditches were used to drain the low lying portion of their farm land. Although this was not the aim of the road officials, the benefit cannot be overlooked, because it did help in an indirect way. By assisting in the drainage of the farms, more crops were grown, the land became worth more and valuations increased, thereby increasing the tax revenue but still not placing an undue burden on the land owner.

DESIGN STANDARDS

To keep up with the increased traffic, with its faster and lower vehicles and its heavier trucks, the commission felt it necessary to up-grade the base designs for flexible pavements as used by the counties. Since the commission approves the construction programs of the counties, desirable base design and pavement thickness have been adopted for general application. The fact that different soil types and drainage conditions may be encountered in each individual county must be recognized. When these soil types have been identified and the types of mineral aggregate available are known, an attempt is made to use these efficiently and economically in construction. In other words, the answer is not in the standardization of materials and methods. Rather, it is one of adopting methods and of using the available materials, which are dwindling in supply, to the best possible results.

In general, the desirable designs are as follows:

For portland cement concrete pavements:

100 to 400 v.p.d., 20 ft.-22 ft. Width, Min. 6 in. thick.

Over 400 v.p.d., 22 ft.-24 ft. Width, 6 in. to 8 in. thick.

For asphalt pavements:

For traffic over 100 v.p.d., 22 ft.-24 ft. Width, Min. base and pavement thickness of 8 in.

The minimum base or pavement thickness is further explained as follows:

Soil-aggregate or granular sub-bases with a minimum density (AASHO Test T-99) of 1.9 will be given credit as base for one-half of the sub-base thickness, not to exceed a total of 2 in.

The lower portion of bases may be of crushed stone, rolled stone, bituminous treated gravel, or of combinations of asphalts or chemicals and mineral aggregate or of combinations of granular aggregates of approved design. Stage construction is permitted within limitations.

Depth requirements may be modified when known local sub-grade conditions will provide satisfactory performance from bases of lesser depth or when known conditions will require a base of greater depth. Findings of research projects from the standpoint of results and costs are also used.

The experience of some Iowa counties, as they increase the mileage of dustless surface, is that these surfaces seem to generate higher traffic volumes than the old surfaces which they replaced. Also, the competing granular surfaced roads are losing appreciable traffic to the new dustless surfaces. These factors probably serve to bring about an overall reduction in annual maintenance costs.

SAFETY FEATURES

Another improved grade design feature being used in today's construction is the railroad crossing approach. The approach is built with adequate stopping distance on a level with the railroad track and not on a steep approach grade as in the past. This allows the motorist a better chance to see approaching trains and to stop on a level road surface. One can imagine the added safety, especially during periods when ice and snow cover the approaches. After seeing these safer railroad crossings, the local populace will not allow any other type to be constructed.

In many locations the "Y" intersections have been changed to "T" connections as shown in Figure 7. By this method the area of conflict is reduced, sight distances are improved, and generally better operational control is permitted. The area where vehicles cross each other's path is also reduced. Comprehensive traffic counts showing turning movements and peak hour volumes assist the traffic engineer to sign the intersections in a rational manner.

Considerable study and effort are being made to develop higher grades at secondary road intersections, especially at these locations where tall growing crops reduce the sight distance. It is calculated that a 3-ft. grade rise for a 300-ft. distance back from the intersection of a secondary road can be made for a reasonable amount. This investment would, no doubt, be one of safety, especially on those roads where the intersection

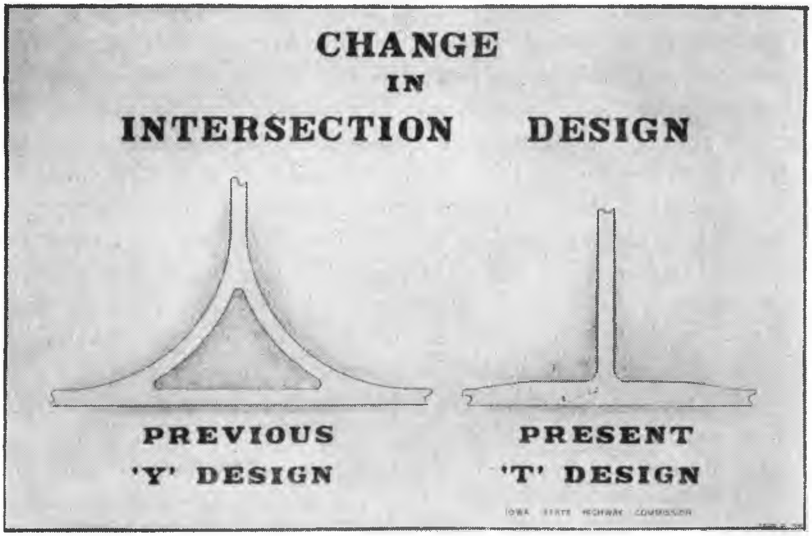

Figure 7. In many locations, "Y" intersections have been changed to the "T" type.

grades are lower in elevation than the grades on the remainder of the road. The safety of the traveling public is increased in traveling at a steady rate on a road that has adequate sight distances. The secondary road intersections in Iowa have a higher rate of fatal accidents per 100 million vehicle miles than those of the primary road intersections.

The fatality rate at intersections on the primary road system is 1.5 per 100 million vehicle miles of travel. On the secondary road system the rate is 3.8, or 2½ times that of the primary road intersections. The primary road intersection accidents are principally due to driver failure while the major cause of secondary road intersection accidents is due to the physical features of the intersections whereby sight distance on the crossing road is restricted.

Accidents at secondary road intersections are caused primarily by obstruction of the view of the driver of the side road. As most secondary road intersections do not involve a stop sign, most of the accidents can be blamed on the physical features of the intersection. Mature corn is involved in the major portion of secondary road intersection accidents as the corn blocks the view of both drivers approaching an intersection. Blind intersection accidents are also caused to some extent by wooded areas or farm buildings in the corner of a field next to an intersection.

There are approximately 8,600 miles of the rural primary road system with an average daily traffic on the entire system of 1,532 vehicles per day. The rural secondary road system includes approximately 92,000 miles which carry an average annual daily traffic of 55 vehicles per day. The chances of two cars being at an intersection on the primary road intersections obviously are much greater than at the secondary road intersections.

In general, the alignment of a road should be of as high a standard as is warranted for the traffic using the road with proper consideration to the terrain. Sharp curves or curves of widely different radii at the ends of long tangents should be avoided, because the surprise element can be deadly. The use of curves of small degree in flat to gently rolling topography is preferable to long tangents connected by relatively sharp curves. In the general alignment, the use of compound curves should be avoided, except for the transitions required at intersections.

The demand for higher grade and alignment standards on the primary and secondary roads will increase as more and more of our road users become acquainted with these superior design features being provided in the interstate system. More care in the design of grades and of alignment on roads built for through traffic is required than when the road is to be used for land service only. Higher grade lines increase the distance from the ground water supply to the sub-grade. This has direct application as to the effect of damaging results from capillary moisture and its resultant softening of the sub-grade. The safety features of these higher standards will prove their worth in a decrease of the number of traffic accidents and in the resultant reduction of injury and loss of life as well as a savings in property damage.

As in so many fields of man's endeavors, we find that success usually follows the intelligent application of the many lessons learned by experience and research over a long period of time. You will recognize readily that this paper discussed many design criteria that have been known and available for several years.