DESIGN OF BRIDGE APPROACH SLABS

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There is one outstanding fault of too many bridges that the motorist is well aware of--the bump at the approach, This shortcoming is particularly noticed in todays well engineered highways and expressways with high-speed traffic. This condition brings to mind several questions. Why does the approach slab cause this bump? Is this deficiency inevitable? How long has this been a problem and what have we done about it? The answers to these questions are becoming more important as traffic speeds increase and the problem requires the attention of engineers concerned with the design, construction and maintenance of highways and bridges. If we are to succeed in obtaining a smooth riding facility, which is so important today, we must fully coordinate our efforts toward that end.

Why does the approach slab cause this bump? First, consider where relatively deep, incompressible foundation soils are overlain by soils subject to considerable compression under load. The bridge abutment is founded on piles that bear on the relatively incompressible soil. The clay soils have consolidated under the weight of the embankment while the abutment has remained fixed. This differential settlement interrupts the smooth grade. An additional factor adding to the embankment-abutment differential is the consolidation of the fill itself. This added factor is due primarily to the improper placing and compacting of the embankment material. This, I believe, is the most common cause of our problem and the one causing the worst bump.

Second, a much less common condition occurs when both the embankment and abutment are founded on compressible clay soils. In this case the abutment will settle more than the embankment. This differential settlement will again cause a sharp break in the grade, resulting in a rough ride.

Third, a fairly common condition exists where granular backfill adjacent to the bridge abutment was inadequately compacted and, subsequently, densified under repeated loads and vibrations.

Another cause of a bump at the bridge is a built-in one. The approach slab is laid to the plan grade rather than the actual grade. This fault can be avoided by running a profile grade across the deck after construction and then adjusting the grade to fit the conditions.

The above listed causes of a rough condition at the approach slab are not necessarily the only causes, but are the major ones by far.

I think we should review briefly the evolution, or history, of approach slab design. Since I have more data on Illinois history and designs than any other area, this information therefore is limited to that area. I believe, however, that it would also apply to many other areas.

Prior to year 1932 approach pavement slabs were not considered vital or necessary, as at that time the Division of Highways followed a policy of omitting concrete pavement on fills where it was anticipated that settlement would occur. These fills were constructed to an elevation higher than the proposed grade in the amount of the anticipated settlement. They were surfaced with gravel or crushed stone and were allowed to consolidate and settle before the pavement was placed.

In 1932 a standard drawing was developed because of wide-spread objections due to the roughness and dust problems resulting from the above mentioned gaps. This standard called for a reinforced concrete slab that spans the construction excavation made necessary in building the bridge abutments. During that period practically all bridge abutments consisted of the solid or slab-type design. One end of the approach slab rested on the abutment proper and the other end on two feet of natural ground.

At about this same time, they adopted a policy of compacting fills by water soaking. Since bridge abutments were not designed for full fluid pressure, this water soaking had to be omitted in the proximity of the structures. It was then suggested that they start designing for full fluid pressure in order that the water soaking could be continuous to the abutments. It was also suggested that the abutment excavation be backfilled with porous granular material. The latter suggestion was followed for a time, but it seems that the consensus of opinion was that the cost was excessive for the slight decrease in settlement that was being obtained.

In 1935 another standard drawing was developed and adopted as the policy for bridge approach pavements. The slab-type abutments were still being used almost exclusively. A 20-foot reinforced concrete slab was provided at each abutment where the depth of footing excavation was 10 feet or less. If the excavation exceeded 10 feet in depth, two 20-foot reinforced concrete slabs were provided with intermediate pile bent supports. Unlike the earlier standard which provided a 9-inch uniform thickness of pavement, the new standard provided a slab 10-1/2 inches in depth with a thickened edge of 16-1/2 inches. This slab was designed to carry the live and dead loads without support from the soil between the abutment and the pile bent.

When the depth exceeded 10 feet and the double approach slabs were used, the intermediate pile bents were constructed using untreated piles. These piles were driven to a bearing capacity of 15 tons with an anticipated life of at least 10 years. Any appreciable settlement occuring within the 10-year period would become apparent so mud jack cylinders were provided in the slabs. Additional material could then be economically introduced beneath the pavement to compensate for the settlement of the fill.

The use of slab-type abutments was gradually replaced by the open type or spill-thru pile bent in the early 1940's. Although there is little excavation required for the spill-thru bent, it was recognized that the fill behind the abutments settled and a new standard drawing was issued in 1941.

In November of 1957 the criteria for the use of two sections of approach pavement was restated for the spill-thru type abutment. If the approach slab extended over fill material, two sections were to be used, and if it was to be supported on natural ground at grade, then one section was to be used.

In 1958 a revised standard was prepared indicating the use of a pile bent abutment that incorporated creosoted piles in lieu of untreated piles still driven to a 15-ton capacity.

In 1961 a comprehensive study was conducted of the amount of settlement at bridge abutments. Each of the districts was requested to submit pavement elevations of a large number of structures throughout the state. These figures were studied, evaluated, and a new criteria established for the determination of the length of approach pavement piles. It is the hope that this criteria will provide a smooth transition in the approach slab if settlement of the embankment occurs. Ideally, the approach pile bent would experience one-half the amount of settlement that occurs 40 feet back from the abutment.

Other states have used similar methods for the design of approach slabs and still others have used several variations. For example, the length of the slabs vary from 10 feet to 30 and more feet, and the thickness of the slab likewise varies. On the Illinois Tollway the length of slab was set at 30 feet. This was done with the idea of making any differential settlement less noticeable since the change in grade would presumably be made over a greater distance.

As previously mentioned, the Illinois Department of Highways made a field survey to evaluate the design procedures in an effort to minimize the bump experiences at the ends of bridges due to differential settlement between the fill and structure.

This survey contained many bridges using both Method I and Method II approaches. Method I approach employs a rigid slab designed to carry maximum legal loads without support other than at the ends of the slab. The end adjacent to the structure rests on the backwall and the other end derives its support from the subgrade.

Method II is similar except that the end away from the bridge is supported on a single row of treated timber piles driven to 15-ton bearing in or below the embankment. The original intent of Method II was that some part, but not all, of the embankment settlement would be reflected in the piles. Any differential settlement would then be spread over two slabs or forty feet rather than be concentrated in the first 20 feet away from the bridge. If this could be accomplished, the bump would be significantly reduced in severity.

A brief summary of this survey is as follows, and I quote the Illinois Department of Highways:

"It was hoped that this study would reveal where the settlement could be expected to take place, i. e., does it occur in the fill, in the subsoil, or in some combination of the two? It is suspected that in the majority of cases the latter is true, but unfortunately the evidence herein contained is too inconclusive to arrive at an answer.

A study of the attached data has indicated that the average settlement experienced with Method I approach slabs is in excess of 90% of the settlement experienced forty feet from the abutment or, in other words, the bump is concentrated in the 20- foot approach.

Of the Method II approaches, about 55% had piles driven to such depths as to preclude the possibility of approach slab settlement. In these situations, the piles served no purpose other than to move the bump twenty feet further from the structure. Of the remaining approximately 45% of Method II approaches, the piles moved enough so that the average approach of that group settled about half of the total movement observed at the joint 40 feet from the abutment, and thus effectively spread the bump over 40 feet.

It was also noted that in situations where the piles were driven into the subsoil, about two-thirds experienced no movement. Of the piles stopped in fill soils, 80% performed as originally intended.

Because in many particulars there is no clear-cut trend, any conclusions reached must be expressed in generalities. It is believed, however, that we can generally make the following comments:

1. Method II approaches appear to materially de-emphasize the bump at the end of structures when they are permitted to settle slightly.

2. Generally, piles should penetrate no more than ten feet into subsoils, and then to penetrate no subsoil materials with Qu values in excess of 2. 0.

3. Piles should be driven to a pre-determined depth rather than a specified bearing."

Other factors also have a tremendous effect on this problem. For example, the stub or spill-thru type of abutment vs. a closed or bin-type. This has a bearing on the quality of compaction obtained near the bridge. Another variable that greatly complicates the problem is the skew of the abutment. The larger the skew, the more difficult the problem becomes. The skew increases the length of the slab if the end away from the structure is squared off with the highway slab. The acute corner of the approach at the abutment creates other problems such as proper compaction of the fill as well as deflection of the slab.

This history brings back one of the questions previously asked-- Is this deficiency inevitable? I am sure that many individuals have arrived at that conclusion. I do not believe, however, that we can afford to admit defeat this easily. We have seen too many bridges that had a reasonably smooth approach to say that we are unable to do anything about the rough ones.

In most offices that I know personally, the approach slab design and construction is a "step-child." The bridge designer feels that it is primarily the responsibility of the highway design engineer since, after all, it is a slab on a grade that resembles the highway slab. Naturally the highway designers are prone to reason the other way. As a result, not too much determined effort has been made by all concerned.

Mr. G. Margason, Road Research Laboratory, England, authored a paper entitled "A Study of the Settlements at a Number of Bridge Approaches on the Maidenhead By-pass" in which he concluded, and I quote:

"This investigation has shown that it is possible to construct approach slabs to bridges that will not exhibit appreciable differential settlement when a good quality fill material is placed, in accordance with the existing M. O. T. * specification, on a stable subsoil. There is evidence to show that this specification should not be relaxed if settlements large enough to affect the riding quality of the road are to be avoided. On the other hand, the work has shown that it would be difficult to comply with a specification calling for a higher state of compaction.

The next step in investigating this problem will be to conduct similar experiments at bridge sites with the same and other types of abutments and again founded on stable subsoil, but using less favourable fill materials.

*Ministry of Transport and Civil Aviation.

Arrangements have been made for this work."

This same position is maintained by many experts in the soils engineering field. They say that the primary reason for the troublesome bump is the lack of proper compaction adjacent to the bridge abutment. Of course, if an underlying stratum of peat, or other highly compressible material is present, additional measures must be taken. This opinion applies to the majority of structures; however, I personally believe that they are correct and if we could actually get compliance with the specifications that our problem would virtually be solved. Instead of assuming that we get compliance with specifications, we must be sure. In order to be sure, we must have the services of highly competent soils engineers and resident engineers. The soils engineer to determine whether or not the subsoil is adequate, type of backfill material required, necessary compaction, optimum moisture content, etc., to minimize any differential settlement. Of course, this would include any special treatment required at the location. The resident engineer must also be competent and have the necessary authority and backing to see that the embankment is built to specifications. There are entirely too many bridges built that simply do not meet the requirements. There are several reasons offered for this non-compliance and a few of them have some basis. One can understand that full compaction is many times more difficult to obtain the acute corner of a closed abutment where it is so restricted, than it is in the highway embankment where roadway machinery can operate.

If we accept for the moment that the necessary compaction adjacent to the abutment is virtually impossible or too costly -- what can we do about it?

Since the slabs are generally designed to carry the load with no support except at the ends, the theoretical cause of the bump is due to the differential settlement between the abutment and the end of the slab. If this is true, a settlement of one or two inches in the embankment, with loss of intermediate subgrade support, would cause the far end of the slab to be under the plan grade by that amount and the resulting break in grade at each end of the slab would be noticed perhaps, but would cause no real concern to the auto passengers. This is assuming no appreciable skew of the structure. An examination of many bridges shows that this is not true at all. With existing slab thicknesses a loss of intermediate subgrade support and an end settlement of the assumed one or two inches, we notice a substantial jolt when we go over it as design speeds. What would be the reason for this? It is due to the permanent deflection of the slab causing a concave warped surface ! I know of cases where the slab has been cored 4 or 5 feet from the back wall and the embankment has settled a foot or more under the slab. If we now consider a structure with considerable skew, and it seems that today most are in that category, we magnify our problem considerably. A great number of the approach slabs are square with the roadway at the end of the slab, 20 feet from the bridge at the centerline of the roadway. Due to the skew one side of the slab has shortened appreciably, while the other edge has lengthened by an equal amount. With no subgrade support the result is that the long edge will deflect much more than the other edge. This causes the slab to warp transversely as well as longitudinally, resulting in a "double" jolt. I believe that the motorist is much more sensitive to the sideways motion than he is to the change in grade. Obviously the acute corner of the slab is the worst one -- with the long side, and less chance of support due to compaction difficulties resulting in excessive deflection and a permanent set.

I would like to offer two suggestions for your consideration which may be beneficial in minimizing this bumpy condition at the bridge.

The first is a cement stabilized backfill adjacent to the abutment that will not require the compaction effort of most soils and will not further consolidate under repeated loads and vibration. This has been used at several bridge sites on expressways in Chicago by the Cook County Department of Highways. The first three have been in for over two years and more have been constructed this year. A recent examination indicates that the riding qualities of the approaches are exellent.

On these projects a borrow sand was specified by the following gradation:

Passing 3/8 sieve	100%
Passing #4 sieve	85-100%
Passing #100 sieve	0-30%
Passing #200 sieve	0-10%

One bag of Type I portland cement was mixed with each yard of the above sand. No additional water was needed to provide the damp mixture required for good compaction. The mixture was discharged from a ready-mix truck onto a platform from which it was placed by a crane bucket. Two workmen directed placement, leveled the fill layers and compacted each layer with gasoline-engine powered tampers. Some of the fills were in excess of ten feet. Proctor cylinders molded from the job mix were broken in compression when saturated and provided strengths of 107 psi in seven days.

Although these materials and methods provided excellent results, a probable cost saving could be obtained by using natural soils at the job site and using different methods for mixing and placing. Of course, the local soil must be appraised and cement requirements would depend on the soil used.

The other suggestion, and one that would be more in line with a bridge engineer's solution, is a definite stiffening of the approach slab.

This more unusual method merits consideration where the skew is quite large. This could be thought of as a "dry-land" bridge spanning the distance from the backwall to the end of the approach. After the embankment has been placed and compacted, several longitudinal and parallel trenches are excavated with a small trenching machine. The trenches would then become the webs of T-beams with longitudinal steel placed in them. No forms would be required as the concrete would be cast directly on the embankment and in the trenches, resulting in a T-beam approach slab with much less deflection and plastic creep than the conventional slab. Very little, if any, extra concrete and steel would be required, and as a result no additional dead load. It may be argued that the backwall must be designed for the load due to the additional "span." This, of course, is true if subgrade support is lost but it is also true for the conventional slabs now being used regardless of whether or not we provide for it in design.

We have considered this approach slab problem historically, the causes of the rough ride and several methods of solving it.

Briefly, the bump at the bridge approach could be greatly reduced or eliminated by securing an embankment that fully meets the requirements of the specifications prepared by a competent soils engineer.

Secondly, when this is not done, for whatever the reasons, I believe that an acceptable job can be had by using a cement stabilized backfill to minimize the consolidation of the fill after the slab is placed.

Thirdly, in a number of cases, particularly in larger skew angles, a stiffened approach slab should be considered to reduce the creep and deflection and, thereby, considerably reducing the bump.

I am grateful to Messrs. Thunman and Nicholson of the Bridge Section, Illinois Division of Highways, for the data concerning this problem in Illinois.

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<u>Subject References</u>

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