Smooth-Riding Bridge Decks

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● MODERN HIGHWAYS, particularly those with limited access, encourage travel at high speeds. For safety and comfort these highways require smooth-riding surfaces, finished to small tolerances.

Why is a distinction made between the construction of a concrete bridge deck and construction of concrete pavement on grade? The answer is that the techniques for construction and the problems are very different. Some major differences are:

1. The support yields appreciably with the addition of the concrete load.
2. The methods of controlling the surface during construction are markedly different.
3. The labor situation differs, often producing profound effects.

Each of these factors is examined because the key to smooth-riding decks will lie in their proper handling.

This report is confined to a discussion of bridges with concrete decks supported on steel members because the overwhelming majority of new highway bridges is still of this type and the problems are more serious than for short structural concrete spans. Secondly, only single course pavements in which the structural slab and wearing surface are placed monolithically are considered.

What is desired in attempting to provide a smooth-riding surface? Most specifications for bridge deck finish tolerances use the same requirements as for paving on grade. These generally call for no surface deviation over 1/8 in. from a straight line 10 ft long, although some agencies say 16 ft. While such a requirement is necessary, it is not in itself sufficient.

It is possible to have long waves in a pavement surface that will meet the 1/8 in. in 10-ft criterion and yet cause a sensation of roughness at high driving speeds. For example, if a straight profile grade line approaches an 80-ft span steel bridge and a smooth sagging curve on the bridge with a 2-in. ordinate at midspan of the structure, the specified 1/8-in. deviation in 10-ft requirement is met and yet a pronounced bump results at high speeds (Fig. 1). If the shape of this smooth sag is assumed to be circular, for simplicity, its radius is 4,800 ft. The deviation from any 10-ft chord would be only 1/32 in., which would be scarcely discernible with a 10-ft straight edge.

Is it at all likely that any such sag as 2 in. can occur in an 80-ft span? It can be demonstrated that it can occur, and will, unless some simple precautions are taken, which are not uncommonly overlooked.

The supporting structural steel girders or rolled beams deflect appreciably during deck concreting with the addition of the dead load of concrete because this load is a large part of the load to be carried. In conventional rolled beam design, this deflection for an 80-ft span is of the order of 2 in. at the center of the span and tapers off parabolically to zero at each support. For longer spans, of 200 ft, for example, a corresponding deflection would be 5 to 6 in.

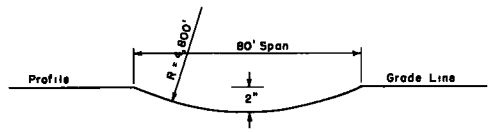

Figure 1. Sag at bridge.

The controls for finishing the concrete surface, such as screed rails mounted on adjustable chairs, are set in position by survey before the concrete is placed and hence some account must be taken of the predicted steel deflection in setting them. The methods of calculating such deflections are well established and their accuracy is generally sufficient for the purpose.

At this point, it is desirable to digress to comment on the confusion occasionally encountered between camber and dead load deflection. Camber diagrams are usually given on the structural steel contract drawings. These show the total vertical curvature specified to be fabricated into the beam or girder to provide for total dead load deflection, plus, occasionally, the vertical curvature of the profile grade line. This camber is not to be confused with the dead load deflection for the concrete only, not even including the reinforcing steel. Such figures are usually obtained from the design office. It is apparent from the figures given that neglect of the concrete dead load deflection must produce an appreciable ripple in the finished riding surface for each span. As a matter of fact, the oscillation described is close to resonance for the spring systems of most passenger cars traveling at approximately 60 mph.

The method of controlling the strike-off of the fresh concrete on bridge decks differs markedly from that used for pavement on grade. At the present time, machine finish is not widely used for bridge decks and may never be warranted for single short span bridges. This means an essentially manual operation with heavy emphasis on the skill and reliability of the cement finishers.

The usual practice is to set screed rails either of tee structural sections or of $1\frac{1}{4}$-in. diameter pipes supported on adjustable metal chairs. The function of the screed rail is to support the screed which strikes off the wet concrete. The screed rails generally lie parallel to the direction of traffic and spaced about one lane width, but preferably so spaced as to place the supporting chairs over a structural member. Needless to say, the spacing of the chairs must be small enough to prevent the rail from sagging under the load of the screed when partly supported by wet concrete.

From time to time there are references to the desirability of detailing the curbs or some element of edge structural steel to serve as a screed rail for the paving. While superficially this sounds like an excellent idea, it has the fatal defect, as will be seen later, that it lacks adjustment to correct for the inevitable improper camber.

The proper setting of the screed rails is a matter of the utmost importance. They are set to calculated grades by surveying methods, and hence are entirely independent of the camber of the supporting structural steel (Fig. 4). The elevations for the screed rail are calculated from the profile grade line, taking account of the transverse roadway slope and the dead load deflection resulting from the concrete load. It must be remembered that the rails are set after the forms and reinforcing steel are in place, but before the concrete has been deposited. This means that the supporting structural steel is carrying its own weight plus that of the forms and reinforcing steel. The table below indicates the proportionate weights the steel must carry, and the corresponding deflections.

LOAD	PROPORTIONATE SHARE	DEFLECTION FOR 80-FT SPAN
Structural steel itself	20 percent	½ in.
Slab forms	5	1/8
Reinforcing steel	5	1/8
Concrete	70	1 3/4

At this point, attention is again called to some common defects in design and fabrication. Slabs are usually designed to be of uniform thickness (from 6½ to 7½ in.) in a given bridge. The top surface of the slab is shaped to fit the profile grade line. For uniform thickness, the bottom surface of the slab should be parallel to the profile grade line. Yet many designs are still seen with no haunches over the beams to take up the variation in shape of these 2 curves—the profile and the beam camber (Fig. 2).

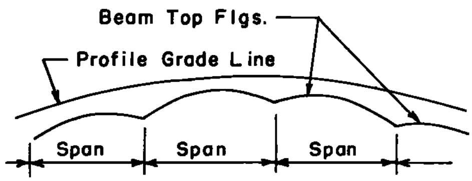

Figure 2. Variation-beam to profile.

Where the above situation is imperfectly understood in the field, some serious troubles arise. The carpenters, for simplicity, will often frame the slab forms in a fixed position relative to the top flange of the beams, ignoring the profile grade line. The top and the bottom reinforcing steel is then placed and the surveyors then set the screed rails. At this point, perhaps the night before concreting, the inspector uses a rule to measure from the screed rail to the form at several places. He may find the slab thickness varying with badly cambered beams as much as 2 in. (Fig. 3).

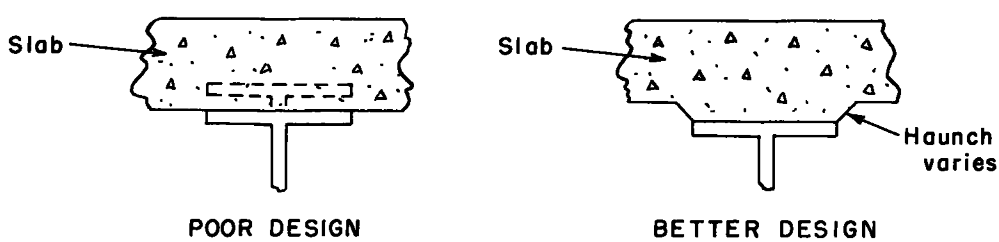

Figure 3. Slab bearing detail.

The correct procedure is to take elevations by level survey on the top flanges of every beam or girder at about 25-ft intervals and from these elevations calculate the accurate relative positions of the form top surface and the beam flange at each point. This information is given to the carpenters and they frame the slab form in the proper position. Only in this way can the slab turn out to have the precise and uniform thickness.

Pursuing this same method will correct another serious defect: namely, the incorrect positioning of the top reinforcing steel relative to the slab surface. The chairs that support this top reinforcing steel are detailed for uniform height. Where the slab varies in thickness, due to field error as described, the position of the top steel varies relative to the riding surface. There have been instances where reinforcing steel designed for $1\frac{1}{2}$-in. cover turned out to have as little as 5/8 in. to the riding surface. This fault was discovered only after 3 years of heavy traffic had caused flaking off of the concrete over each rod. Only rapid repair of such defects can save such a deck from complete deterioration. At this point it may be well to stress the importance of adequate cover over the top reinforcing steel in achieving improved durability of the wearing surface. Two inches is not excessive.

Because the structural steel and dams should lie exactly in the riding surface, it is of the utmost importance to set them carefully to the proper grade. When properly detailed, they have provisions for facilitating exact setting. Such adjustments may be by shims at the bearing surfaces or by reaming undersized rivet holes after C-clamping or tack welding the end dam to exact elevation. It is necessary, of course, not only to set them to the proper grade but also to the exact inclination so that their top surfaces will lie in the plane of the bridge and approach pavement. Similarly, because it is usually easier to adjust the approach slab paving, this is properly done after the bridge paving in the end spans has been completed.

Figure 4. Checking camber.

Everyone has experienced the disconcerting bumps frequently encountered when entering or leaving a bridge. These are usually caused by settlement of poorly compacted fill behind the abutment which has dropped the approach pavement. The best solution, albeit not inexpensive, is the use of a structurally designed concrete approach slab bearing on a concrete seat built into the back of the abutment wall. Such structural slabs are used even where the approach pavement is bituminous. Some authorities, wishing to save money, advocate the omission of the structural approach slab and set the approach pavement about 3/4 in. high. Such a practice definitely creates a bump for some indeterminate period until the approach pavement settles, and it is manifestly impossible to predict how much settlement will take place. This practice is not recommended. If a structural approach slab is omitted for economy, it is better to exercise close inspection to secure proper compaction of the fill behind the abutment and finish the approach pavement to meet the bridge pavement. Securing good support is greatly aided by limiting the excavation for the abutment to a minimum, and specifying a coarse granular backfill behind the abutment.

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In regard to the actual paving operation, no matter what precautions have been taken in early preparation, the conduct of the operation itself will have a major effect on the final riding quality of the deck. The exact details and sequences of operations must be well known to both the contractors' supervisory force and the owner's inspection force. There is no time to resolve differences or improvise while the paving is in progress. For example, with the mass of reinforcing steel in the slab it is most difficult to bulkhead if it becomes desirable to stop the work before reaching an end dam. Accordingly, the exact details for such a bulkhead, including the steel dowels, should be known and any possible preparations made for its installation before the concreting starts (Fig. 5).

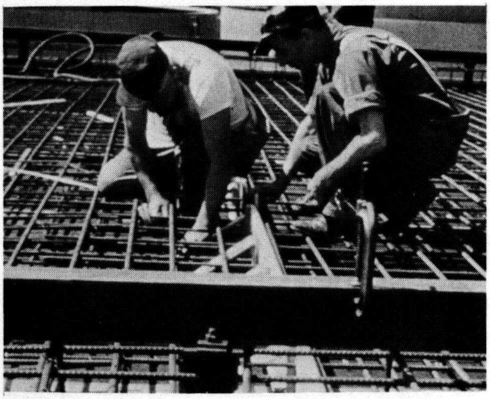

Figure 5. Placing a bulkhead.

Contrasted with the situation of paving on grade, the working space on bridge decks is severely limited. The space becomes progressively smaller, hence the sequence of moves, the placing of equipment, and even the lines of travel of the personnel should be planned in advance. Many concrete slabs have had their surfaces damaged by careless workmen walking over the wet surface at the end of the day.

Since bridge paving employs manual methods to a greater degree than paving on grade, the experience and attitude of the labor force must be considered. There are many union locals in this country which, while containing an adequate number of experienced cement finishers, have few if any who have done highway paving. The finisher usually is concerned with texture rather than accuracy of alignment, and may have a very poor appreciation of the necessity for very close tolerances in the final riding surface. Where a long stretch of pavement on grade is to be done, the contractor and owner have 2 major factors working for them:

1. The prospect of steady employment for many weeks, with large earnings from overtime pay, induces an exceptionally cooperative attitude in the finisher.
2. The operation continues long enough for even inexperienced finishers to learn the proper techniques, if given appropriate guidance.

On bridge decks, the exact opposite is true. The number of finishers required is such that the contractor usually must augment his regular finisher force greatly for the single day or two required to pave the limited area he has ready for paving. With the prospect of only 1 or 2 days' work on this relatively strange operation, the extra finishers have small incentive either to learn the new techniques or to observe the care necessary to secure the desired results.

This factor is by no means of merely academic interest. It is a basic difficulty and not readily solvable under the customary methods of contracting for work.

In the author's experience, the best results have been attained where the bridge construction was part of a large package contract for highway construction and where the bridge work was not subcontracted. In such cases it has occasionally been possible periodically to interrupt the paving on grade and to use the same experienced paving crew on the bridge deck paving.

In designing the concrete mix, in addition to the usual requirements for paving on grade, a more fluid consistency must be adopted because of the large amount of reinforcing steel in the slab. Somewhere between a 2-in. and a 4-in. slump will usually be required. Efforts to maintain a high degree of uniformity in the consistency are well worth the trouble. Variations in the consistency are believed to account for unexpected settlements in portions of surfaces which appear to have been properly struck off when the concrete was placed.

While it is unquestionably the contractor's responsibility to provide all the necessary tools and equipment, the writer has found it a good practice to have his inspection force check these off the day before the early stages of concreting. These include vibrators, screeds, scraping straight-edges, lutes, testing straight-edges, longitudinal floats, burlap and, last but not least, portable cross-bridges from which to work over screeded wet concrete.

Since the final finishing operations require good light for proper performance, the engineer should exert his influence to see that the size of deck paving and the starting hour are so chosen as to permit finishing during daylight hours. Further, he should assure himself that adequate labor, both skilled and unskilled, is available for work before starting the concreting. There is only one time to obtain a good riding surface and that is the day the concrete is placed. Corrective grinding of the surface later is of very limited effectiveness and may do more harm than good.

Proper distribution of the concrete to the deck is important. The method varies with the size of bridge and the site conditions. For small bridges a common method is by crane and bucket. This has the advantage of great flexibility, since the concrete may be deposited in any part of the deck and in any sequence. However, it has the disadvantage of placing concrete in a heap as the bucket is discharged, with the tendency to develop dense spots at the center of each heap, connected by less dense concrete shoveled into the spaces between. The author has sought to overcome this tendency by swinging the bucket like a pendulum during discharge in order to get a more uniform density. Manually, this is admittedly an awkward operation and there is no positive proof of its efficiency. The least that should be done is to spread the heaped concrete as uniformly as possible by manual shoveling, and to vibrate all areas fully.

For long bridges or viaducts, especially where all parts are not readily accessible by crane, a common method is by buggies (manual or power-driven) operating over portable platforms which are progressively removed as the concrete is placed (Fig. 6). If a second roadway or a wide dividing mall is available for concrete delivery, this method has flexibility as to sequence of placing concrete. If not, each successive move should be thought out carefully in advance to avoid possible "cold joints" in the concrete.

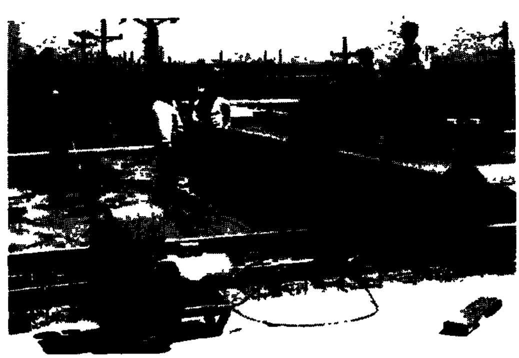

Figure 6. Distributing concrete with a power buggy.

In planning the sequence of concrete distribution in any given span, a controlling factor is the position from which the various finishers must work. It is not feasible for a finisher to manipulate a scraping straight-edge or testing straight-edge much beyond 12 ft from where he stands. This has led to the practice of placing and finishing one lane at a time. This method has the disadvantage of deflecting the supporting structural steel some hours after concrete in an adjacent lane has been placed. Unless the concrete set has been retarded, either by cold weather or by a chemical retarding agent, such movements can open cracks in the young concrete or reduce bond effectiveness through movement of the concrete and reinforcing steel relative to one another. Where at all possible, the concrete should be placed and finished across the entire width to be poured simultaneously and advanced uniformly along the roadway (Fig. 7). This procedure requires the use of cross-bridges close to the concrete surface from which the finishers can work. Such cross-bridges are substantial and must be fabricated in advance of the concreting. Also, means must be provided to move them from position to position.

Figure 7. Spreading concrete manually.

A similar problem arises where continuous steel main framing for 2 or more spans is used. If the concrete were to be placed in a single advancing movement from one end toward the other over the intermediate support, the angular deflections of the steel over the intermediate support would tend to open cracks in the partially set concrete at that point as the weight of the concrete was added to the second span. Two methods have been used to overcome this effect:

1. Require in the specifications that the contractor employ 2 concreting crews and simultaneously deposit concrete in both spans working from the ends toward the intermediate support.

2. Add a retarder to the concrete mix design and refinish over the intermediate support if necessary.

The first method meets with very strong objections from the contractors, even when specified, and is more costly. Also the question arises: what to do in a 3-span continuous bridge?

The second method has much to recommend it and the effects of its use should be studied and reported on.

Another consideration is the method of striking off the wet concrete to the proper elevation and slab thickness. The screed rails of pipe or structural tee section properly supported on adjustable metal chairs that remain in the finished slab have already been described. If the screeding is completely manual the screed may be no more than a wooden 2 x 6 about 14 ft long moved with a sawing motion by 2 finishers. This method, while primitive, is still in use and can produce good results. However, a much more common device is a metal screed which may consist of a steel beam or channel with web vertical and a bearing surface of about 6-in. width (Fig. 8). It should be of sufficient stiffness to support a vibrator mounted at its center without observable deflection. If the deflection under its own weight and that of the vibrator exceeds 1/16 in., it should be performed with sufficient camber to eliminate this deflection.

Figure 8. Vibrating screed.

The metal screed with the centrally mounted vibrator is conventionally moved forward along the screed rails by 2 laborers who pull on light lines fastened to the ends of the rail. No sawing motion is necessary, since the vertical oscillatory motion imparted by the vibrator both strikes off and consolidates the concrete. While it is true that the screed is partly supported by the wet concrete, it is the author's observation that the support provided while vibrating is small. For this reason, it is most important that the spacing of chairs and the flexural strength of the screed rails be such as to prevent sagging of the screed rail under the weight applied by the screed. Clearly, if the screed rail is too weak to support the screed properly it is of small value. It can be shown that under normal paving consistency of concrete, the conventional $1\frac{1}{4}$-in. pipe screed rail, if supported at 6- to 8-ft centers, will deflect excessively and so tend to put a ripple in the struck-off concrete. Although it is true that other later finishing operations tend to minimize these ripples, it is bad practice to strike off the concrete with a built-in ripple.

The reason larger diameter pipes are not used is the obvious one that the designed cover dimension over the reinforcing steel will not permit their use. However, since the deflection of any beam under central loading varies as the cube of the span, the deflection of the screed rail can be reduced to negligible proportions by decreasing the spacing between the supporting chairs to about 4-ft centers. The only proper way to do this is to write such a requirement, in general terms, into the specifications so that the contractor includes the cost in his bid.

For best results with the vibrating screed, several precautions are necessary:

1. A uniform roll of concrete should be maintained ahead of the screed. This is done by the laborers who spread the concrete to a reasonably uniform thickness.
2. When working with concrete of less than a 3-in. slump, it may be necessary to watch the bearing of the screed on the screed rail, to be sure that the screed is not "riding up" on the concrete and thus losing the control the screed rail should provide. In this connection, care should be taken to prevent dragging pieces of the coarse aggregate ahead of the screed rail over the top reinforcing steel. Designing for an absolute minimum cover of $1\frac{1}{2}$ in. will minimize this difficulty.
3. Whenever it is necessary to stop the screed, the vibrator should be disengaged in order to avoid the formation of a mortar pool caused by excessive vibration in one spot.

After satisfactory screeding has been done, it is necessary to remove the screed rails. This must be done from cross-bridges in order to avoid any deformation by laborers standing in the fresh concrete. The

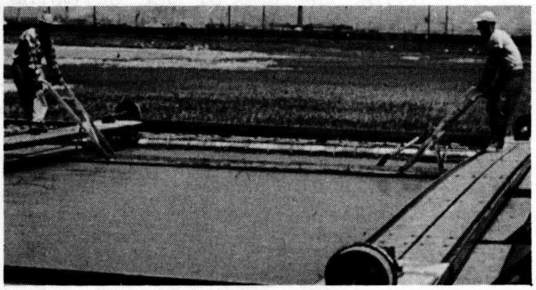

Figure 9. Longitudinal float.

timing of the removal of the screed rails is important. It should not be done so early as to permit the soft concrete alongside the screed rail to slump into the space left when the rail is removed. Neither should removal be so delayed as to break pieces out of the set concrete and prevent proper bond with the concrete added to fill in the space left by the rail.

Occasionally, screed rails are seen placed at right angles to the direction of traffic. This is usually done on wide roadways in order to give the finishers a place to stand when the concrete is being placed the full width of the roadway. This arrangement is not advisable, as it tends to produce ridges across the line of traffic that give a sensation of roughness or poor riding quality.

Following the screeding operation, a longitudinal manually operated float is used (Fig. 9). This may be a 10-in. steel channel about 15 ft long. It is placed parallel to the direction of traffic with the web on the concrete surface. The sharp corners have been slightly ground off to avoid pulling out pieces of coarse aggregate as the float is moved transversely with a longitudinal sawing motion imparted by 2 finishers, one at each end operating from cross-bridges. Wherever ripples across the roadway may have been left in the strike-off by the screed, the longitudinal float tends to diminish or remove them. The important thing is to have a plane surface parallel to the direction of traffic. The longitudinal float tends to produce this as well as to consolidate the concrete surface. It is advanced only $\frac{1}{2}$ its length at each pass in order to produce continuity of the smoothed surface.

After the longitudinal float, the scraping straight-edge is used. One common type is a piece of 1 3/4-in. oak about 10 ft long and about 6 in. wide. This is fastened at its center at right angles to a long handle. It is placed parallel to the direction of traffic and pushed across the lane with the handle about knee-high. It is then pulled back with the handle shoulder-high. In this way the sharp edges of the 1 3/4-in. surface scrape over the wet concrete surface and further reduce any ripples which may remain from the earlier operations. The scraping straight-edge is also advanced only $\frac{1}{2}$ its length after each double pass.

The scraping straight-edge is followed by the lute (Fig. 10). The lute is a smoothing tool used to smooth down any local irregularities that may have been caused by the action of the scraping straight-edge in turning up pieces of coarse aggregate. It is usually a piece of pressed aluminum about 6 in. wide and 4 ft long attached to a long handle. It is manipulated in the same direction as the scraping straight-edge.

Finally, it is a good idea to follow up the foregoing operations with a testing straight-edge 10 ft long. This is gently placed on the surface and the handle wiggled slightly to make a fine line imprint in the surface. The uniformity of the slight imprint will show clearly how true the surface is. This is commonly done 2 to 3 times in the width of each lane and every 5 ft longitudinally. It is late to discover irregularities, but these can usually still be corrected by repeating the use of the scraping straight-edge. The great value of the testing straight-edge is that it shows whether the preceding operations were done with sufficient care while it is still possible to take corrective measures. Its use is particularly important on the concrete adjacent to or crossing joints such as end dams.

For proper results all these tools are tested at least once a day for straightness and either discarded or repaired if not found to be perfectly true.

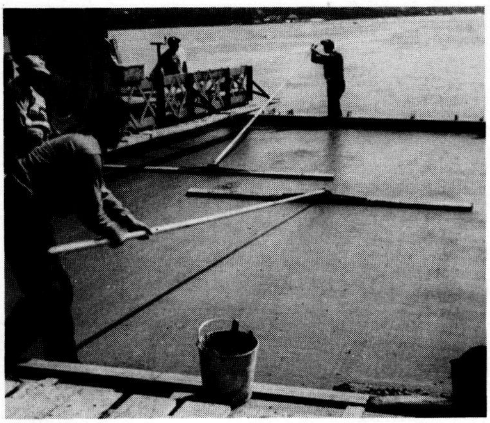

Figure 10. Smoothing floats.

Figure 11. Final surface texture.

The final step before curing is the texturing by the use of either burlap drag or the drag followed by brooming (Fig. 11). The burlap drag is a double piece of a seamless burlap about 42 in. wide and long enough to stretch across the width being paved. It is kept wet and clean by dipping frequently in a metal trough half filled with water. It is most important, for good results, that no hard spots of dried mortar be allowed to form, as these will gouge lines into the surface of the concrete. If the broom is used it is equally important to keep the bristles clean and free of hardened mortar.

Curing has little to do with early riding quality, however vital it may be to the production of a durable concrete surface. Hence no comment on curing methods will be made here.

It is apparent from the foregoing exposition that the attainment of concrete bridge decks with smooth-riding surfaces requires more than the ordinary techniques for placing concrete. Although nothing very profound has been said, it will be apparent to even the casual observer of bridge deck construction that many of the elementary requirements are being regularly ignored. This accounts for the obvious difference in riding quality as one passes from the approach pavement on grade to the bridge deck. There is plenty of justification for close supervision by experienced engineers in constructing concrete bridge decks.

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