Research Report

THE BUMP AT THE END OF THE BRIDGE

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Abstract

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The nature and causes of the differential settlements between a bridge deck and the adjoining highway approach pavement have been the subject of an increasing number of investigations in recent years. This settlement of the highway approach pavement not only presents a hazardous condition to rapidly moving traffic, but creates a rough and uncomfortable ride. These defects of the pavement surface require costly maintenance and, where a heavy traffic flow exists, the maintenance operation may tend to impede the normal flow.

Bridge abutments in Kentucky are usually founded on relatively a stable foundation such as rock or point-bearing piles to rock, and practically speaking, cannot settle. Highway approach pavements, on the other hand, are located on an embankment and foundation which are potentially free to settle. The extent to which either settlement of the embankment or foundation contributes to the approach settlement will obviously depend on the particular conditions at any given bridge site. Data obtained from a survey of existing bridge approaches conducted in the summers of 1964 and 1968 have provided general information as to the prevalence of the problem in Kentucky. In addition, these data imply there is a general relationship between development of the approach fault and such possible causative factors as the type of abutment, geological conditions, and soils conditions. This report summarizes the general relationship between the occurrence of bridge approach settlement and various conditions at the bridge sites.

INTRODUCTION

The nature and causes of the differential settlement between a bridge deck and the adjoining highway pavement have been the subject of an increasing number of investigations in recent years. This settlement of highway pavement at the approach to the bridge deck not only presents a hazardous condition to rapidly flowing traffic but creates a rough and uncomfortable ride. In addition, these surface faults require costly maintenance which usually involves either mudjacking or patching the approach pavement. Where a heavy traffic flow exists, this maintenance operation may tend to impede normal flow. Moreover, settlement of bridge approaches adversely affects the durability of road and structure. With increasing construction of modern, high-speed highways, the problem has become more evident -- at least to an extent that highway engineers are looking for ways and means of eliminating or minimizing the effects of these undesirable conditions at ends of bridges.

Data obtained from a preliminary survey of existing bridge approaches, conducted in the summer of 1964, have provided general information as to the prevalence of this problem in Kentucky. In addition, these data imply there is a relationship between development of the approach fault and such possible causative factors as the type of abutment and geological and soil conditions. In order to determine if the number of defective bridge approaches has increased since 1964, a follow-up survey of many of the same approaches was conducted in the summer of 1968. Such information coupled with known conditions at any particular bridge approach should be valuable in assessing why some approaches do not fault.

Usually bridge abutments, and therefore bridge decks, are founded on relatively stable foundations such as rock or point bearing piles to rock, and practically speaking, cannot settle. Highway pavements, on the other hand, are located on an embankment and foundation which are potentially free to settle. The extent to which either settlement of the embankment or foundation contributes to the approach settlement will obviously depend on the particular conditions existing at any given bridge approach. A few such factors affecting differential settlement would be type and compressibility of the soil in the embankment and foundation, height of the embankment, thickness of the compressible foundation material, and lapse of time between completion of the embankment and construction of the approach pavement. Other factors may include type of abutment and extent to which compaction of the embankment is in accordance with accepted specifications.

The major portion of approach settlement can probably be attributed, in most cases, to volume changes or consolidation of the embankment and(or) foundation. Furthermore, the primary and secondary phases of consolidation are significant in development of the approach fault when either the embankment or foundation contains highly plastic clay; this significance decreases whenever the embankment or foundation is composed of silt or sand. Moreover, settlement of the approach resulting from the initial phase of consolidation and immediate settlement were considered to be insignificant. Some evidence exists that suggests creep is important in some cases, especially where clays are present in the embankment or foundation. In addition, it has been noted that field compaction practices which deviate from accepted field procedures tend to aggravate development of the approach failure, making the embankment more susceptible to compression and creep settlement. Also, swelling, shrinkage, and vibration of soils could, under certain conditions, have some influence in development of the approach fault.

SURVEY OF EXISTING BRIDGE APPROACHES

A survey, conducted in the summer of 1964, of 782 bridge approaches located on the Western Kentucky Parkway; the Mountain Parkway; sections of I 64, I 65 and I 75; the Lexington Relief Route (Beltline); and US 41 revealed that 51 percent of these approaches had required some form of maintenance. Generally, concrete approaches were mudjacked and bituminous concrete approaches were patched with an asphaltic-aggregate mixture. By 1968, in a similar survey, the percentage of approaches requiring maintenance had increased to 78. Locations of the above routes in relation to the physiographical, geological, and major soil association areas of Kentucky are shown in Figures 1 and 2.

The approaches were classified according to one of the following settlement categories:

Group I Settlement - no maintenance necessary and no approach fault noticeable.
Group II Settlement - no maintenance performed; however, an approach fault was observed.
Group III Settlement - maintenance performed on the approach.

The criterion used to distinguish between Groups I and II was whether or not a 'bump' was evident when an automobile passed onto or off the bridge deck. Additional information was obtained by visually inspecting each approach. Figure 3 summarizes the 1964 and 1968 data, showing the total number and percentages of approaches classified in accordance with each settlement group. In addition, the ages (approximate dates opened to traffic) of the approaches are shown. The majority of approaches were at least two years old in the 1964 survey. From these data, it is evident that present design and construction procedures are not sufficient to obtain smooth bridge approaches.

Results of methods currently used in maintaining a smooth transition between a bridge deck and the roadway were not always satisfactory. Use of mudjacking to raise or lift rigid approach pavements was often detrimental to concrete approaches, primarily because this maintenance procedure induced cracking, thereby making the approach more susceptible to water infiltration, freezing and thawing, and further deterioration. Mudjacking in many cases provided only temporary relief in maintaining a smooth transition between the approach pavement and bridge; differential settlement was not reduced, but spread over a greater distance. Hence, sudden profile changes were reduced or eliminated. Of 195 mudjacked approaches examined in 1964, roughly 60 percent were cracked. Moreover, approximately 20 percent of the mudjacked approaches examined were severely cracked. Most approaches had been mudjacked two or three times. Mudjacking appeared successful only when the differential settlement was small. Patching to reduce sudden profile changes at approaches appeared somewhat more successful; however, this measure had to be repeated two or more times in many cases to be effective.

A comparison of portland cement concrete and bituminous concrete approaches, Figure 4, shows a markedly higher percentage of bituminous concrete approaches with patching than rigid approach pavements with mudjacking in 1964. In addition, there was a much greater percent of smooth approaches (Group I) for concrete approaches than for bituminous approaches. However, in 1968, the difference in percentage of mudjacked and patched approaches, as well as smooth approaches, was almost insignificant. Furthermore, the 1968 data, when compared to 1964 data, showed that there was an appreciable percentage decrease in smooth approaches and an increase in maintained approaches for both types of pavements. Apparently, at least for a short period of time, the rigidity of portland cement concrete pavement reduced the occurrence of the approach fault by bridging the presumed depression behind the abutment. Generally, the approach settlement appeared to be confined within 100 feet of the end of the

bridge, and settlement of the approach pavement seldom exceeded six inches.

Figure 5 shows the distribution of bridge approaches with respect to the three settlement groups in each of eight physiographic regions of Kentucky in which the observed bridges were located. 1964 data show that the best approaches, or the lowest percentages of defective approaches, occurred in Regions 4 and 5 (the Western Coal Field). But by 1968 there was a large increase in defective approaches in both regions. This area is a topographic as well as a structural basin; it is a dissected plateau with rolling hills and moderately wide valleys. An outstanding feature of this area is the broad alluvial bottoms of larger rivers. A large number of approaches studied lie within these recent alluvial deposits. Soils of this area have been formed by weathering of sandstone and shales, and large quantities of silts are present.

The highest percentage of approaches in Settlement Group III in 1964 occurred in Region 7, referred to as the Knobs, and Region 8, commonly called the Outer Blue Grass. The Knobs Region, characterized by conical knobs, erosional remnants of former uplands, is a narrow belt of land surrounding the Blue Grass limestone country. Consequently, a rough topography has emerged with the major stream beds flat and wide. This area contains large amounts of shale and plastic clays. The comparatively impervious and easily eroded shale of the Outer Blue Grass has produced a rough, hilly terrain. This region also contains large amounts of plastic clays derived from limestone and shales. For both 1964 and 1968, the proportion of smooth and defective approaches was about the same.

The next ranking group of approaches with high percentages of faulted approaches in 1964 was located in Region 9, Eden Hill Country, followed by approaches located in Region 12, the Eastern Coal Field. By 1968 there was a substantial increase in the percentage of faulted approaches in both regions. The Eden Hill Country (Hills of the Blue Grass) has rough, hilly terrain with valleys that are narrow, winding and entered by numerous streams. Soils of this area have been formed by the decomposition of limestone and shales. Hence, the soil is highly plastic and is considered to provide poor pavement support at normal moisture contents. The Eastern Coal Field is a region of extremely rough topography containing narrow ridges and deep, narrow valleys. Flat lands are at a minimum. However, locally, in areas of shale outcrop, numerous bottom lands have developed. Massive sandstones have given rise to local upland flats. Soils derived from these sandstones and shales are considered good subgrade material. Soils of this area are similar to those of the Western Coal Field.

Distribution of approaches in Regions 10 and 6 with respect to the three settlement groups were markedly similar in 1964. But in 1968 this similarity was not as noticeable. The percentage of defective approaches in both regions increased considerably; however, Region 10 had the highest percentage of smooth approaches for all regions. Region 10, the Inner Blue Grass area, is a lowland with a gently rolling terrain containing many solution channels as well as caves and sinkholes. Rivers in this area have entrenched themselves to depths of 400 to 500 feet. Deep residual soils derived from limestone occur in the uplands of this area. These soils are well drained, mainly because limestone bedrock allows water to escape through the many cracks, joints and solution channels. As a result, the clay soils have developed a fragmentary structure. When this structure is destroyed, these soils become quite plastic. Region 6, the Mississippian Plateaus, is a rolling upland plain formed from limestone with small local relief. Except for larger rivers, the drainage is underground. The gently rolling topography and lack of surface drainage favor the development of thick, residual soils, similar to those of the Blue Grass Region. This area contains large amounts of highly plastic clays.

A comparison of the most commonly used types of abutments (see Figure 6), with respect to the three settlement groups, Figure 7a, revealed that the open-column type (open-end) was more commonly

associated with Settlement Group III than either the pile-end-bent (open-end) type or stub type (closed-end) in 1964. The relationship between average height of embankment, average thickness of foundation soil and type of abutment with respect to settlement groups is shown in Figures 7b and c. Notice that stub abutments are associated with smoother bridge approaches, smaller average heights of embankment and thinner foundation soils. The pile-end-bent abutments had greater average heights of embankment and thicknesses of foundation soils than the open-column abutment, but the pile-end-bent abutments had better bridge approaches. The better performance of approaches located behind stub abutments may be attributed to smaller settlements associated with shallower embankments and foundation soils. The comparatively larger time for consolidation before construction of the pavement and the need for less hand compaction near the abutment may account for better performance of approaches associated with pile-end-bent abutments than those approaches at open-column abutments. However, in 1968 there was an increase in percentage of faulted approaches for all types of abutments with the percentage for pile-end-bents increasing the most. There were small differences in percentages between the pile-end-bent and open-column abutments. Although the percentage of faulted approaches increased, stub abutments still had a comparatively high percentage of smooth approaches in 1968. For both surveys, there was a large number of defective bridge approaches associated with all types of abutments.

In a few cases, the 1964 study indicated that erosion of soil adjacent to the abutment (Figure 8) contributed to the development of the approach fault. In one observed case, grouting material from the mudjacking operation had effused from underneath the face of the abutment. As shown in Figure 9, there was an increase in the percentage of repaired approaches when such erosion occurred. This type of erosion appears to be a result of ground water seepage (including runoff from the pavement) as shown diagrammatically in Figure 10.

Loss of material around the abutment could result in a loss of subgrade material and, consequently, cause the approach to settle. By 1968 the percentage of defective approaches had increased noticeably, and there were no significant differences in percentages of smooth approaches as well as faulted approaches for approaches with erosion and without erosion. However, the number of faulted approaches with erosion at the face of the abutment increased considerably.

Other supporting evidence that seepage may, in some cases, result in settlement of the approach is presented in Figure 11. A comparison was made among those approaches which sloped toward the abutment, those which sloped away and those which were relatively level with respect to the three settlement groups. Those which sloped toward the abutment had a higher percentage of Group III approaches than the other two categories.

There was suggestive evidence that progressive failure, or creep, of the approach embankment may, in some cases, contribute to development of the approach fault. Figure 12 is a comparison of approach embankments with cracked concrete slope protections, embankments with uncracked concrete slope protections, and embankments with no slope protection, suggesting a relationship between cracked slope protections and bridge approach settlement. One possible explanation for the cracked slope protections could be progressive failure of the embankment, as shown in Figure 13, resulting in a loss of subgrade support. In some cases, slope protections did appear to be bulging outward.

A comparison of those approaches with embankments that appeared to have settled from the face of the abutment and those which had not (see Figure 14) revealed that there was a greater percentage of

Group III approaches for the former category in 1964. These data are shown in Figure 15. By 1968 the percentage of defective approaches had increased significantly, and both categories exhibited little difference.

Different types of embankments were studied with respect to the settlement groups. These data, Figure 16, show that embankments located in valleys of major streams had a much greater percentage of Settlement Group III approaches than embankments at other locations. Side-hill fills were considered to be those embankments which were generally part fill and part cut. Grade separation embankments were those considered to be built-up on a relatively flat plain. It is reasonable to assume that valley fills were located on foundations which were thicker than the other types of fills. Hence, these data probably reflect the importance of the foundation as a variable in bridge approach settlement. Those faulted approaches with embankments three feet or less in height may reflect improper backfill placement and compaction and such other causative factors as erosion or swelling and shrinkage.

A comparison of bridge approaches (four traffic lanes – two bridges), Figure 17, with regard to direction of travel revealed only a slight difference in settlement between northbound and southbound traffic approaches, and between eastbound and westbound approaches. Furthermore, a comparison between entry and exit bridge approaches, Figure 18, also showed little difference. Also shown in Figure 18, for the purpose of comparison, is the distribution of bridge approaches, located at sites involving only one bridge, with respect to the different settlement groups.

At 54 bridge approaches located on I 64 between Frankfort and Louisville, the approach embankments were constructed of a special granular fill material extending approximately 20 to 60 feet behind the abutments. The special fill was formed and placed around the abutments, primarily open-column, in accordance with Kentucky Standard Drawing SF-1 (see Figure 19), which is no longer in use. Below original groundline, the special fill consisted of either sand, crushed or uncrushed gravel, crushed limestone, crushed sandstone, crushed slag, broken stone from solid rock excavation, or a combination thereof and was required to meet the gradation shown in Figure 19. Above groundline, the special backfill was of a type listed above; however, gradation requirements were waived. Whenever crushed stone or slag was used, the backfill was formed and compacted by spreading with a dozer or grader blade in such a manner that voids, pockets and bridging were minimized; the maximum layer thickness did not exceed three feet. Whenever sand was used, the backfill was compacted by saturation with water. In this case, the layer thickness did not exceed one foot. No stone or fragment of the special fill material was placed within one foot of the finished subgrade elevation.

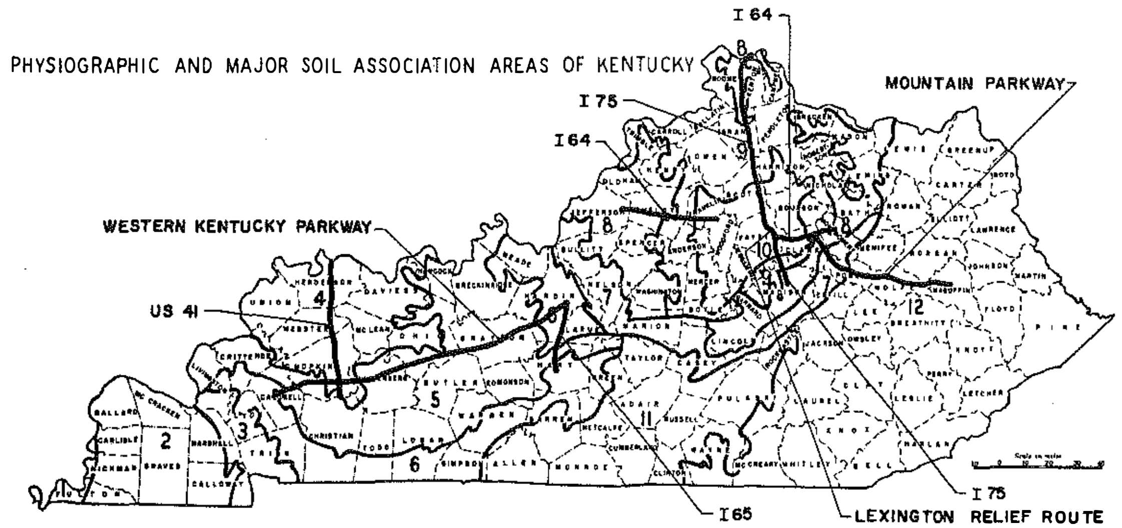
The performance of bridge approaches associated with the special granular backfill is shown in Figure 20 and compared with bridge approaches not associated with the special backfill on the same route. The data show that backfilling behind abutments in a manner specified by Kentucky Standard SF-1 did not check the development of faulted approaches. Moreover, for cases involving the special backfill when compared to cases without the special fill, there was an increase in frequency of faulted approaches.

SUMMARY

Data obtained from two surveys of existing bridge approaches show that current design and construction techniques have been inadequate for preventing settlement of bridge approaches. Moreover,

the use of a special granular backfill material in a manner specified by Kentucky Standard Drawing SF-1 was unsuccessful in preventing the development of faulted approaches. Results of methods currently used in maintaining a smooth transition between a bridge deck and roadway were not always satisfactory; in many cases, approach pavements had to be mudjacked and(or) patched as many as two or more times. Patching was considered to be more effective than mudjacking, mainly because patching did not crack the approach pavement. Apparently, at least for a short period of time, rigidity of portland cement concrete pavements reduced the occurrence of approach faults by bridging the presumed depression behind abutments. Generally, approach settlements seldom appeared to exceed six inches and were confined within 100 feet of the end of the bridge.

A general relationship between approach settlement and different geological and soil conditions seemed apparent in 1964. Approaches passing through areas of soils containing large amounts of granular material did not fault as frequently as approaches passing through areas of soils with large amounts of plastic clays. However, in 1968 the influence of different geological and soil conditions was only slightly noticeable.



AREA	IMPORTANT SOIL SERIES	AREA	IMPORTANT SOIL SERIES
1. PURCHASE - MISSISSIPPI RIVER FLOOD PLAIN	SHARKEY-DUNDEE-COMMERCE	7 KNOBS	COLYER-ROCKCASTLE-OTWAY
2. PURCHASE - THICK LOESS BELT	GRENADA-CALLOWAY-COLLINS	8 OUTER BLUEGRASS	LOWELL-SHELBYVILLE-FAIRMOUNT
3. CUMBERLAND-TENNESSEE RIVERS SECTION	BRANDON-GUIN-BOOINE	9. HILLS OF THE BLUEGRASS	EDEN-NICHOLSON-MADOOX
4. WESTERN COAL FIELDS-LOW HILLS & VALLEY AREAS	LORING-ZANESVILLE-COLLINS	10 INNER BLUEGRASS	MAURY-HAMPSHIRE-LORADALE
5. WESTERN COAL FIELDS-HILLY UPLANDS, AND WESTERN PENNYROYAL-SANDSTONE, SHALE, LIMESTONE AREA	TILSIT-MUSKINGUM-CHRISTIAN	11. EASTERN PENNYROYAL	BAXTER-DICKSON-WESTMORELAND
6. WESTERN PENNYROYAL-LIMESTONE AREA	PEMBROKE-CRIDER-RUSSELLVILLE	12 MOUNTAIN AND EASTERN COAL FIELD	MUSKINGUM-JEFFERSON-STENDAL

Figure 1 Location of Highway Routes Surveyed with Respect to Physiographical Regions

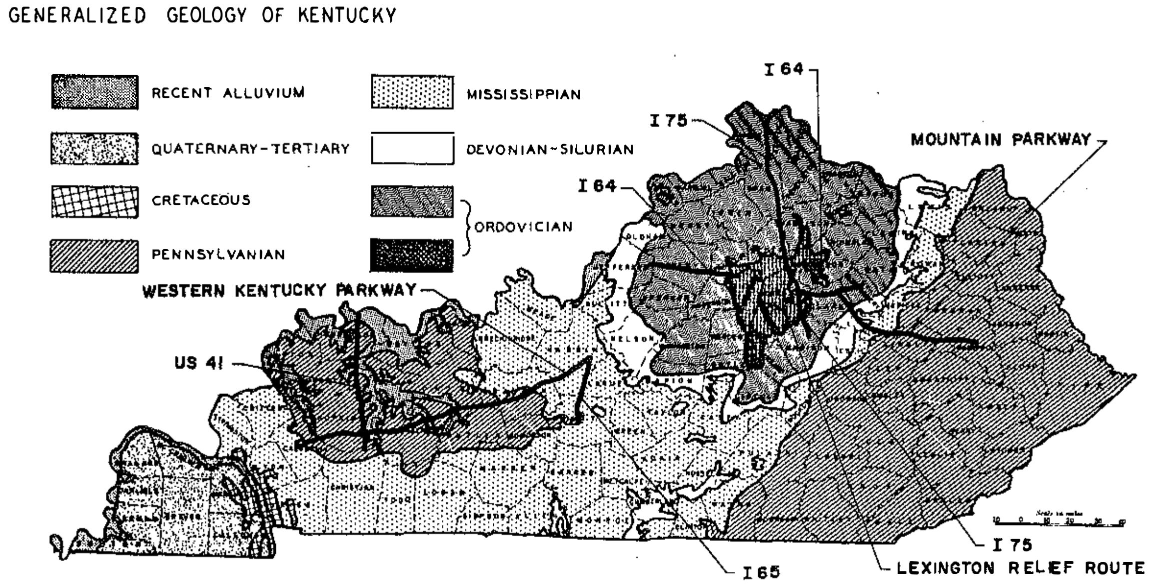


Figure 2 Location of Highway Routes Surveyed with Respect to Geological Regions

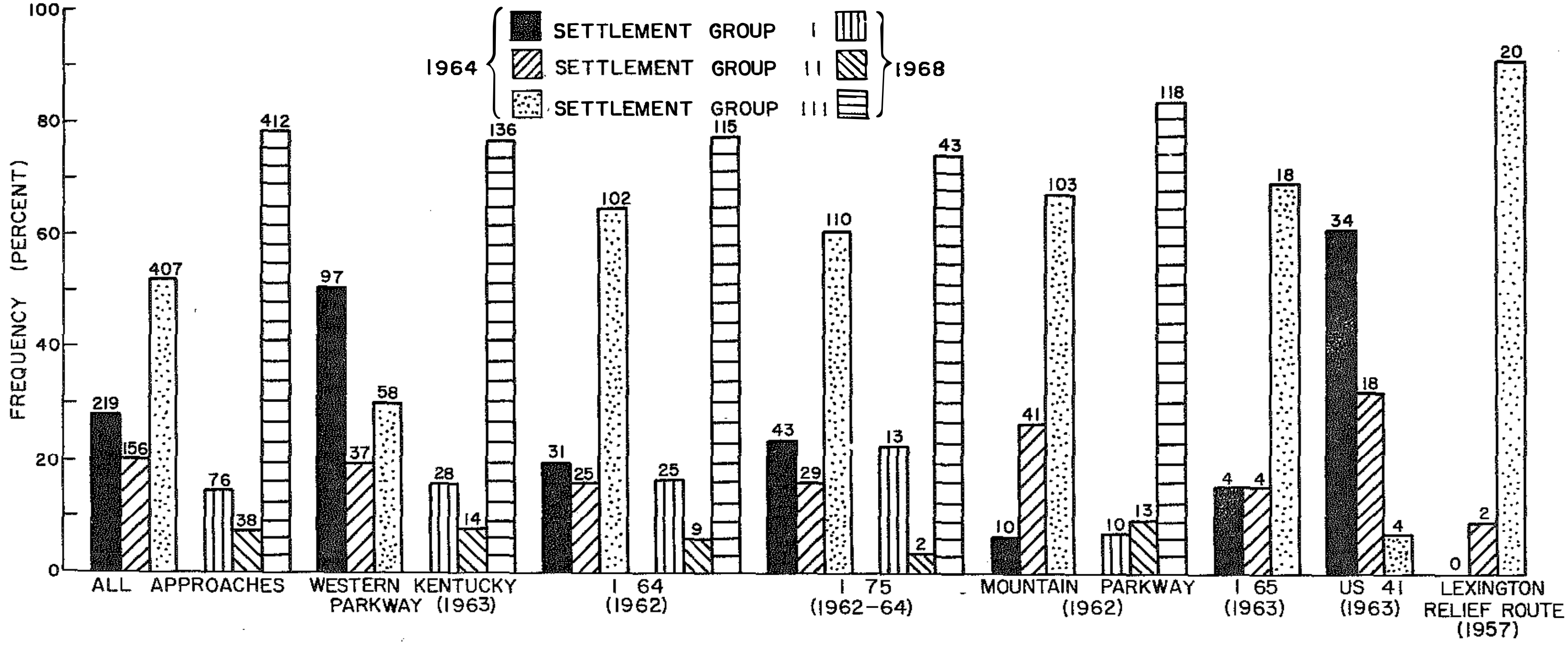


FIGURE 3. COMPARISON OF BRIDGE APPROACHES BY ROUTES

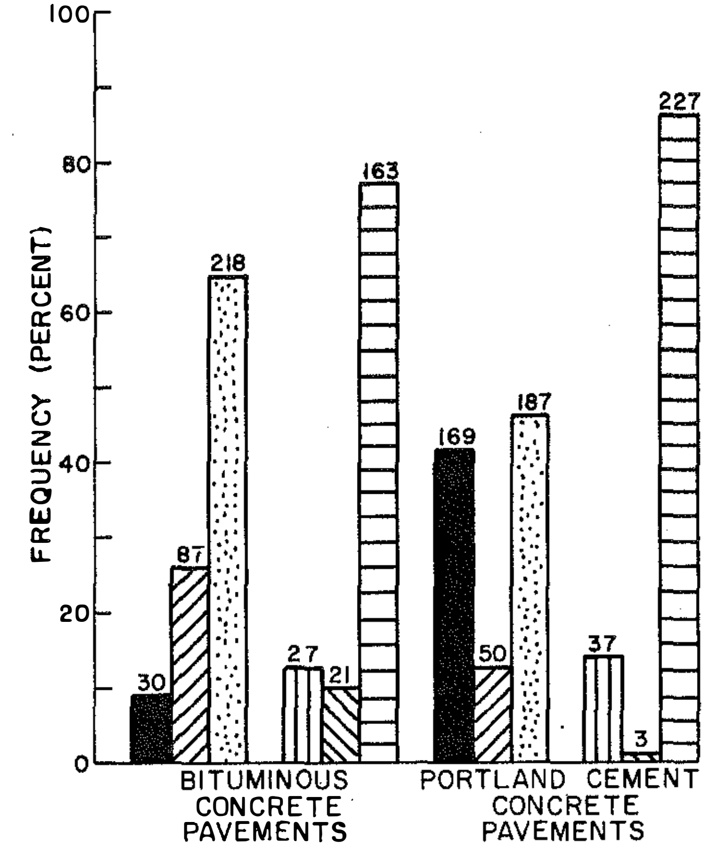


FIGURE 4. COMPARISON OF BRIDGE APPROACHES BY PAVEMENT TYPE

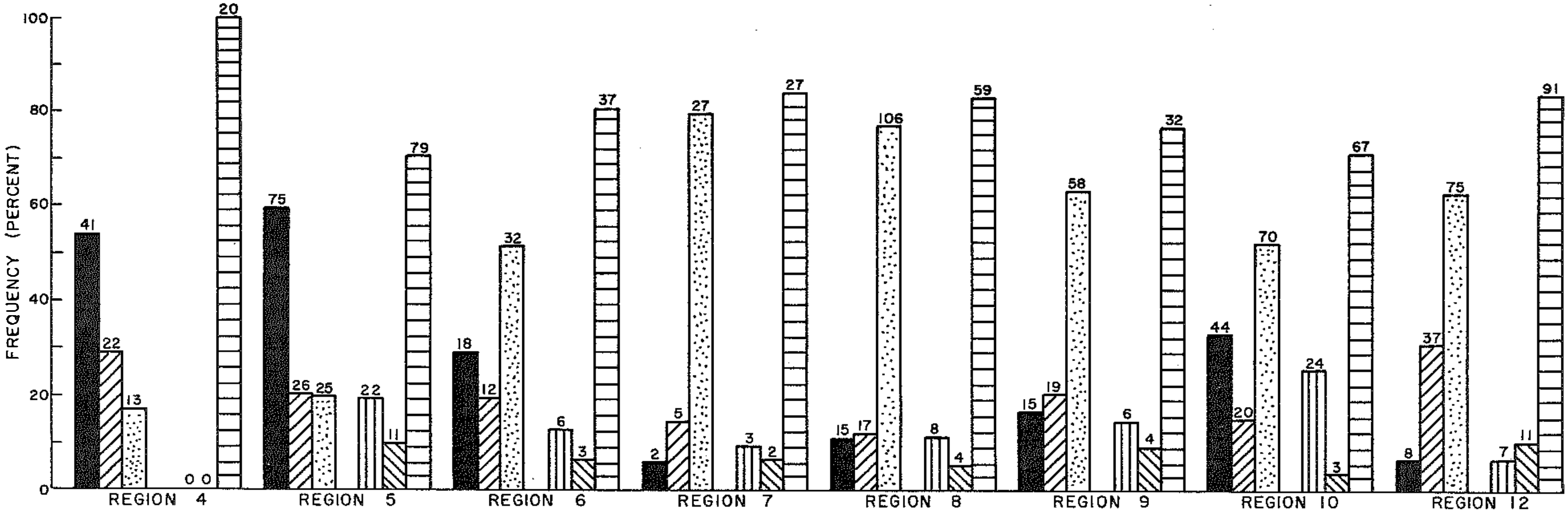


FIGURE 5. COMPARISON OF BRIDGE APPROACHES BY PHYSIOGRAPHIC REGIONS

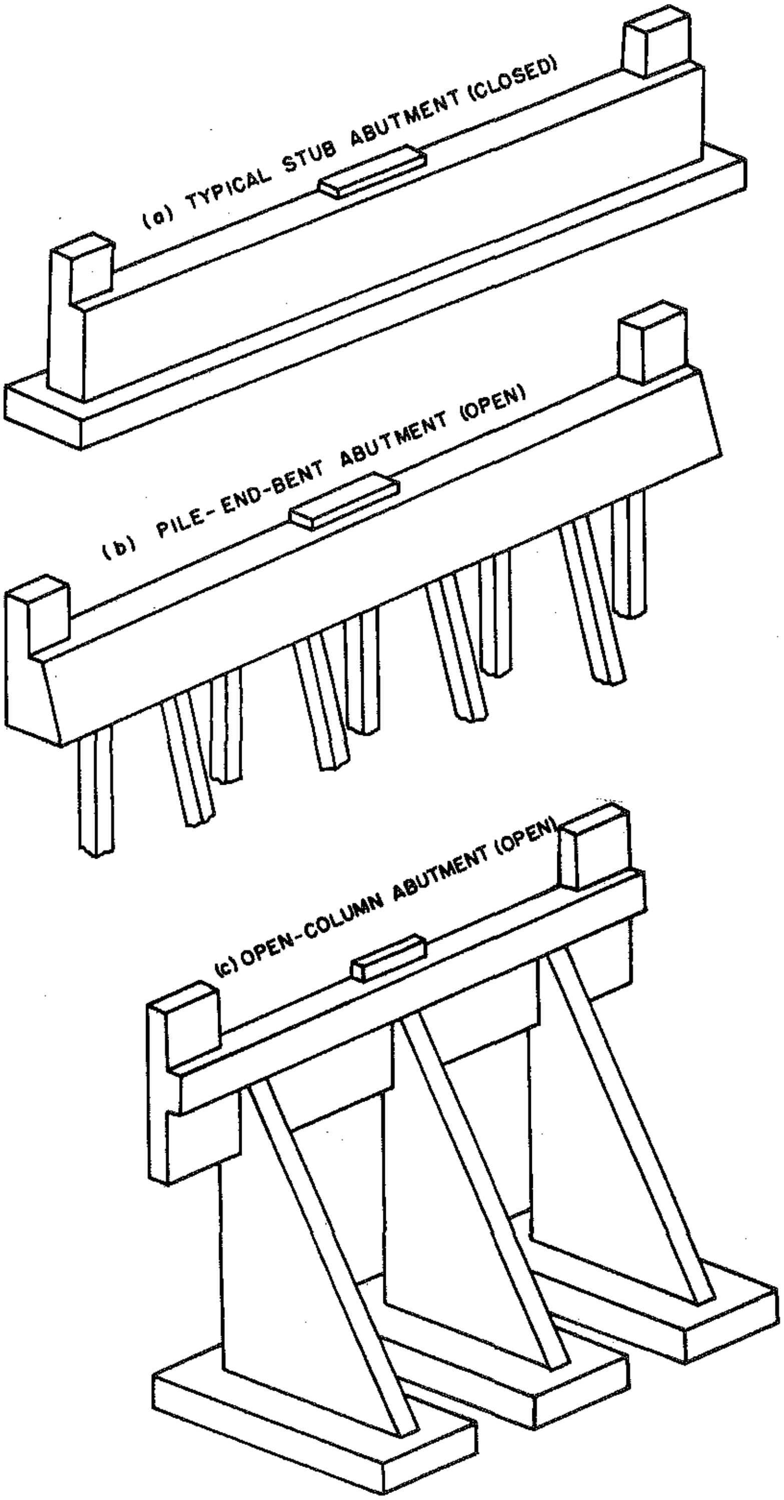


Figure 6 Typical Types of Abutments Used in Kentucky

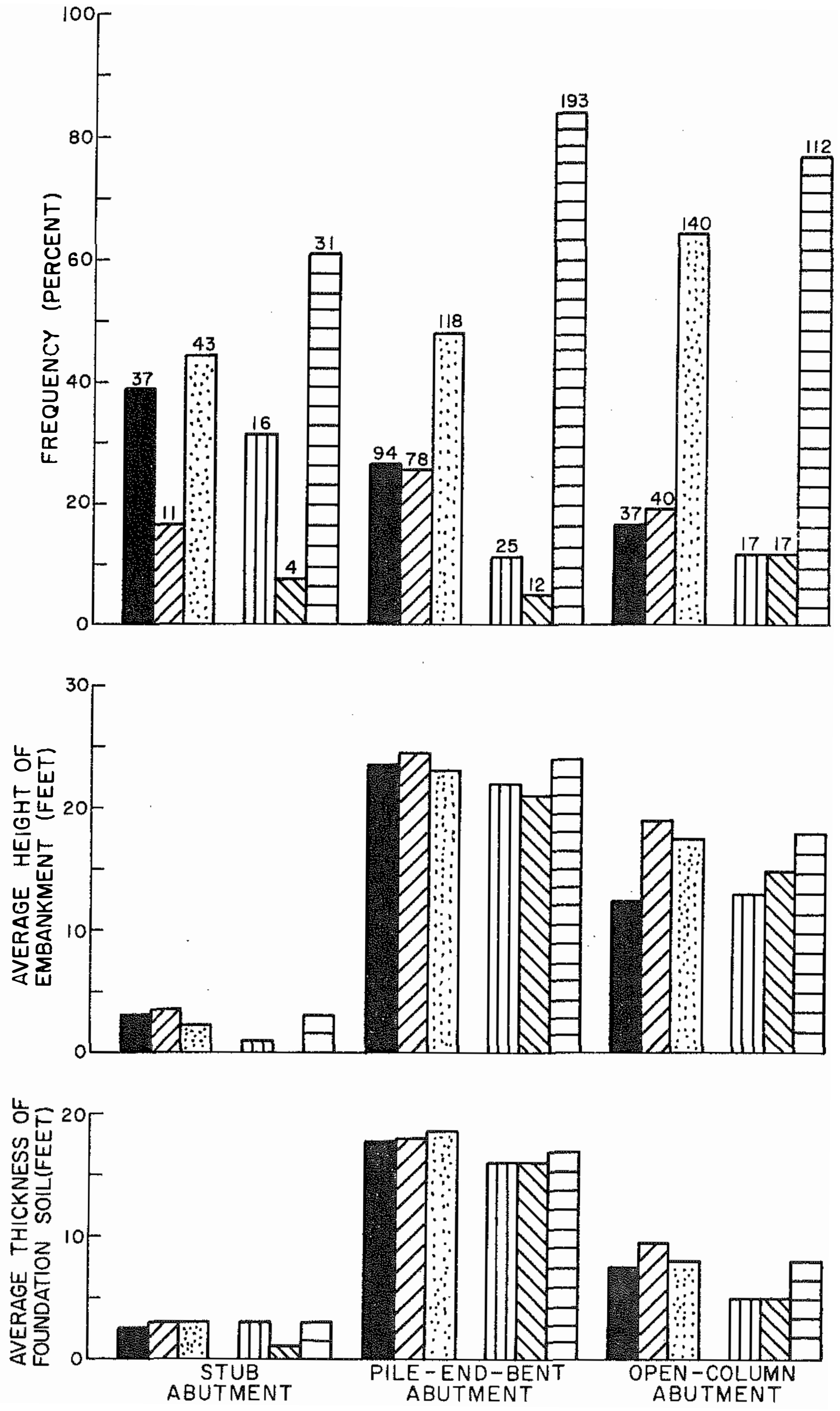


FIGURE 7. COMPARISON OF BRIDGE APPROACHES BY ABUTMENT TYPE

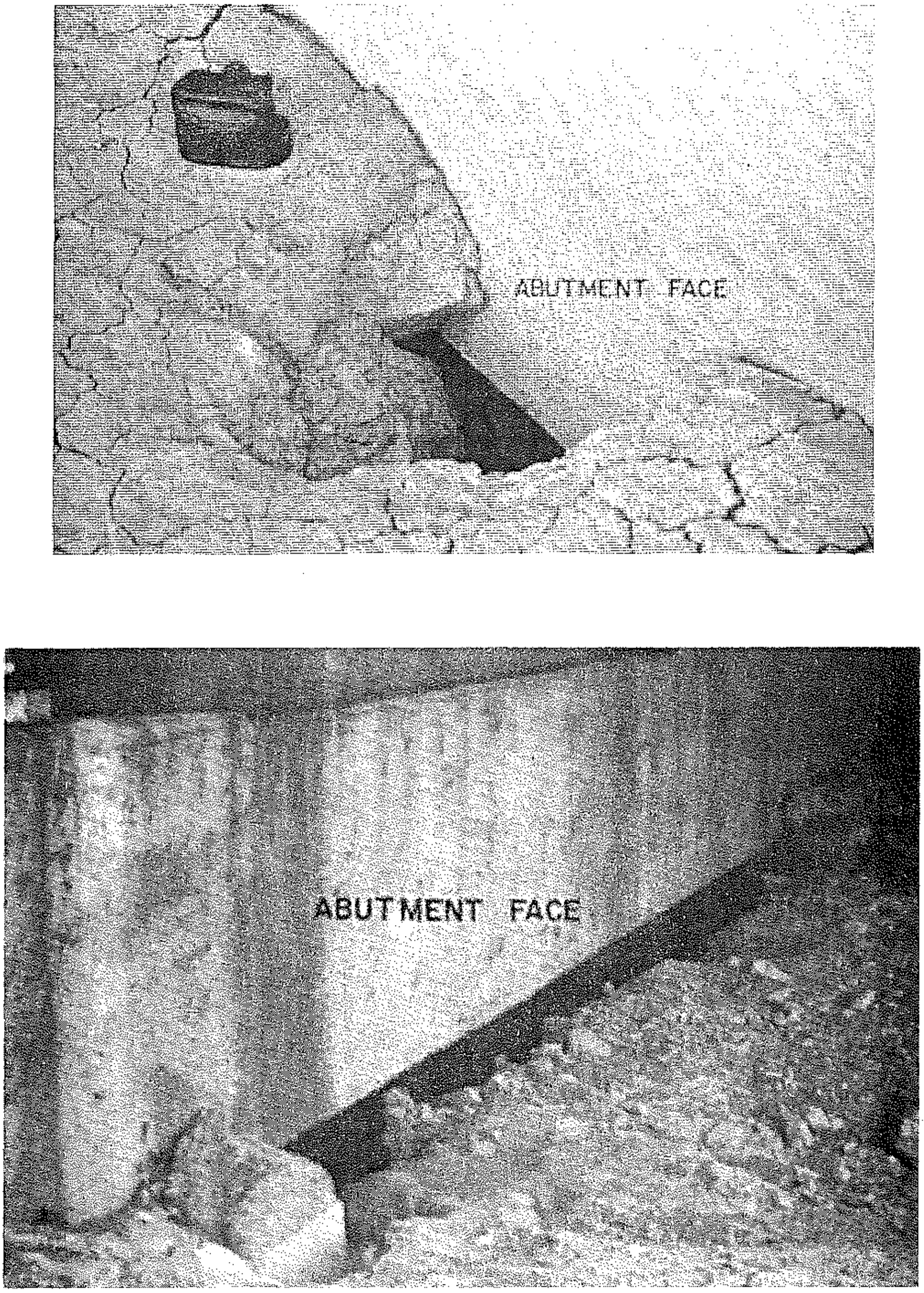


Figure 8 Illustration of Erosion of Soil at the Abutment Face

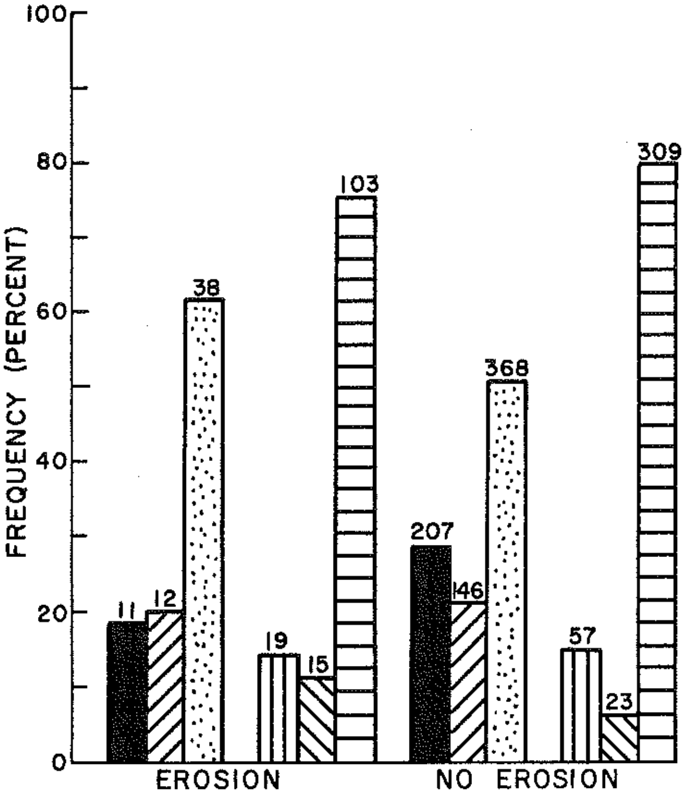


FIGURE 9. COMPARISON OF BRIDGE APPROACHES BY EXTENT OF EROSION AT FACE OF ABUTMENT

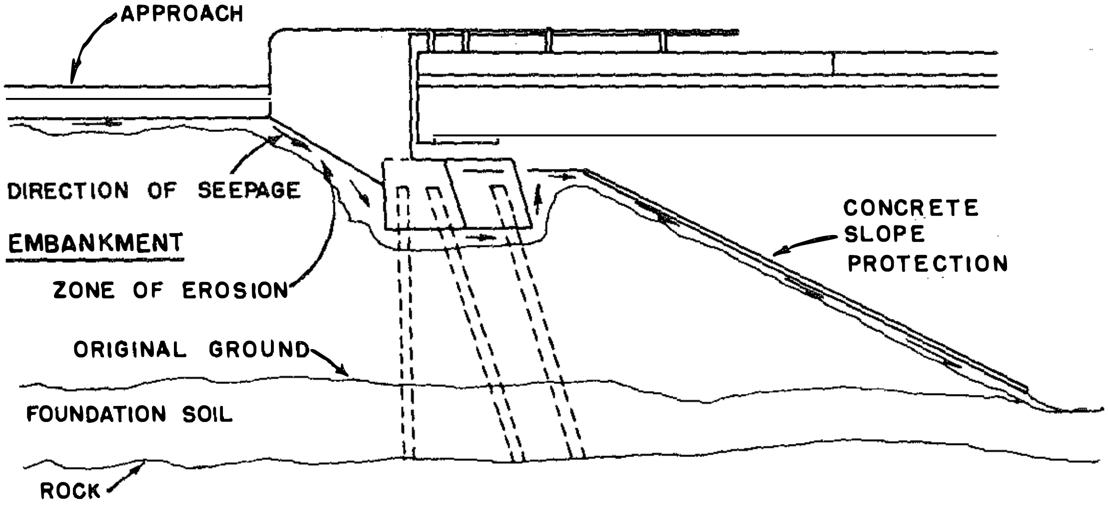


Figure 10 Direction of Seepage and Zone of Erosion

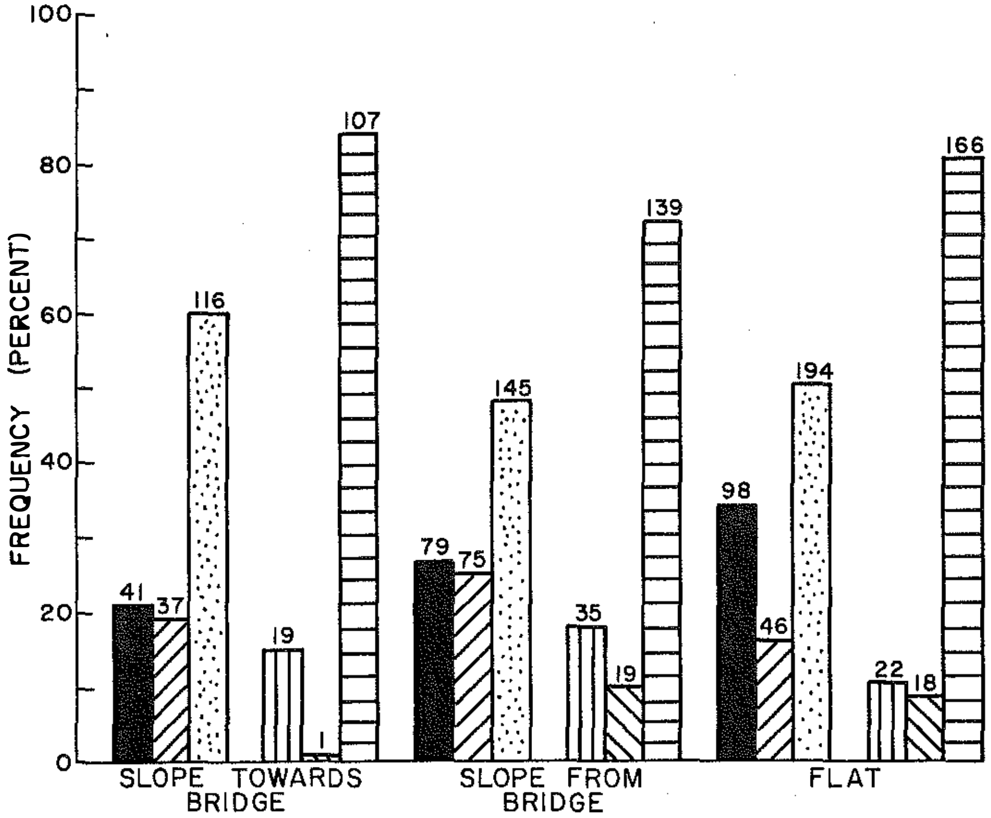


FIGURE 11. COMPARISON OF BRIDGE APPROACHES BY SLOPE OF APPROACH PAVEMENT

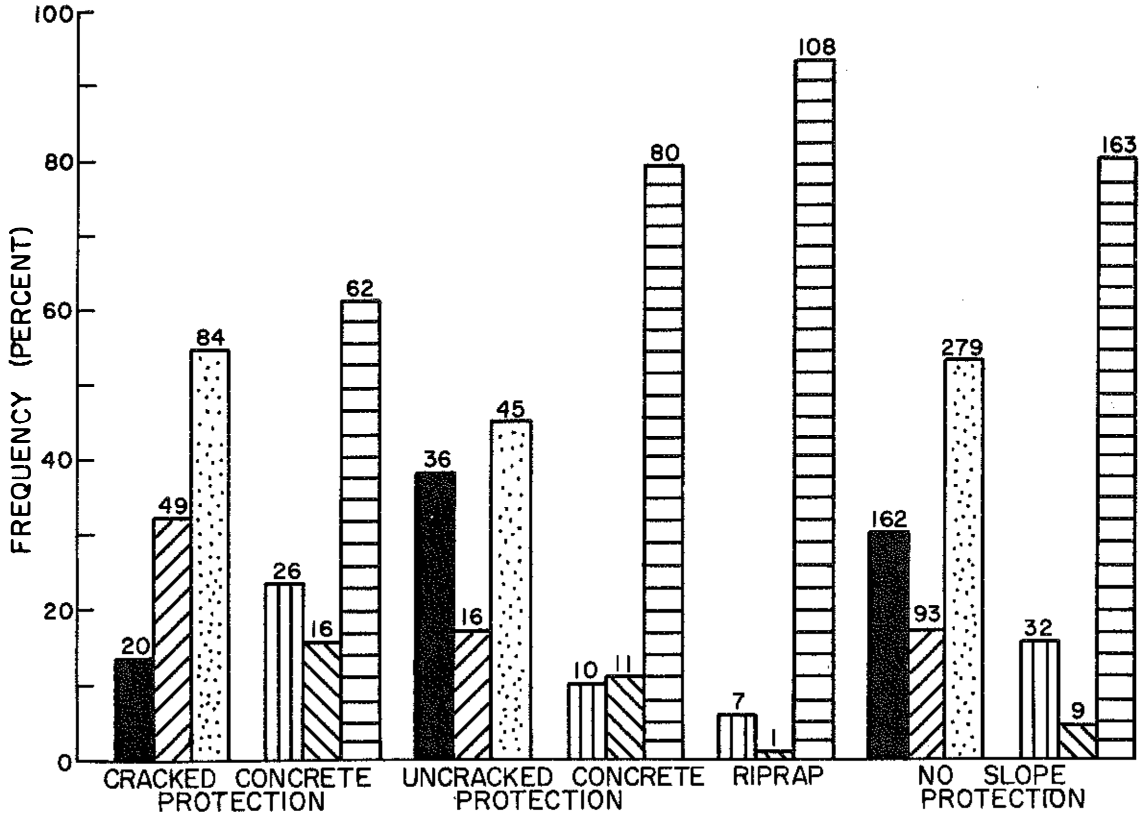


FIGURE 12. COMPARISON OF BRIDGE APPROACHES BY TYPE OF SLOPE PROTECTION

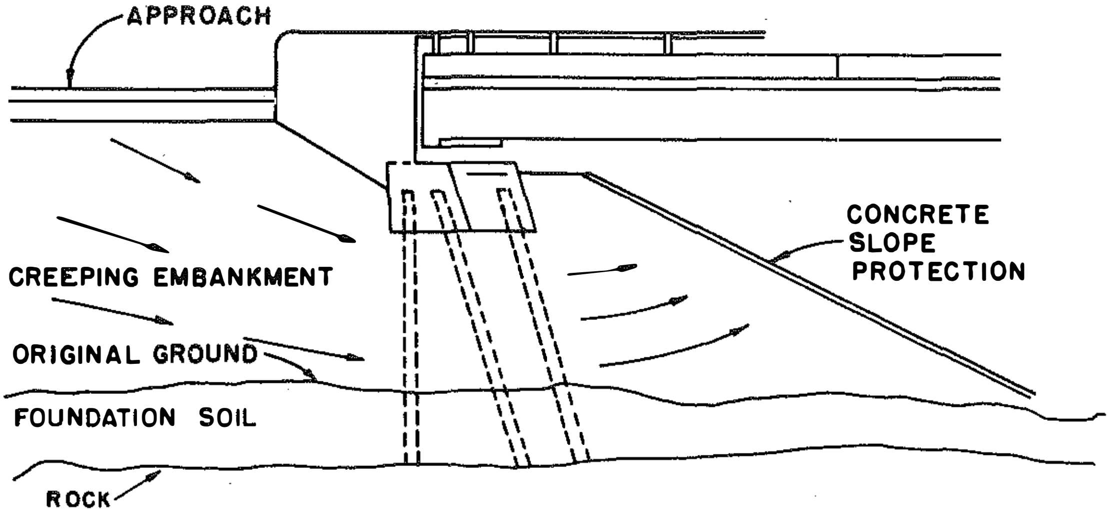


Figure 13 Creep of Embankment Slopes

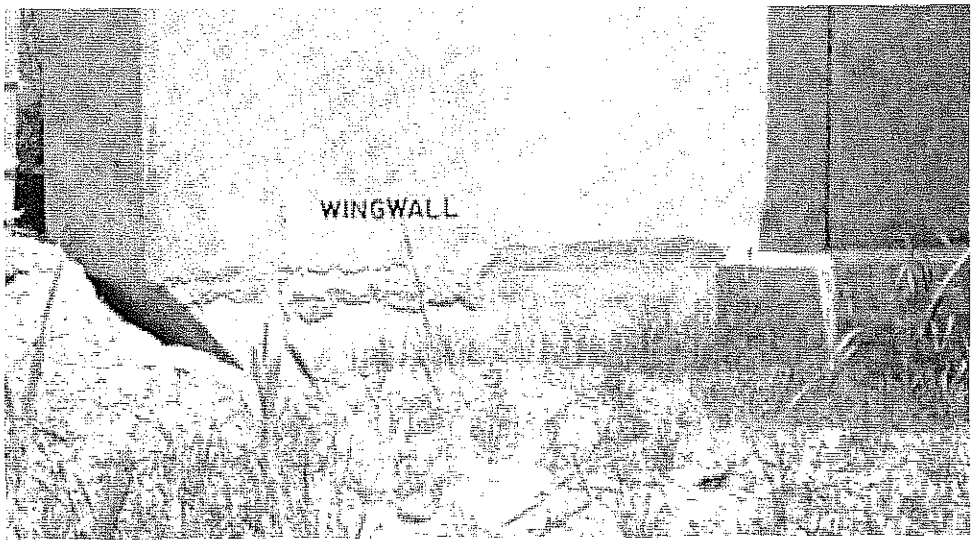


Figure 14 Settlement of Fill from Wingwall and Abutment

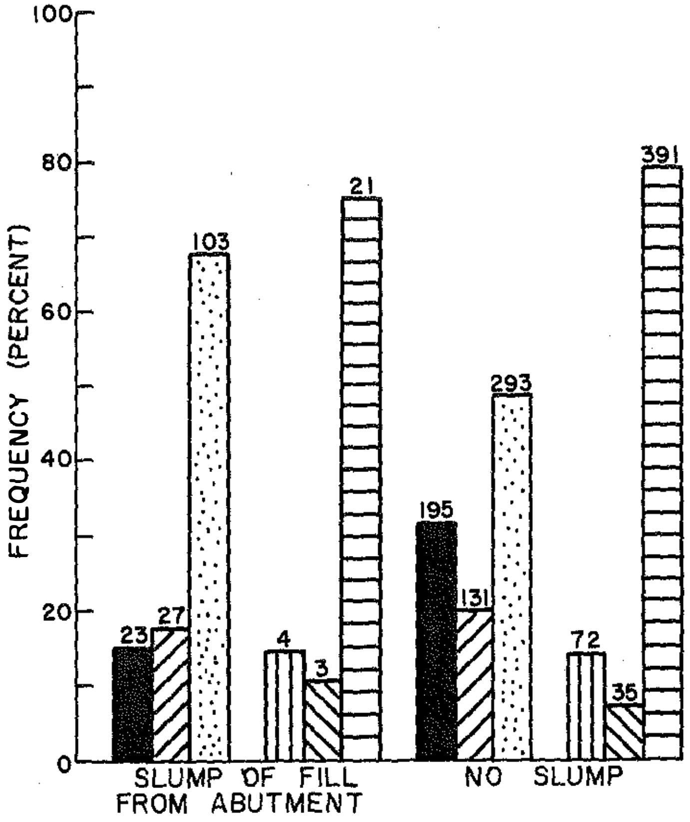


FIGURE 15. COMPARISON OF BRIDGE APPROACHES BY EXTENT OF SLUMP OF FILL FROM FACE OF ABUTMENT

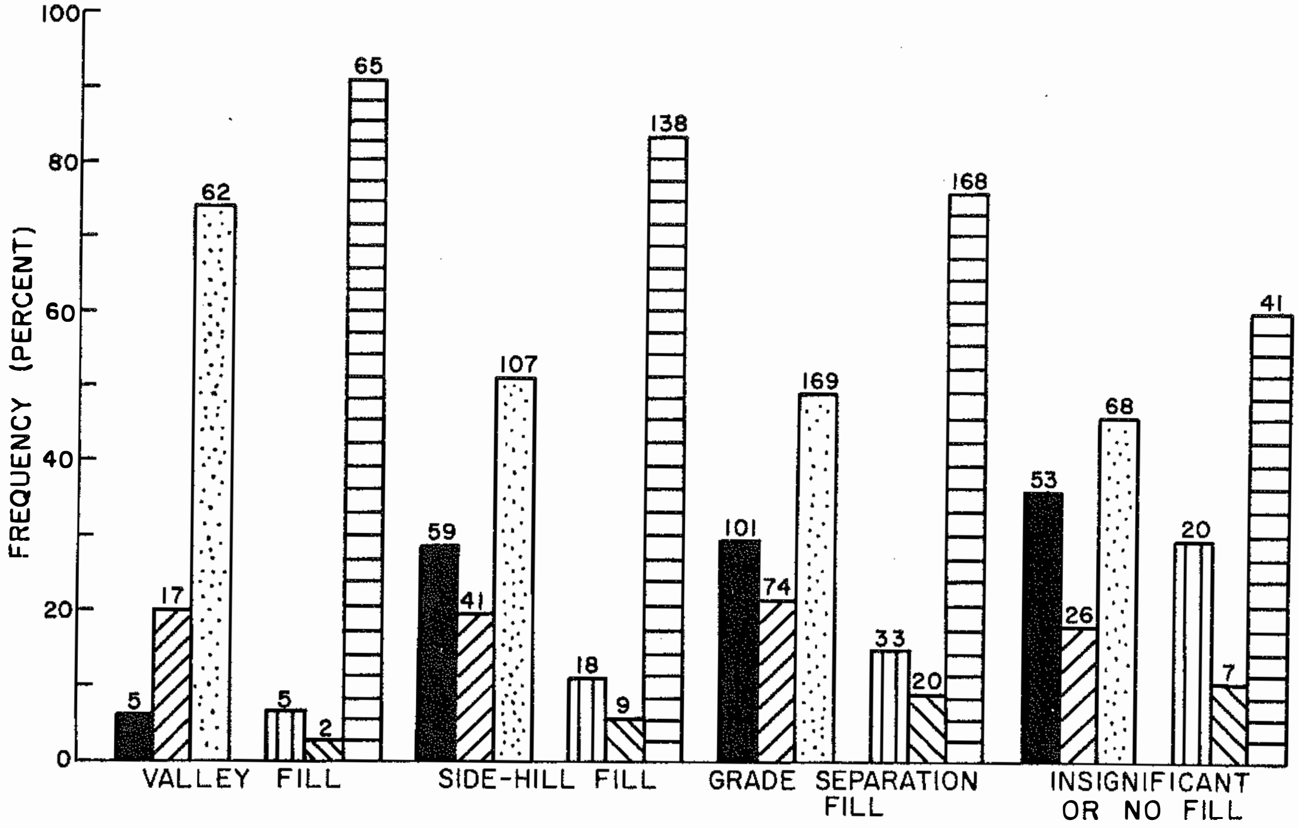


FIGURE 16. COMPARISON OF BRIDGE APPROACHES BY TYPE OF EMBANKMENT

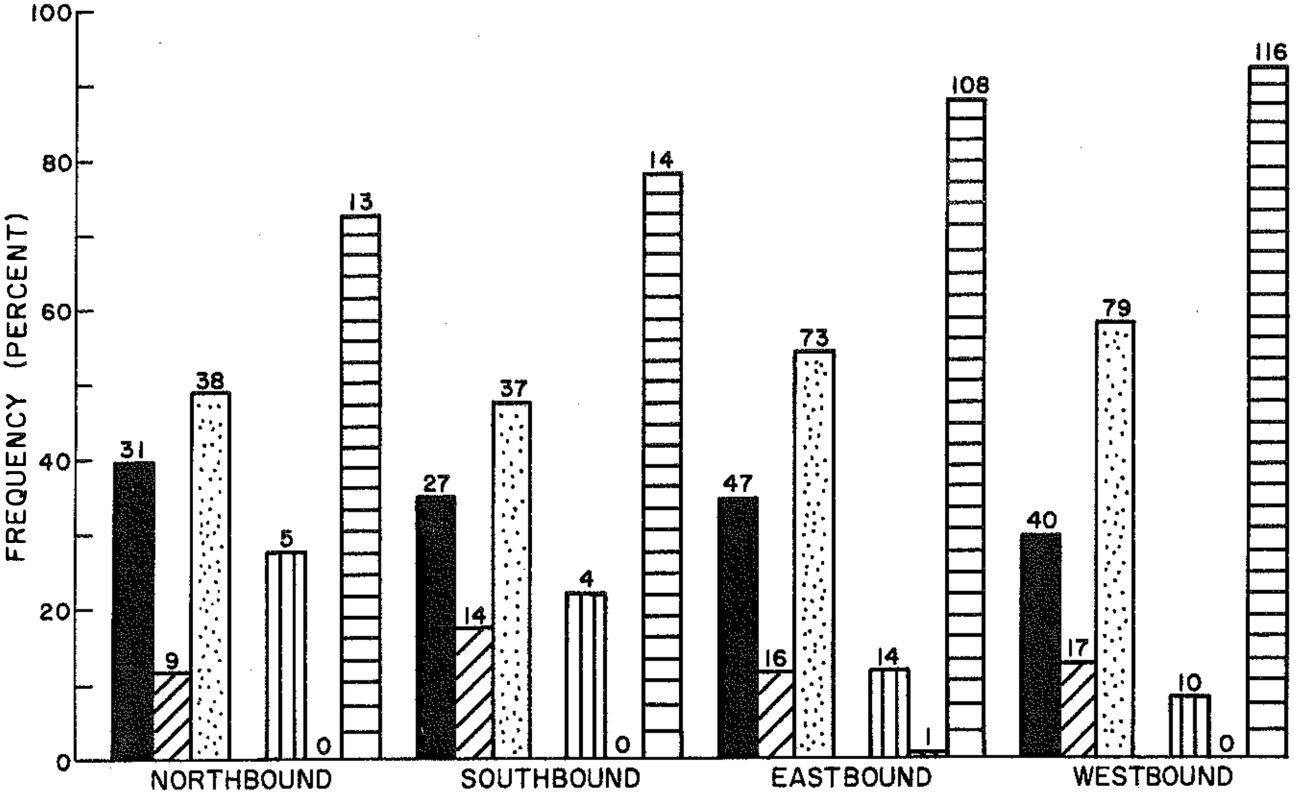


FIGURE 17. COMPARISON OF BRIDGE APPROACHES BY DIRECTION OF TRAVEL

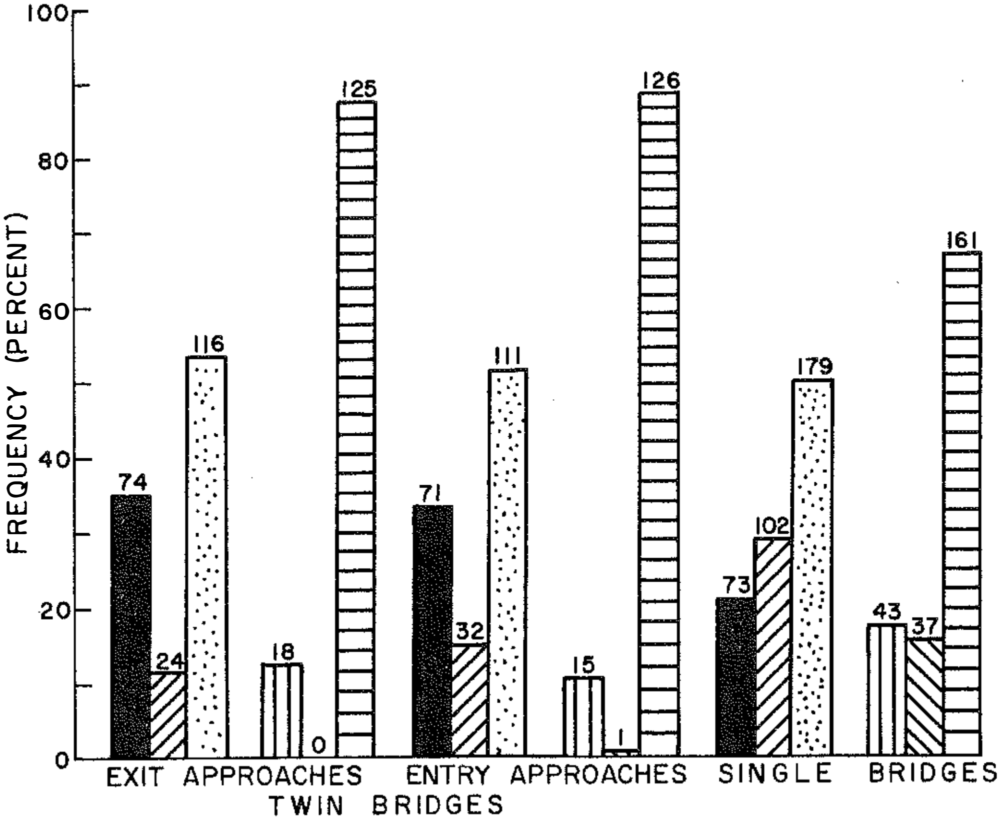
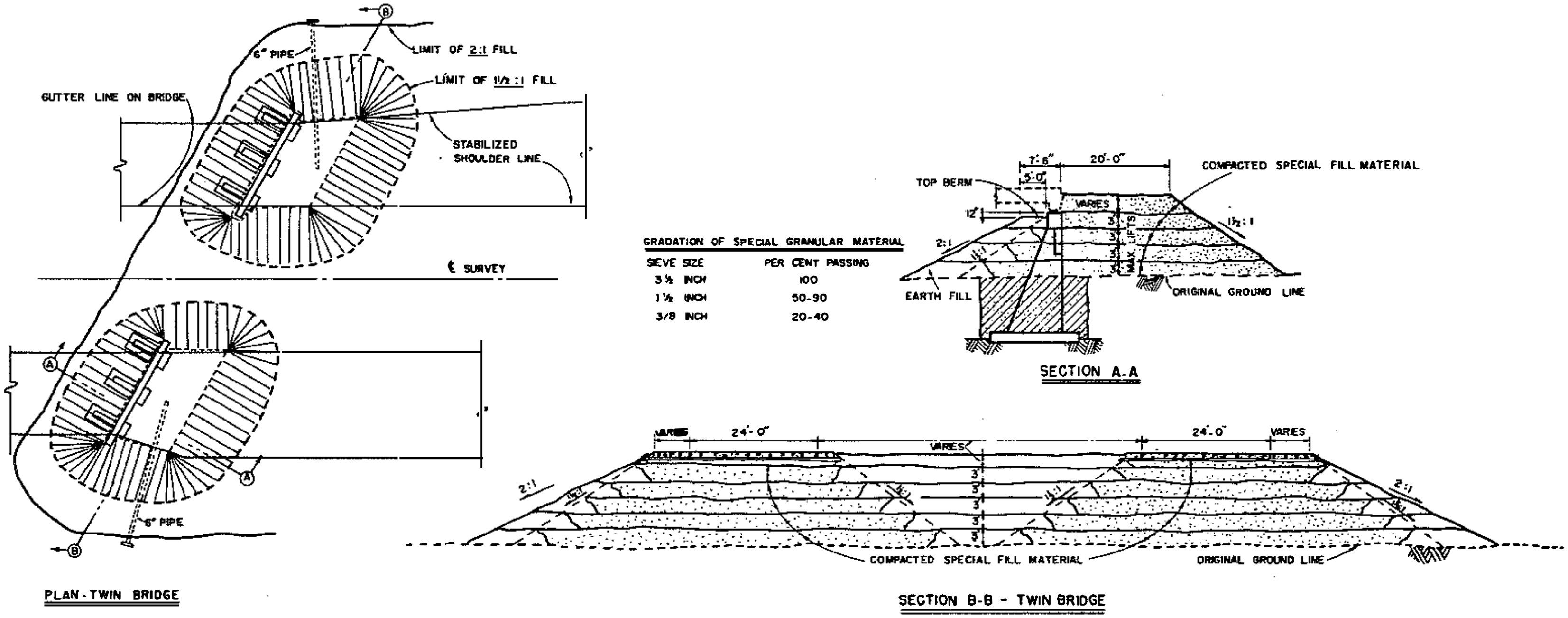


FIGURE 18. COMPARISON OF BRIDGE APPROACHES BY EXIT AND ENTRY APPROACHES



GRADATION OF SPECIAL GRANULAR MATERIAL

SIEVE SIZE	PER CENT PASSING
3 ½ INCH	100
1 ½ INCH	50-90
3/8 INCH	20-40

Figure 19 Kentucky Standard Drawing SF-1 showing the Requirements for Backfilling around Abutments with a Granular Material

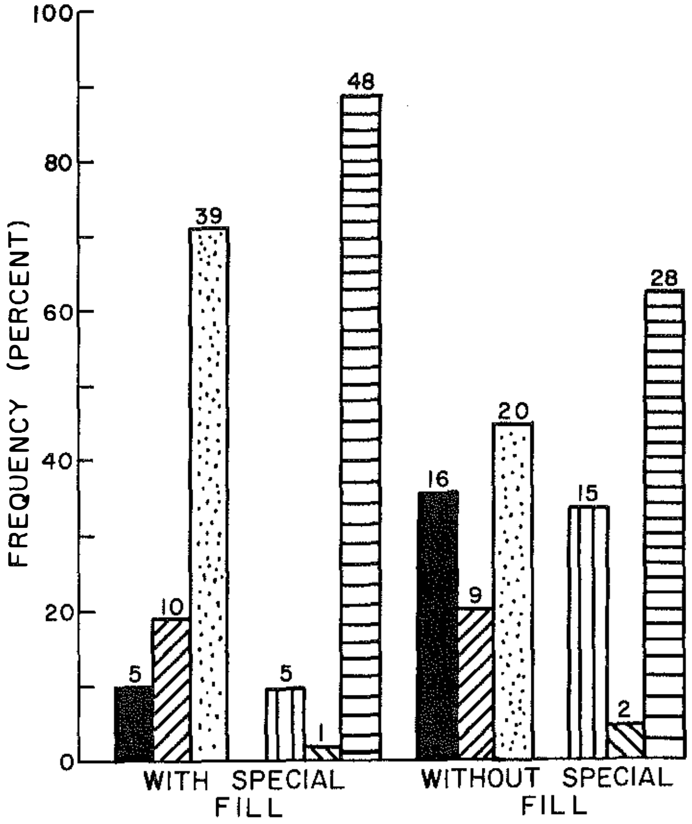


FIGURE 20. COMPARISON OF BRIDGE APPROACHES BY USE OF SPECIAL BACKFILL MATERIAL