ROAD and BRIDGE GUIDEBOOK For OKLAHOMA LOCAL GOVERNMENTS

Prepared By

Center for Local Government Technology
Oklahoma State University

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STATE OF OKLAHOMA

OFFICE OF THE GOVERNOR

212 STATE CAPITOL BUILDING

OKLAHOMA CITY, OKLAHOMA 73105

GEORGE NIGH

Governor

405 / 521-2345

Fellow Oklahomans:

This guide book has been prepared for the purpose of assisting city and county governments to build better roads and bridges. Funding has been provided by the Oklahoma Civil Defense Agency through a grant from the Federal Disaster Assistance Administration (Public Law 93-288). The Center for Local Government Technology, Oklahoma State University, prepared this book which sets forth standards and construction practices. Proper city and county road bridge construction can mitigate flood damage and also meet federal assistance minimum standards requirements.

As a result of a higher standard of road and bridge construction, costs and traffic interruption will be reduced.

This guide book serves as an adjunct to the state, "Demonstration Bridge Project" and is a ready reference for local road and bridge construction.

George Nigh

Contents

Road and Bridge Guidebook for Oklahoma Local Governments

This manual was prepared to aid county and municipal officials in the efficient construction, maintenance, rehabilitation, and replacement of roads and bridges. It presents construction standards and practices that are appropriate primarily to non-urban areas. Use of these standards and practices would reduce costs and improve efficiency in the following ways:

- Properly planned and maintained structures greatly reduce the occurrence and magnitude of flood damage.
- Standardization of designs and parts makes maintenance easier to perform and parts more readily available at a lower cost.
- Replacement of damaged structures could be accomplished with a minimum delay for design preparation and with elimination of some major engineering costs.
- Proper designs would reduce damage from heavy traffic and provide safer conditions resulting in reduced costs for traffic accidents.
- Improved transportation arteries would reduce operation costs of agriculture and other industries and would stimulate the economic development of the state.
- The quick reaction time provided by the described methods would greatly reduce the time of disaster relief required in the event of major structural damage.

The methods of construction detailed in this manual are presented in such a way that they may be applied to most rural bridge and road repair and replacement. The need for such methods is readily apparent in Oklahoma and other states simply by noting the construction dates of many rural bridges. Those bridges constructed in the early days of the automobile could readily accommodate Model "T" Fords and similar vehicles, but they are quite inadequate to handle the modern demands created by heavy agricultural equipment, large transport trucks, and even school busses.

One major reason that bridges have been unable to keep up with the modernization of the vehicles using them is because bridge designers and builders have failed to learn from Henry Ford's success. By using mass production and interchangeable parts, he was able to produce a low-cost product with predictable and dependable quality. In the meantime, bridges were still designed one at a time creating a costly custom-made product with no real advantage in service. The primary emphasis of this manual is the application of mass production techniques and parts standardization to the construction of rural bridges and roads.

High production volumes result in lower preparation costs because of less production time needed per item and because of the greater number of pieces produced for the same investment in equipment as for low volume production.

Standard, interchangeable parts reduce production equipment and design investment, reduce inventory requirements, and increase availability of parts. With standard parts, installation and replacement procedures become standard, and costs of technical instructions and labor are reduced.

There are many good reasons for adopting basic standards for roads and bridges as previously stated. One additional, and sometimes critically important, reason is the benefits this provides should you wish to apply for Federal Disaster Assistance. If a county or city has adopted road or bridge standards prior to a disaster such as a flood, it may apply for funds required to restore the damaged road or bridge to these standards, even if the original structure was old and did not yet meet these standards. In other words, if you have passed a resolution adopting standards for roads and bridges and can show that these are being applied to new construction, disaster aid funds might well pay to replace a washed out bridge that was old and inadequate with a larger one with higher load carrying ability up to the level of your local standards. The Federal Disaster Assistance Administration provides the following guidelines in their Eligibility Handbook (3300.6, 12/75):

c. *Category C – Road Systems*

(1) *General Eligibility of Emergency Work*

(a) *Eligible are existing street, road, and highway facilities maintained by an applicant,* except those facilities on the Federal Aid and other designated systems under the statutory authority of the Federal Highway Administration.

(b) *Methods of repair and materials utilized* to accomplish emergency repairs or replacements should generally be the most economical available that meet the minimum requirements at the site.

(2) *Limitations of Emergency Work*

(a) *If detours or bypass* roads are feasible, such provisions will constitute emergency replacement.

(b) *Emergency repair or replacement* will be limited to the minimum required to provide safe two-way traffic, except that the pre-disaster roadway width will not be exceeded.

(c) *Emergency repair or replacement* will not be eligible if the existing road network will handle the traffic requirement.

(3) *Criteria for Emergency Work.* Examples of specific criteria to be used as guidance for emergency repair or replacement of streets and roads are as follows:

(a) *The construction of an emergency detour* or bypass road as required to accommodate traffic during restoration of an eligible damaged facility.

(b) *Where paved roads and streets have been damaged to an extent that holes, cracks, blisters, or other areas of deterioration have made them impassable* or create a hazard to personal safety, patching is eligible. Gravel or its local equivalent will normally provide a minimum safe repair to accommodate light movement of traffic. Bituminous patching may be authorized on roads or streets subject to heavy or high speed traffic.

(c) *Substitute replacement* with gravel or other surfacing material is eligible where hard road surfacing has been damaged to an extent as to make patching impractical. The volume, flow, and type of traffic, and the length of time the temporary repairs will be in use, shall be the controlling factors in determining the kind of replacement material to be used in providing a minimum all-weather road.

(4) *Nonpublic Streets, Roads, and Bridges.*

(a) *Related facilities that are not publicly owned* or are not under the direct supervision of an eligible applicant may be eligible as a result of a major disaster for emergency repairs or replacement provided:

1 *The owner of the facility is not able to make or finance the emergency repairs* necessary to return the facility to operation, and

2 *It serves a public purpose* to the community at large and is available at all times and essential for public use, and

3 *It is considered essential for public health and safety* with no alternate facilities immediately available within a reasonable distance, and

4 *The necessary emergency work can be provided on a one-time basis* and will in no way obligate the Federal Government to fund further emergency work or maintenance.

(b) *Limitations.* Such approval is on the basis that these repairs constitute emergency work essential for the immediate preservation of life and property. The repair or reconstruction of these facilities is limited to providing the minimum effort to make them passable, or to replacing them with emergency facilities, whichever is less costly to the Federal Government. Current engineering design codes, specifications, and standards are not applicable to this emergency work. Permanent restoration of these facilities is not authorized. If the estimated cost of the work exceeds $2,000 per family or business served, the matter should be referred to the FDAA Regional Director for guidance.

(5) *General Eligibility of Permanent Work*

(a) *Existing streets, roads, and highway facilities which are maintained by an eligible applicant,* and which are damaged or destroyed as a result of a major disaster may be eligible for restoration on the basis of predisaster design in conformity with current applicable codes, specifications, and standards, when not covered by insurance.

(b) *Highway facilities* are any construction features within the public right-of-way that are essential to make the street, road, or facility itself a functional whole. They include, but are not limited to, bridges, drainage structures, travelled way, shoulders, and safety features.

(c) *Facilities which are repairable to predisaster capacity are not eligible for replacement if the estimated cost of replacement is more than the estimated cost of repairs.* However, in those cases where the advisability of repairing the facility is questioned by the applicant or by the State, a determination by the Regional Director is required to verify whether the facility shall be repaired or replaced in accordance with FDAA minimum safety standards. Eligible repairs shall be limited to restoring the damaged portions of the facility to pre-disaster design capacity in conformity with current applicable codes, standards, or specifications for repair. If the applicant desires to replace the facility rather than repair it, he may request a grant-in-lieu based on the eligible cost of repairs.

(d) *Before a Damage Survey Report is prepared* for a damaged bridge, the Federal Inspector should identify the stretch of road which generally includes this bridge. He should classify the road involved as to type (rural, urban, or industrial). He should also note those characteristics of the involved road that would have a bearing on the bridge design capacity, including traffic count; posted speed; width of road surface, shoulders, and bridges; type of pavement; load limits; flood frequency; detours; etc. A Bridge Survey (Appendix 5) may be prescribed by the Regional Director for reporting such information.

(6) *Guidelines for Permanent Work*

(a) *Nonessential Features.* Although constructed and maintained by the applicant, nonfunctional features of only aesthetic value such as landscaping are not eligible.

(b) *Facilities Not in Use.* If a street, road, or highway facility was not in use due to obsolescence or generally unsafe condition prior to the major disaster, repair or replacement of such structure is ineligible.

(c) Facilities which were in limited use prior to the disaster, or were being used for other purposes than originally designed, may be eligible for assistance only to the extent necessary to resume immediate pre-disaster use, and in conformity with current applicable codes, specifications, and standards.

(d) *Bridge Replacement Projects* are to include only those items that are directly related to the bridge design and are within the bridge right-of-way.

(e) *Replacement of Bridges* will be in accordance with current applicable local pre-disaster codes, specifications, and standards and FDAA minimum safety standards in the following paragraphs. If local standards require bridge widths or other improvements which exceed the minimum safe requirements outlined in the following paragraphs, the applicant must provide verification acceptable to the FCO that such standards were in actual use prior to the disaster under like circumstances. Best evidence of the increased standard are recently constructed local bridges with comparable circumstances.

(f) *Minimum Safe Bridges* — It is the intent of FDAA that no unsafe bridges be built using Federal funds. Therefore, in order to provide safe and usable bridges, the following minimum standards will be met even where local standards do not specifically require such minimums, or would otherwise specify less. However, an exception may be approved by the Regional Director for replacement bridges already under construction to local codes, specifications and standards prior to the damage survey.

(g) *A bridge, located on a two lane road,* carrying an average of 50 or more vehicles per day shall be replaced with a bridge having a minimum 22-foot clear roadway width. (See Figure 1.)

(h) *A bridge located on a single lane road* which carries an average of 50 or more vehicles per day shall be replaced with a bridge having a minimum clear roadway width of 18 feet.

(i) *A bridge located on a road carrying an average of less than 50 vehicles per day* shall be replaced with a bridge having the same width as the bridge being replaced or the same average width as the travelled way of the approach roads whichever is greater.

(j) *If the approach roads were undamaged* and a bridge can be replaced at the existing site without unacceptable traffic safety hazards, the Regional Director may authorize eligible restoration costs to replace the bridge in accordance with current applicable codes, specifications, and standards. If relocation of the bridge is proposed by the applicant and approved by the FDAA Regional Director to achieve a safer road alignment and requires replacement of existing, undamaged approach roads, all costs of approach roads not resulting directly from major disaster damages are the responsibility of the applicant. Such relocated approach roads of any replacement bridge shall conform at least to the minimum AASHTO standards outlined in Tables 1 thru 7, AASHTO Geometric Design Guide for Local Roads and Streets. Skewing of any replacement bridge to conform to an FDAA-approved safer alignment is eligible for Federal reimbursement. If an applicant decides not to provide at its own cost the approach roads, relocated and upgraded to minimum AASHTO standards, Federal assistance under PL 93-288 shall be limited to a replacement bridge at the original location with the same capacity as existed at the time of the disaster and with width not exceeding the minimum safe standards stated above. Such replacement bridge shall be properly posted to alert drivers to safety considerations.

(k) *Sidewalks on Bridges* are not eligible unless existing on the damaged bridge prior to the disaster or required by current, written applicable codes, specifications and standards.

(l) *Bridge and Culvert Waterway Openings* shall be based on applicable local standards in use prior to the disaster. In all bridge opening designs, consideration will be given to the drainage area involved above and below the bridge site. Where economically feasible and practical, the bridge deck may be elevated above the approach roads, so that the deck will not be inundated even if the approach roads are flooded. Normally any restored bridge structure will be about the same length as the bridge prior to damage or destruction by the disaster. Design for floods less frequent than 50 years will not be authorized unless there is proof in writing that such design frequency is mandatory either by law, or by local flood plain management requirements that are actively enforced and were in effect prior to the disaster.

(m) *HUD Regulations pertaining to National Flood Insurance Program* provide for prevention of "new encroachments" into the 100-year floodway of those natural streams to which those regulations apply. However, the replacement of bridges under Public Law 93-288 damaged or destroyed is not "new encroachment" within the meaning of those regulations.

(n) *Channel Improvements Related to Bridge Restoration* including lining and straightening, bank protection or rip-rap that did not exist prior to the major disaster, and wing walls for undamaged abutments generally are not eligible unless such work will reduce overall project costs eligible for Federal funding of new construction. However, some stream clearance beyond the bridge right-of-way may be eligible as emergency work under Category B when justified.

Replacement Bridge Widths Eligible For FDAA Reimbursement

Pre-disaster Approach Traveled Way for Two Directional Traffic	Clear Roadway Width of Replacement Bridge Current Average Daily Traffic 50-399	400-749	Over 750
Up to 18 Feet	22 Feet	24 Feet	*
19	23	25	
20	24	26	
21	25	27	
22	26	28	
23	27	29	
24	28	30	
25	29	31	
26	30	32	
27	31	33	
28	32	34	
29	33	35	
30	34	36	

*Limited to pre-disaster approach roadway width or that shown under 400-749, whichever is greater. This includes width of pre-disaster pavement and improved shoulders but does not include ditch slopes.

(7) *Examples of Eligible Permanent Work*

(a) *Specific examples of eligible work are:*

1. Bridges damaged as a result of a major disaster are eligible for repair in accordance with the applicant's current standards for the traffic volume which the bridge carried immediately prior to the disaster. If the bridge is damaged to such an extent that repairs cannot be made, the entire bridge should be replaced in accordance with pre-disaster design and in conformity with current applicable standards. For example, if the bridge originally had two 10-foot lanes, no shoulders, and was designed for H-10 loading and the standards and traffic volume required 12-foot lanes, shoulders, and H-15 loading, the Federal contribution would properly include such costs. If only a portion of a multispan structure is destroyed and the other span or spans remain sound, the Federal contribution would be limited to the cost of replacing the damaged span or spans. In this case, the design of the replacement section would be similar to the undamaged section. If the applicant decides to build a facility adequate for future traffic volumes, such as a four-lane bridge, the additional cost of the betterment will be the applicant's responsibility.

2. A One-Lane, Single Span, Steel Truss Bridge with a timber deck is damaged by a major disaster. The damaged portions include damage to the deck and undermining of one abutment. The repair costs will be based on returning the bridge to its pre-disaster capacity. The repair cost will be estimated, using materials which conform to local standards, but covering only the repair of damages caused by the disaster and not including any costs for upgrading the bridge to meet the local specifications and standards for new construction or for its demolition and removal. In such a case, the applicant may elect to take a grant-in-lieu toward replacement of the bridge, limited to the costs of eligible repairs.

3. A One-Lane, Single Span, Steel Truss Bridge with a timber deck is severely damaged by a major disaster. Inspection reveals that it is not feasible to repair the bridge to its pre-disaster capacity. In such a case, demolition and replacement of the structure would be eligible. The replacement structure will be designed and constructed in accordance with minimum current codes, specifications, and standards, applicable prior to the major disaster to new construction in that location or to FDAA minimum safety standards.

4. Roads or sections of roads that are destroyed by a major disaster will be replaced only to their pre-disaster design in accordance with current standards. If the destroyed section of road contains a single 10-foot lane, only a single 10-foot lane will be replaced. However, if the applicant, at his own expense, is concurrently rebuilding sections of road adjoining the destroyed road, the Federal contribution will be based on the estimated cost of rebuilding the destroyed areas in accordance with the current standards of the applicant for a one-lane road. Any cost for increasing the capacity of the road such as adding additional lanes will be the responsibility of the applicant.

5. A 16-Foot-Wide Gravel Road is severely damaged or destroyed for a length of 300 feet. The unpaved ditches along each side of the road are damaged for a length of 400 feet. Eligible repair in this case would be grading, shaping, and placing gravel or borrow material in the damaged areas as necessary to return the road and ditches to their condition prior to the disaster. Placement of bituminous concrete or other permanent surface on the roads and ditches is not eligible in this case.

6. *A 20-Foot-Wide 2-Lane Bituminous Concrete Road* is inundated during a major disaster because of lack of drainage structures. As a result the road surface fails and requires replacement. Construction of the necessary drainage structures is not eligible, except for minor work justified as disaster proofing, since these structures did not exist prior to the major disaster.

(b) *Additional examples of eligible repair or replacement work under this category are given below.*

1. *Culverts that are washed out* may be replaced by culverts of similar construction or by larger culverts if required by current applicable standards. However, if a culvert is merely plugged, and no other damage has been sustained, the Federal contribution will be limited to the cost of emergency work required to clean the culvert.

2. *Manholes, Curbs, Gutters,* and related items damaged by the disaster or by equipment performing emergency disaster work.

3. *Public Sidewalks* if their maintenance is the responsibility of the local government.

4. *Shoulders, Embankments, and Drainage Ditches* in accordance with current applicable standards.

5. *Road or Street Name Signs, traffic control signs, signal lights,* and other publicly owned traffic control equipment.

6. *Boardwalks* if publicly owned and used for public safety or commercial purposes, i.e., necessary to provide access for fire-fighting equipment, ambulances, police protection, etc., or serving commerical establishments.

All bridge and road work described in this manual is designed to meet Federal Highway Administration approved standards and, thus, will provide adequate systems for heavy equipment which might occasionally use the rural system while also providing adequate widths for more frequent usage by agriculture machinery.

The Oklahoma Department of Transportation has prepared and adopted the standard plans and specifications for the establishment, construction, and maintenance of state highways and bridges. The following chart from the County Commissioner Handbook (Oklahoma State University, 1979) illustrates the basis standards which county roads must meet to be eligible for federal aid. Exceptions or variations to any part of these design standards may be negotiated on a project-by-project basis.

(A) Thickness of base will be determined by soils tests for the Design Load.

(B) On projects having a gravel surface, no base will be required.

(C) Where guardrail is used, the graded width of shoulder should be increased by two feet.

(D) Temp. R/W for Construction may be negotiated where permanent R/W will not be required.

(E) The bridge may be sized for the design flood shown, provided the roadway can be designed with an overflow (fuseplug) to protect bridge from washout. If the roadway cannot be designed so that overflow (fuseplug) will carry run-off for a 50-year flood, then the bridge will be sized to carry the 50-year flood.

(F) Small structures are where drainage area is less than ten square miles.

(G) It shall be permissible to leave a bridge in place if the clear roadway width is at least as wide as the approach surfacing and if the design loading capacity is at least H-15.

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These standards are intended to provide maximum benefit/cost ratio to the using public. It is reasonable to assume that if your traveling public gets used to traveling on state and federal-aid roads, it will expect the same safety on off-system roads. We must also look to the future because low volume roads today are not going to remain low volume roads tomorrow. Predictions are that vehicle traffic will increase 50 percent but our total road mileage will increase only 1 percent, so the additional travel is going to occur on the local road system.

Secondly, studies in various states, particularly in Arkansas, a state that has similar road conditions to those in Oklahoma, showed that renewing or improving low volume roads to meet present ASSHTO standards reduced accidents 26 percent, while renewing to a compromised standard reduced accidents only 5 percent. It was also found that simple resurfacing of the highway *increased* accidents by 75 percent. A study in Vermont revealed similar results. When we rebuild these low volume roads, we must keep these items in mind. We must have better records in order to locate the areas where we should spend our limited funds.

The presentation of material in this manual has been divided into sections on bridges and on roads to provide ready access to information required by the reader. Every attempt has been made to make the concepts clear and free from specialized jargon, so that the concepts and procedures can be applied to real situations without further interpretation. Adherence to the presented methods will lead to maximum efficiency and minimum cost for rural road and bridge work.

County Federal Aid Road Design Standards

Design features shall, as a minimum, be in accordance with the requirements established by the American Association of State Highway and Transportation Officials (AASHTO).

STANDARD NUMBER		1			2			3			4			5			6		
AVERAGE DAILY TRAFFIC		Over 6,000			1,600- 6,000			750- 1,600			400- 750			50- 400			*0 50		
DESIGN SPEED		50	40	30	50	40	30	50	40	30	50	40	30	50	40	30	50	40	30
MAXIMUM	Flat	6			6			6			6			6			6		
PERCENT	Rolling		8			8			8			8			8			8	
GRADE	Mountainous			10			10			10			10			10			10
MAXIMUM CURVE (DEGREE)		9	14	26	9	14	26	9	14	26	9	14	26	9	14	26	9	14	26
BASE DESIGN WHEEL LOAD (A)		9,000#			7,000#			7,000#			5,000#			5,000#			5,000#		
SURFACE TYPE (B)		Asphalt			Bituminous			Bituminous			Bituminous			Gravel			Gravel		
NUMBER OF LANES		4			2			2			2			2			2		
SURFACE WIDTH		48'	48'	48'	24'	24'	24'	22'	22'	22'	22'	22'	22'	20'	20'	20'	18'	18'	18'
SHOULDER WIDTH (C)		8'			8'			8'			6'			4'			2'		
RIGHT-OF-WAY (D)		AS REQUIRED FOR CONSTRUCTION AND MAINTENANCE																	
DITCH DESIGN		18 Inch Minimum Depth, Width will be determined by Drainage Area and Terrain																	

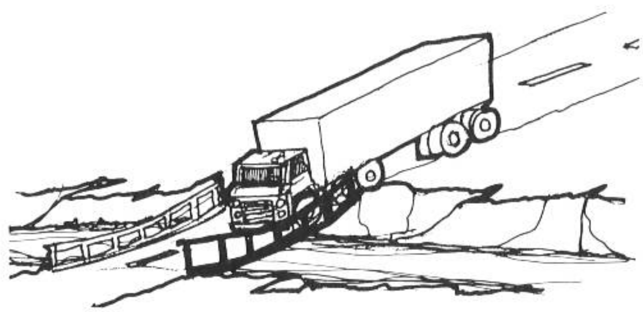
*Standard Number 6 may be used on minor roads with few trucks.

Bridge Design Standards

HYDRAULIC DESIGN CAPACITY (E) (F)	25-Year Flood									10-Year Flood (small structure) 25-Year Flood (major structure)								
DESIGN LOADING (G)	HS-20			HS-20			HS-20			HS-20			H-20			H-20		
BRIDGE WIDTH (G)	64'	54'	54'	40'	30'	30'	38'	28'	28'	28'	28'	26'	26'	24'	24'	24'	24'	24'

NOTES: The intent of these design standards is to provide an all weather facility for the greatest number of people at a minimum of cost. Therefore, a county may request that a proposed Federal Aid Project be constructed to standards in excess of the design standards cited herewith.

Bridge Replacement

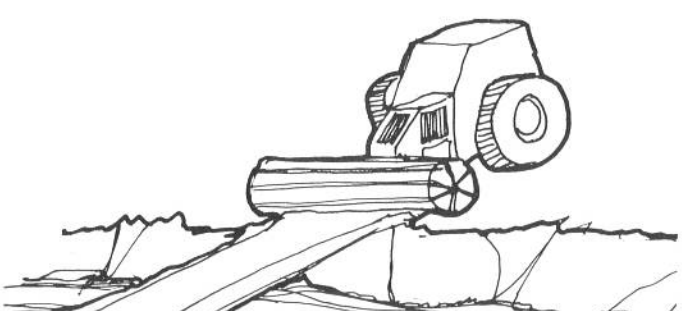


Bridge failure

The need for bridge replacement occurs for many reasons. Failure can be caused by overloads from heavy equipment or by floods and washouts. Other times the existing structure needs replacement simply because it cannot properly accommodate today's traffic needs.

Bridge washout

In some cases, only the deck may need replacing while in others in the entire structure may have failed. This chapter describes some procedures for building various kinds of abutments and placing several types of bridge decks. Depending on your location, available skills and equipment, and your own needs, some of these will be more suitable than others. This chapter will discuss the re-use of existing abutments and construction practices for new abutments using steel and concrete pilings and poured-in-place concrete abutments, as well as the installation of both steel beam-concrete surface decks, prestressed concrete with poured-in-place decks and wood decks.

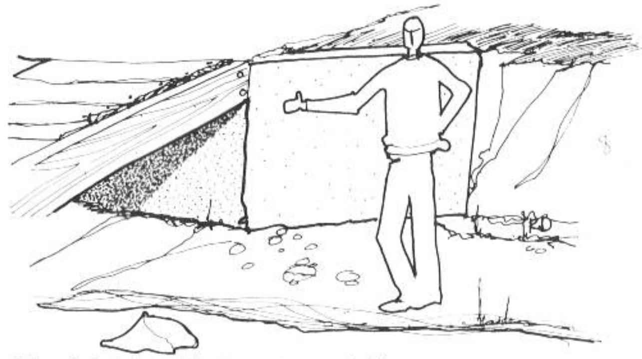


Bridge too narrow for equipment

Before a decision is made to replace all or a portion of a bridge the entire structure should be inspected by qualified county inspection personnel under the supervision of a registered professional civil engineer. The following items should be considered in the inspection and are included on the following typical inspection sheets as illustrated on pages 14-18.

Roadway Approaches. Approach pavement should be checked for unevenness, settlement, roughness, cracks, and joint condition. Condition of the shoulders, slopes, drainage, and approach guard rail should be inspected.

Waterway. The adequacy of the waterway opening under the structure should be determined. Look for debris, sand and gravel deposits, signs of flooding and erosion, and any other evidence of potential damage from water flow.



Check bridge abutment condition

Piers and Abutments. Investigation of the footings should be made for evidence of significant scouring or undercutting. These inspections preferably should be made at low water elevation; even so, the water depth at some piers may require probing or diving.

All exposed concrete should be inspected for cracks and deterioration of the concrete.

Structural steel partially encased in substructure concrete should be inspected at the face of exposure for deterioration and for movement.

Stone masonry should be checked for cracking in the mortar joints and to see that the mortar itself is in good condition. Check for erosion, cavities, cracking and other deterioration of the stones.

Any suspected movement or settlement should be checked with an engineer's level and compared with previous records.

Bents. Timber piles should be checked for decay, especially where they are alternately wet and dry. Timber piles in salt water should be checked for damage by marine borers, at and below tide line down to the mud line.

Steel and concrete piles should be examined for corrosion and deterioration.

Caps and bracing should be observed under heavy load for unusual movement.

Stringers. Stringers should be checked for damage, deterioration, and accumulation of dirt.

Steel Girders. Steel should be examined for cracking and corrosion.

Flanges and webs should be checked for any damage or misalignment and web stiffeners checked for evidence of buckling. Determine if any unusual vibration or excessive deflections occur under passage of heavy loads.

Hinges should be checked to see that all elements are functioning properly.

Concrete Girders. Stems of "T" beams should be checked for abnormal cracking and any disintegration of the concrete.

The soffit of the lower slab in box girder structures and the outside face of the girders should be examined for significant cracking. Look for any offset at the hinges which might indicate problems with the hinge bearing.

Prestressed concrete girders should be examined for alignment, cracking, and deterioration of the concrete. Check for cracking or spalling in the area around the bearings and at cast-in-place diaphragms where creep and humping of the girders may have had an effect.

Bearings. All bearings devices should be examined to ascertain that they are functioning properly.

Anchor bolts should be checked to see that they are secure and the nuts are properly set to permit normal movement.

Examine the concrete for cracks and spalls at abutment seats and pier caps where girders such as "T" beams bear directly on concrete.

Expansion Joints. There should be adequate space for thermal movement; check to see if the joint is open an excessive amount. Care should be taken in a sealed-type joint to prevent the entry of rocks, sand, or other noncompressible material.

Steel finger type joints and sliding plate joints should be examined for evidence of loose anchorages, binding, cracking or breaking of welds, or other defects.

The underside of expansion joints should be inspected for sheared and spalled concrete.

Deck. Timber decks should be examined for decay at the contact areas with stringers and between layers of planking or laminated pieces. Between layers of planking or laminated pieces, nails or spikes should be visually checked under passing traffic to see if they are secure.

Concrete decks should be checked for cracking, leaching, scaling, potholing, spalling, and other evidence of deterioration.

Steel decks should be checked for corrosion and unsound welds.

All decks should be examined for slipperiness and water ponding. Drains and scuppers should be checked and cleaned if necessary.

Curbs. Concrete curbs should be examined for cracks, spalls, buckling, or general deterioration and for loss of height resulting from building-up of surfacing on the deck.

Timber wheel guards and scupper blocks should be checked for splits, checks, and decay. Check to determine if they are aligned and bolted securely in place. Note paint condition where it improves visibility.

Sidewalks. Concrete sidewalks should be examined for cracks, scaling, potholing, spalling, or other deterioration.

Timber sidewalks should be checked for soundness of the timber and to determine if the floor planks are adequately supported and securely fastened.

Steel sidewalks should be examined for proper drainage and to see that the surface is not excessively rough nor slick. Any item which constitutes a hazard for pedestrians should be noted and corrected.

Bridge Railings. Concrete handrails should be examined for cracks, spalls, scaling, or other deterioration.

Metal handrails should be examined for the condition of paint and for corrosion.

Timber handrails should be examined for decay and to insure that all sections are secure.

All handrails should be checked for any damage from traffic and for vertical and horizontal alignment.

Barrier Railing. Barrier railings should be examined for traffic damage and for alignment. Concrete in the barrier railing should be checked for cracks, spalls, and other deterioration. Steel in the barrier railings should be checked for corrosion and to insure that anchor bolts and nuts are secure.

Steel Trusses. The vertical and horizontal alignment of the truss should be observed and the causes of any misalignment should be determined. Each of the truss members should be checked as to condition, connection, adjustment, and intended function.

The condition of the paint and extent of corrosion should be noted. The condition of pins, nuts, keys, rivets, and bolts should be determined.

Timber Trusses. The alignment of trusses should be checked for sag. All timber members should be examined for checks, splits, and decay. Ends of compression chord and diagonal members should be checked for any evidence of crushing. All splice points should be checked for soundness in the shear connections. All bolts should be checked to insure that they are tight and in good condition. Roof and sides of covered bridges should be investigated for adequacy of protecting the structural members from the weather. Fire hazards should be noted for correction.

Movable Bridges. Trusses, floor system, and other structural elements require the normal inspection procedures mentioned in previous paragraphs.

Additionally, counterweights and counterweight cables should be examined to insure that all elements are sound, secure, and functioning properly.

The machinery should be checked for proper lubrication, noise, and looseness in the shaft and bearings. The electrical system should be checked for the condition of controls, wiring, conduits, motors, and lights. Traffic gates, barriers, and signal systems for highway and marine traffic should be checked.

Suspension Span. Main suspension cables should be examined to insure that the protective covering is in good condition. Suspender connections should be ex-

Please turn to Page 18

STRUCTURE INVENTORY 8 APPRAISAL SHEET

Revised 12-78

IDENTIFICATION

1 State
2 Hwy District
3 County ___ 4 City/Town
5 Inventory Route ___ On ☐ Under ☐
6 Features Intersected
7 Facility Carried by Structure
8 Structure No. ___ 1 of ___
9 Location
10 Min. Vert. Clearance, Inv. Rte. ___ ' ___ "
11 Milepoint
12 Road Section No
13 Defense Bridge Description
14 Defense Milepoint
15 Defense Section Length
16 Latitude
17 Longitude
18 Physical Vulnerability
19 By pass, Detour Length
20 Toll
21 Custodian
22 Owner
23 FAP No

CLASSIFICATION

24 Highway System
25 Administrative
26 Functional

	By	Date
Transfer of Data		
Maintenance Insp.		
Condition Analysis		
Appraisal		
Cost Estimate		
General Review		

STRUCTURE DATA

27 Year Built
28 Lanes on Str ___ under ___
29 ADT ___ 30 Year
31 Design Load
32 Appr Rdwy Width w/Sh'ld
33 Br Median ☐None ☐Open ☐Closed
34 Skew
35 Structure Flared ☐Yes ☐No
36 Traffic Safety Features
37
38 Navigation Control ☐Yes ☐No
39 -Vertical ___ ft
40 -Horizontal ___ ft
41 Open, Posted, or Closed

42 Type Service ___ code
43 Structure Type - Main
44 - Approach
45 No of Spans - Main
46 - Approach
47 Total Horiz. Clearance ___ ft
48 Max Span Length ___ ft
49 Structure Length ___ ft
50 Sidewalk Lt ___ ft, Rt ___ ft
51 Br Roadway Width (curb-curb) ___ ft
52 Deck Width (out-out) ___ ft
53 Vert Clearance over Deck ___ ' ___ "
54 Underclearance - Vertical ___ ' ___ "
55 Lateral - Right ___ ft
56 - Left ___ ft
57 Wearing Surface

CONDITION — Material — Condition Analysis — Rating (9-0)

58 Deck
59 Superstructure
60 Substructure
61 Channel & Channel Protection
62 Culvert & Retaining Walls
63 Estimated Remaining Life ___ 65 Approach Roadway Alignment
64 Operating Rating ___ 66 Inventory Rating

APPRAISAL — Deficiencies — Rating (9-0)

67 Structural Condition
68 Deck Geometry
69 Underclearances - Vertical & Lateral
70 Safe Load Capacity
71 Waterway Adequacy
72 Approach Roadway Alignment

PROPOSED IMPROVEMENTS

73 Year Needed ___ Completed ___ Describe (item 75)
74 Type of Service
75 Type of Work
76 Improvement Length ___ ft
77 Design Loading
78 Roadway Width ___ ft
79 Number of Lanes ___ 82 Prop Rdwy Improvement - Year
80 ADT ___ 81 Year ___ 83 - Type

Remarks:

84 Cost of Improvements $ ___ , ___ ,000
85 Prel Engrg. $ ___ , ___ ,000
86 Demolition $ ___ , ___ ,000
87 Substructure $ ___ , ___ ,000
88 Superstructure $ ___ , ___ ,000
90 Insp Date

Revised 1-79

STRUCTURE INVENTORY AND APPRAISAL SHEET
ABRIDGED (SHORT FORM)

IDENTIFICATION
1 State ______
3 County ______
4 City/Town ______
5 Inventory Route ______
6 Features Intersected ______
______
8 Structure No. ______
12 Road Section No. ______
19 By-Pass, Detour Length ______

CLASSIFICATION

24 Highway System ______

STRUCTURE DATA
27 Year Built ______
28 Lanes on Str. ______ under ______
29 ADT ______
31 Design Load ______
32 Appr. Rdwy. Width W/Sh'ld ______
36 Traffic Safety Features ______
41 Str. Open, closed or posted ______
42 Type Service ______
43 Str. Type-Main ______
49 Str. Length ______
51 Br. Roadway Width (curb-curb) ______
52 Deck Width (out-to-out) ______
53 Vert. Clearance over Deck ______

CONDITION

	Material	*Condition Analysis*	*Rating*
58 Deck			
59 Superstr.			
60 Substr.			
62 Cul. & Ret. Walls			
66 Inventory Rating			

APPRAISAL

	Deficiencies	*Rating*
67 Str. Condition		
68 Deck Geometry		
69 Underclearances-Vert. & Lat.		
71 Waterway Adequacy		
72 Appr. Roadway Alignment		

PROPOSED IMPROVEMENT & COSTS

75 Type of Work ______
84 Cost of Improvements $____,____,000.
85 Prel. Engineering $____,000.
86 Demolition $____,000.
87 Substructure $____,____,000.
88 Superstructure $____,____,000.
90 Date of Inspection ______

REMARKS:

DATE: 04/26/79

Structure Inventory & Appraisal Sheet

** Identification **

1. STATE 406 (OKLA.)
2. HWY. DISTRICT 5
3. COUNTY TILLMAN
4. CITY/TOWN 0000
5. INVENTORY ROUTE 121000620
6. FEATURES INTERSECTED CREEK
7. FACILITY CARRIED US 62
8. STRUCTURE NO. 71 002 00.430 x
9. LOCATION 0.4 MI E JACKSON CO
10. MIN. VERT. CLEARANCE, INV. RTE 99' 99''
11. MILEPOINT 0.043
12. ROAD SECTION NO. 0290

13. DEFENSE DISC.
14. DEFENSE MILEPOINT 13.500
15. DEFENSE SECTION LENGTH 54.5
16. LATITUDE 34 DEG 38.4 MIN
17. LONGITUDE 099 DEG 5.2 MIN
18. PHYSICAL VULNARABILITY 8
19. BYPASS, DETOUR LENGTH 40
20. ON FREE ROAD
21. CUSTODIAN STATE HIGHWAY DEPARTMENT
22. OWNER 1
23. F.A.P.NO. F 216 (15) (16)

** CLASSIFICATION **

24. FED. AID. SYSTEM 03
25. ADMINISTRATIVE 1
26. FUNCTIONAL 02

27. YEAR BUILT 6800
28. LANES ON STR. 02 -UNDER STR. 00
29. A.D.T. ON STR. 002400
30. YEAR 77
31. DESIGN LOAD UNKNOWN
32. APPR. RDWY. WIDTH W/SHLD 034
33. BR. MEDIAN NONE
34. SKEW 00
35. STRUCTURE FLARED NO
36. SAFETY FEATURES 0000

38. NAV. CONTROL 0
39. - VERTICAL 0.0
40. - HORIZONTAL 0.0
41. OPEN, POSTED, CLOSED A
42. TYPE SERVICE 15
43. STRUCTURE TYPE MAIN 119
44. APPROACH 000
45. NO. OF SPANS MAIN 003
46. APPROACH 000
47. TOTAL HORIZONTAL CLEARANCE 83.0

48. MAX. SPAN LENGTH 8 64. OPERATING RTG. 36
49. STRUCTURE LENGTH 27 66. INVENTORY RTG. 20
49A RCB BARREL LENGHT
50. SIDEWALK RT. 0.0 LEFT 0.0
51. BR. RDWY. WIDTH (CURB TO CURB) 83.0 FT.
52. DECK WD. (OUT TO OUT) 85.0 FT.
53. VERT. CL. OVER DECK 99 FT. IN
54. UNDERCLEARANCE-VERT 0 FT o IN
55. LATERAL-RIGHT 99.9
56. -LEFT 0.0
57. WEARING SURF. OTHER

POSTED VERT. CL.	1. 0' 0"	2. 0' 0"	3. 0' 0"	4. 0' 0"
MEASURED VERT. CL.	1. 0' 0"	2. 0' 0"	3. 0' 0"	4. 0' 0"

** PROPOSED IMPROVEMENTS **

73. YEAR NEEDED 00
74. TYPE OF SERVICE 0
75. TYPE OF WORK 000
76. IMPROVEMENT LENGTH 0.00

77. DESIGN LOADING 0
78. ROADWAY WIDTH 0.00
79. NUMBER OF LANES 00
80. A.D.T. 00

81. YEAR A.D.T. 00
82. PROPOSED IMPROVEMENT YEAR 00
83. -TYPE 0

** COST OF IMPROVEMENTS **

84. COST OF IMPROVEMENTS 0
85. PREL. ENGINEERING

86. DEMOLITION
87. SUBSTRUCTURE 0

88. SUPERSTRUCTURE 0

DESCRIPTION 3/8' x 5' x 83' R.C. BOX WITH 3' ADDITIONAL CURTAIN WALL DOWNSTREAM

OKLAHOMA DEPARTMENT OF TRANSPORTATION
BRIDGE MAINTENANCE INSPECTION

Form OBMI-4

	COND	RATE	REPAIR RECOM.	REMARKS
Traffic Service				
Br. End Marker				
Load Limit Signs				
Traffic Signs				
Approach Slabs				
CONDITION RATINGS				
Desk				
Wearing Surface				
Floor				
Railing				
Exp. Device				
Curbs				
Debris-Gutter				
Superstructure				
Truss Members				
Paint				
Bearing (Shoes)				
Beams				
Debris-Lower Chord				
Substructure				
Debris-Br. Scats, Pr. Tops				
Anchor Bolts				
Cracks				
Settlement				
Drift				
Paint				
Channel & Channel Protection				
Active Erosion				
Drift				
Siltation				
Rip Rap				
Pile Diversions				
Scour				
Slopewall				
High Water				
Flow Line				
Side Drain/Ditch Checks				
Culvert & Retaining Walls				
Cracks				
Settlement				
Drift				
Fill over R.C.B.				
Curbs				

Continued

Form OMBI-4 Continued

Estimated Remaing Life				
Appr. Rdy. Alignment				
APPRAISAL RATINGS				
Structural Condition				
Deck Geometry				
Under Clearance				
Safe Load Capacity				
Waterway Adequacy				
Appr. Rdy. Alginment				

HISTORY

Conc. Bridge Deck Rating

Paint Rating

Railing Type

Date of Inspection ____________________
Reported By ____________________
With ____________________

Repairs Recommended ____________________
CX-Critically Needed ____________________
FX-Minor Repairs Needed,
Lower Priority ____________________

Continued from Page 14

amined for correct positioning and tightness. Anchorages should be examined for corrosion and protection against moisture.

Signs. The condition and location of signs to indicate restricted weight limit, reduced speed limit, or reduced vertical clearance should be checked. For bridges over navigable streams, required navigational signs for water traffic should be checked for location and condition.

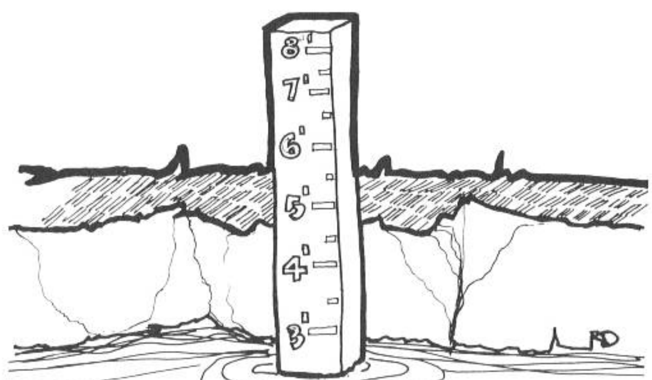
Encroachments. Number, location, size, and type of utilities, sewer pipelines, and other encroachments attached to or enclosed in the structure and in the immediate vicinity should be recorded. Observation should be made as to any potential danger to highway or water traffic, to the structure itself, and to the maintenance thereof.

Planning Bridge Replacement

Once a decision has been made to begin reconstruction or repair, a number of different concerns must be investigated and decisions made with regard to adequacy of existing structures and designs of new ones.

Considering Water Flow

One of the primary concerns in selecting bridge design is the amount of water expected to flow under the bridge. The final design should include an opening below the bridge large enough to pass flood flows without causing damage to the bridge. This should always be a major design item, but particular attention should be given to drainage in areas where runoff has damaged bridges in the past. The best way to determine the necessary opening is to have a professional engineer conduct a hydrology survey and from that survey to determine the maximum flow to be expected at the bridge site. In some cases, the U. S. Soil Conservation Service (SCS) may be able to provide drainage information on the area. Procedures for this analysis are outlined in SCS National Engineering Handbook,



Consider water level and seasonal flow

Section 4, Hydrology (NEH-4). This could be used with the procedures outlined in NEH-4 and in the Technical Release #55, "Urban Hydrology for Small Watersheds" published by SCS (Jan., 1975). Another excellent reference is provided by an SCS publication "A Method for Estimating Volume and Rate of Runoff in Small Watersheds" (SCS-TP-149, rev., 1973).

In a detailed engineering analysis, many factors are considered. One method of estimation is presented for use as guidelines by this manual. The general equation known as the "Rational Equation" is a preferred method in many references.

First—Estimate the peak runoff flow.

$$Q = CIA$$

where
Q = Flow in ft^3/sec
C = Runoff coefficient (for rural Oklahoma, assume $C=0.2$)
I = Rainfall in inches/hour (for Oklahoma assume 4"/hr)
A = Drainage area in acres

Second—Compute the opening required under the bridge.

$$O = Q/V$$

where
O = Opening under bridge in ft^2
V = Allowable water velocity in ft/sec (for Oklahoma, use $V = 8$ ft/sec)
Q = Flow in ft^3/sec

Third-Estimate the minimum bridge length.

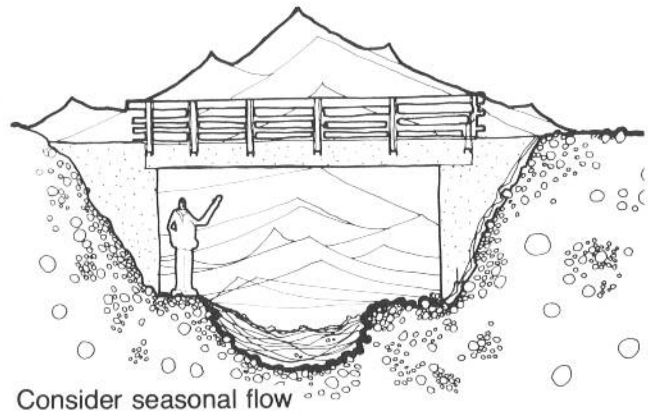
$$L = \frac{O}{D}$$

where
L = minimum bridge length in ft
O = Opening under bridge in ft^2
D = Average creek depth in ft

The table below may be used in estimating a minimum bridge length based upon the average creek depth and drainage area. Note — if your bridge is in a hilly area, you may need a longer bridge to accommodate the rapid runoff. When in doubt, review the past floods and get a detailed study.

Estimated Minimum Bridge Length, Ft.

Drainage Area, Acres	*Average Creek Depth Under Bridge, Ft.*				
	10'	*15'*	*20'*	*25'*	*30'*
500	5 ft or less				
1,000	10'	8'	5 ft or less		
2,000	20'	13'	10'	8'	7'
4,000	40'	27'	20'	16'	13'
6,000	60'	40'	30'	24'	20'
8,000	80'	53'	40'	32'	27'
10,000	100'	67'	50'	40'	33'



Consider seasonal flow

Adapting Existing Abutments

In some cases, existing abutments can be used or adapted for new decks. To do this, the first step should begin with a careful inspection of the existing bridge structure as outlined at the beginning of this chapter.

If the existing abutments are satisfactory for the new load, the next step is to be sure that they will work with the new deck that is to be placed. The two major items to be checked are the width and the method of attaching the deck to the abutments. To achieve compatibility on those items, various modifications can be made if the abutments are strong enough for the new load.

What if the old abutments are too narrow? One way to increase the width is by pouring a concrete cap on top of the present abutments or piers. This cap should be large enough and should contain enough reinforcing steel to meet the needed load carrying ability. These specifications can be obtained from an engineer familiar with this type of construction. After framing this cap with plywood and tying the reinforcing steel in place, the concrete can be poured.

IMPORTANT. Be sure to vibrate or work the concrete carefully to make sure that the concrete fills all voids and completely surrounds and contacts the steel. This is a vital step, and the strength of the bridge depends upon a good job. It is also important that the steel rods be tied with wire in the positions indicated in the specifications. The strength of the cap has been designed with the steel in these selected locations. This is not hard to do but should be done carefully and all measurements checked before pouring the concrete.

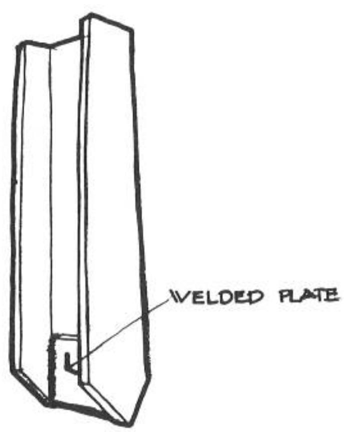
For a detailed discussion of pouring a concrete cap, see this section under construction of new abutments.

If steel piers form the foundation of the abutment, it is also possible to widen the abutment by placing a steel beam of an appropriate length across the existing piers. This may be attached to the in-place piers by welding. The size of the beam should be large enough to provide adequate load carrying capacity, and the strength and the type of beam to supply it should be determined by your engineer. If there is a large overhang from the outside pier to the end of the new beam, it may be advisable to drive two additional piers, one at each end of the new cap beam. This will allow you to use a lighter beam as it will reduce the cantilever load on the ends. If you are in doubt, an engineer can check this and specify this requirement.

Installing Bridge Structures

Building Abutments with Steel, Concrete, and Wood Piling

Steel Piling. One common way of building abutments for a single span bridge is by driving steel beams and pouring a concrete cap to hold the deck. Although there are many options available to the bridge builder, this guidebook will present some of the procedures that are suitable for most Oklahoma conditions and to the bridge decks which will be discussed later in this chapter. This concept utilizes a poured-in-place concrete riding surface that may be placed on top of either steel beams or pre-stressed concrete beams.



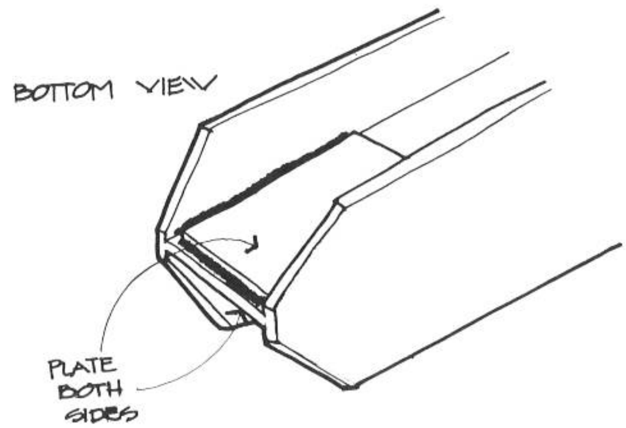
Pile bearing H beam

H-beams are normally used as piles for steel supported bridges. They are driven into the ground to provide solid support for the bridge superstructure. The number and size of H-beams should be specified on the bridge plans. This will depend upon the span and the bridge width. A carefully engineered design will be required to insure maximum support from properly placed piles.

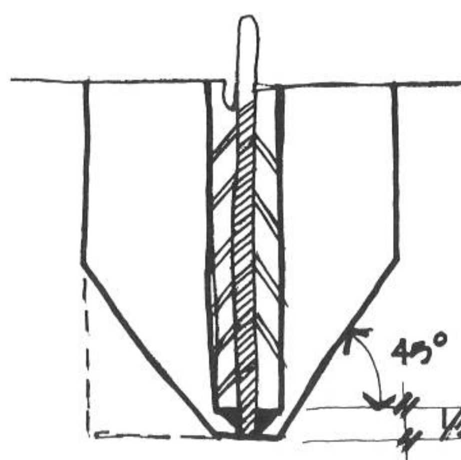
Before driving the beam, the tip of each beam should be prepared for good penetration as indicated in the following sketch.

Note that the flanges of the beam are to be cut on a 45-degree angle as indicated in the illustration. As this section indicates, the resulting "point" will be approximately 2 inches to 2 1/2 inches wide at the tip of the point after cutting each side of the flange to 45 degrees.

Steel plates are to be welded to both sides of the web at the end of the beam. These plates are 3/4 inch thick, 1 foot long, and of appropriate width to match the beam size (8 inches wide for a 10-inch beam, 10 inches wide for a 12-inch beam and 12 inches wide for a 14-inch beam). As indicated by the bottom view,



they should be welded in such a manner so as to completely fill any space between the sides of the steel plate and the flange of the beam. A 3/8-inch fillet weld should be made across the entire width of the bottom of the steel plate. (See section below). Note also that these plates are located 1/2 inch above the bottom of the end of the H-beam. This welding may be done in the shop or field.



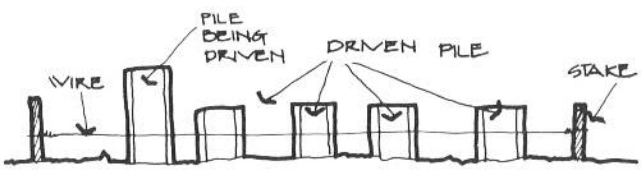
Section through web

As an alternative, premanufactured driving tips may be welded on the bottom of the piles instead of using the above procedure.

The bridge design will specify the details for driving the pile. A typical note on the plans might read like this:

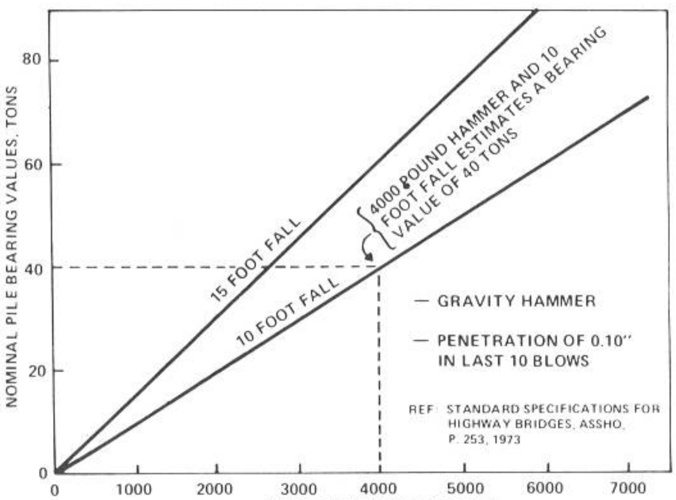
"All abutment piling shall be driven through the compacted fill. All piling shall be driven to practical refusal if above grade or to a minimum bearing of 50 tons at abutments and 60 tons at or below grade."

The phrase "driven to practical refusal" means to keep driving until it won't go any deeper. One common way of checking this is to drive until the pile does not go any deeper than 0.10 inch in 10 strokes of the driver. In this case, the weight of the driver and the height of the fall should be matched to the specified bearing capacity of the piling. The driver should have a weight of more than half that of the pile. A diesel or steam powered driver delivers more power than a standard driver and can be rated accordingly.



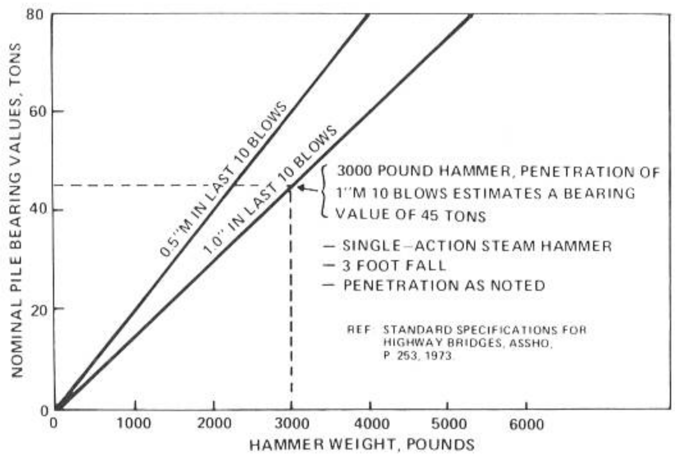
NOTE: Mark piles before and after 10 strokes driven to refusal.

The following graph may be used to estimate the pile bearing value for piling driven with a gravity hammer. If a gravity hammer having a total falling weight of 4000 pounds had reached "practical refusal" (0.10 inch in 10 blows), the graph can be used to estimate the bearing value. After measuring the height of the fall, approximately 10 feet, the line for a 10-foot fall isused to indicate a bearing value of 40 tons. These curves can also be used to estimate other combinations of hammer weight and height of fall. If you desire, a sample calculation is provided at the end of this chapter for checking other values.

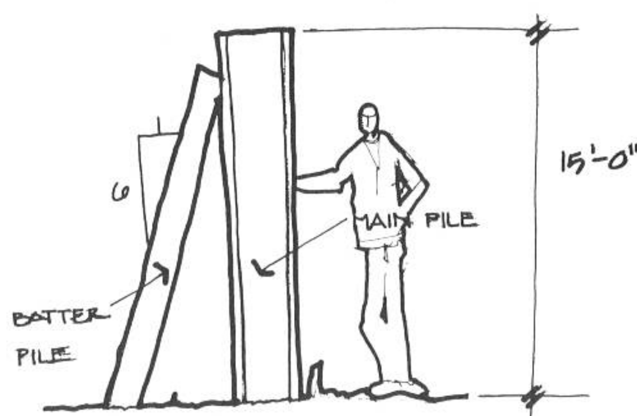


Steam-powered or diesel-powered pile drivers are much more powerful and the average penetration per blow is higher than for a comparable gravity pile driver. The second graph may be used to estimate pile bearing values for a single-action steam-powered pile driver. Note that these values are computed using a 3-foot height of fall. If a longer fall were used, say 6 feet, the bearing value estimates would increase accordingly (for a 6-foot fall, the estimate would double). Referring to the graph, if a 3000-pound hammer powered by a single-action steam pile driver were used with a 3-foot fall, a penetration of 1 inch in 10 blows would indicate an estimate of the bearing value to be 45 tons. A sample calculation is provided at the end of this chapter for if you wish to check other values.

Diesel-powered pile drivers are probably more commonly used for county bridges in Oklahoma than steam powered drivers. The reference formulas from ASSHO were developed for steam powered drivers but in reviewing equipment specifications for both types of equipment, it appears that the bearing values estimated for steam powered drivers could also be



used for diesel powered drivers. Actually, the specifications reviewed indicate that most diesel powered drivers are more powerful and thus the estimates will be on the low, or safe, side anyway.



Batter pile concept

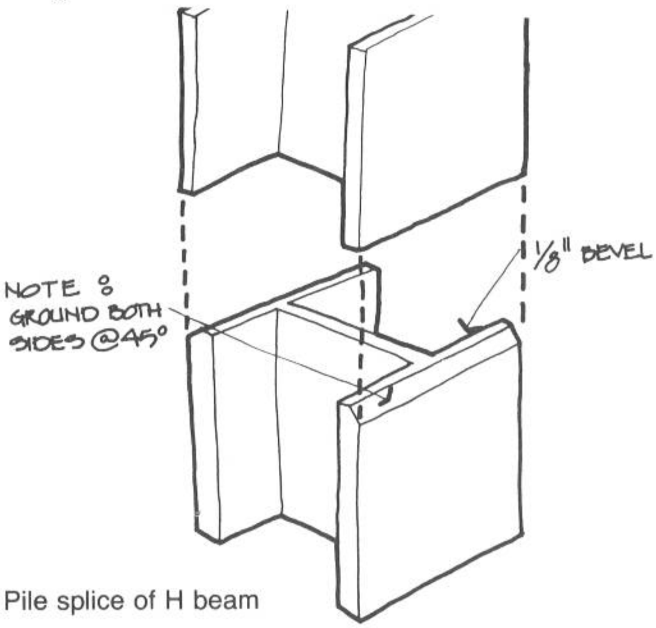
Some bridge specifications may call for "batter piles" although most county bridges do not use this concept. A batter pile is a second pile driven at an inclined angle to the main support pile (see sketch). The purpose of this pile is to provide horizontal (side) support to the main or vertical pile. This is done when the soil conditions do not provide adequate support for the vertical pile. A typical batter pile might be driven at a 6 to 1 incline although this should be specified exactly on the bridge plans. In this example, the batter pile would have an incline of 1 foot for each 6 feet of vertical height. If the top of the vertical pile was 15 feet above the creek bed when the batter pile would enter the earth, it should be set out 2½ feet from the base of the vertical pile. Example:

6 to 1 incline—

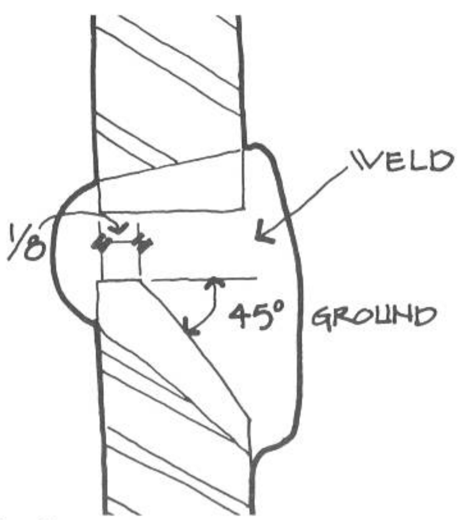
$$15' \text{ (vertical height) } \times \frac{1}{6} = 2.5' \text{ set out}$$

There are several ways to check for this condition. One way would be to use a transit and mark the pile before and after 10 strokes of the driver. Another simple way would be to stretch a steel wire next to the pile and mark before and after 10 strokes. In this case, be sure that the wire is anchored securely at two points remote from the pile.

If the beam must be spliced for an extended length, the beams should be prepared for welding by grinding both the flange and web of the next beam being attached as indicated below:



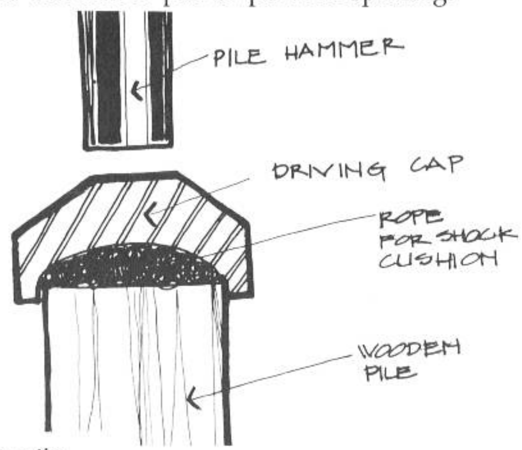
Pile splice of H beam



Detail of splice

As indicated, the flange and web are ground at a 45-degree angle leaving a flat end of ⅛ inch. A separation of ⅛ inch between the ends of the beams being joined allows room for making a weld completely through the joint, filling the 45-degree slot with the new weld material.

Wood Piling. Many county bridges in Oklahoma are supported by wood piling. When wood is to be used as a bearing pile, except for temporary repairs, it should be suitably treated to resist deterioration. The heads of these piles should be protected by a cap of an approved design, preferably having a rope or other suitable material next to the pile head and fitting into a casting which in turn supports a timber shock block. When the area of the head of a timber pile is greater than that of the face of the hammer, the cap should distribute the blow of the hammer across the entire section of the pile. In other words, you must protect the end of the timber pile to prevent splitting.



Pile driving tip

If the soil conditions require it, the timber pile may be pointed to allow penetration. In some cases, a metal shoe may be used on the penetrating end of the pile. Although it is relatively simple to splice another length onto a steel pile, this should be avoided with timber piles.

A timber pile may be driven in the same manner as a steel pile. Refer to the previous section on driving steel piles. The American Association of State Highway Officials (1973) recommends a gravity hammer of not less than 2000 pounds, preferably 3000 pounds, with a fall of 15 feet or less. If a steam hammer is used, the total energy developed by the hammer should be at least 6000 foot-pounds per blow. Many steam or diesel hammers now available far exceed this level.

Concrete Piling. In general, most county bridges in Oklahoma do not use a precast concrete piling even though standard design specifications are available from the Oklahoma Department of Transportation. The American Association of State Highway Officials (1973) makes the following recommendations for driving concrete piles:

> If a steam hammer is used, the total energy developed by the hammer should be at least 6000 foot-pounds per blow.
>
> If a gravity hammer is used, it should weigh at least 50% of the weight of the pile and at least 3000

pounds. The total drop of the hammer should be 8 feet *or less.*

As in driving timber piles, the head of the piling should be protected against damage. Driving steel shells for cast-in-place concrete piling requires the same precautions and standard as for concrete piles.

Poured-in-Place Concrete Abutment. One common way to provide a footing for the deck beams is to pour a concrete abutment. Although plans for any specific bridge will vary from others, they would all require four steps in construction.

Excavate
Prepare forms
Place and tie reinforcing steel
Pour concrete

Both the dimensions for the abutment and the location and size of the reinforcing steel should be specified on the bridge plans. Since these plans will be general in content but vary in detail, this guidebook will use a specific example for purposes of discussion. Other plans with different details might be preferable for your location but the construction procedures should be similar.

Excavate. Your plans might have words like these to specify the excavation:

Abutment Excavation

Substructure Excavation Common:

Contractor may excavate to the neat lines of the abutment, and if in satisfactory condition to the engineer, he may pour the concrete against the compacted fill. If necessary, the contractor shall use forms on the back vertical face of the abutment and remove the same after concrete is set. Backfilling shall be compacted to 95 percent standard density in accordance with Section 202.04(c) of the current Standard Specifications for Excavation for Structure Measurement and payment for "Substructure Excavation Common" at abutments shall be in accordance with the diagram shown on the plans.

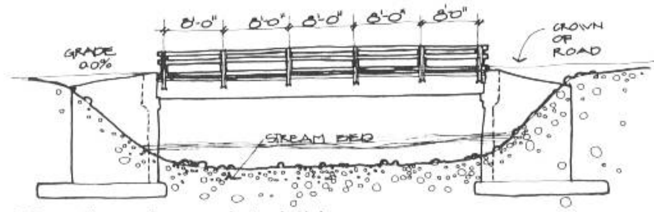
Borrow:

Item "Select Borrow" or "Unclassified Borrow", as called for in the Summary of Quantities, is for placing the fill behind the bridge abutments to top of fill slope and for material needed for shaping the fill around the abutments. The fill placed by the Bridge Contractor shall be compacted to 95 percent standard density in accordance with Section 202.04(c) of the current Standard Specifications for Excavation and Embankment. The quantity for Borrow shown on the plans includes 20 percent for compaction.

What this means is that if it is desirable, the builder may remove the material in the shape of the abutment to be poured. In this case he will not be required to use forms for all sides but let the dirt serve as the formwork where possible. Note the statement "...excavate to the neat lines of the abutment, and if in satisfactory condition..., he may pour the concrete against the compacted fill." Particularly on the backside and perhaps on the ends it might be possible to excavate to the dimensions of the bridge seat while maintaining a smooth, tight soil surface. Otherwise you must remove enough material to place forms for all sides. If you do place forms, they must all be removed after the concrete is set, *even* on the backside. The sketches indicate that the fill material must be compacted for two feet from the seat to 95 percent of the original density of the soil. To do this, deposit the fill in one-foot layers and compact each layer before adding more material.

The item on "Select Borrow" means the fill material must be free from large or frozen lumps, wood or other extraneous material and it is expected to compact by 20 percent during the backfill and compacting operation.

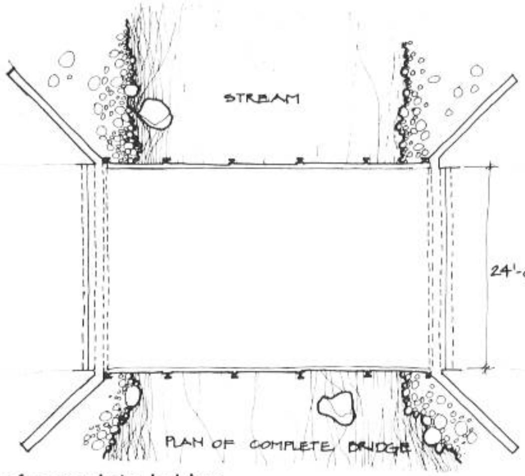
In excavating for the footing of the abutment, the elevation or depth of the bottom as shown on the plans is approximate. What is desired is to pour the footing on a solid surface, preferably rock. If the bottom is not rock, take care to have a clean, unbroken surface. This is most easily done by making the final excavation just before pouring the concrete. In all cases, all loose pieces of rock, hard materials, etc. should be cleared, leaving a clean, firm surface for pouring.



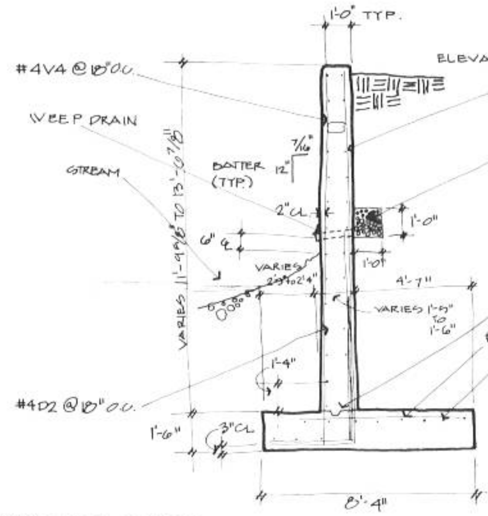
Elevation of complete bridge

Now let's look at some plan sketches and see what the excavation for a footing would look like. First examine the elevation view. This indicates that material must be removed for the footing, abutment, and wingwalls. Note that the footing is below the stream bed. This means that the water flow must be diverted to allow excavation and pouring in a dry bed. In this example it was a nearly dry stream and the water was channeled into the center of the stream. If necessary, temporary dams, called cofferdams and cribs, may be built around the foundation area to keep the water out during excavation and pouring.

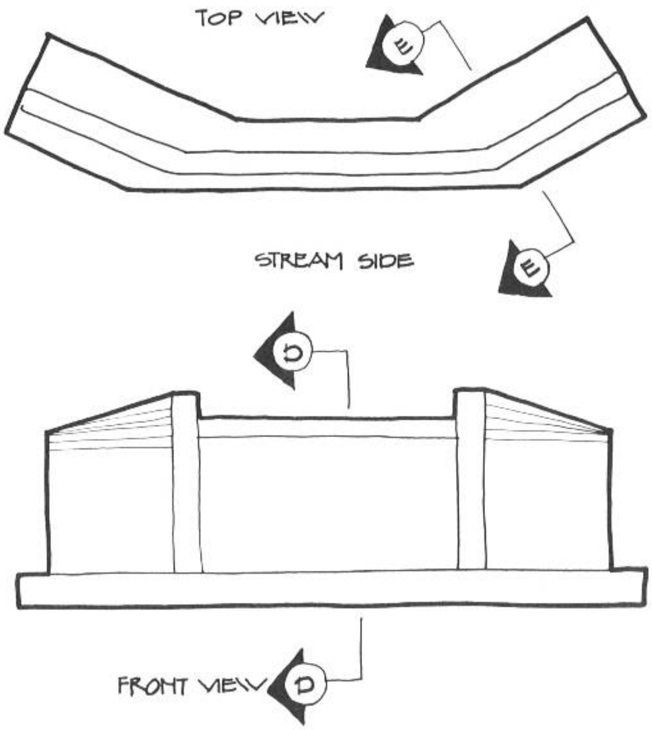
The front and top view shows the shape of the entire abutment while sections E and D show the cross section of the wingwall and abutment respectively. The bottom of the footing is given by an elevation of 648.70 feet, (shown in the front view) which is three feet below the low point of the stream bed (shown by the Elevation view). The footing is to have a thickness of 1 foot 6 inches (shown in the front view and in sections D and E). The shape of the footing is given by the top view. Note that the footing has a total width of 8 feet 4 inches under the wingwalls and 2 feet 6 inches



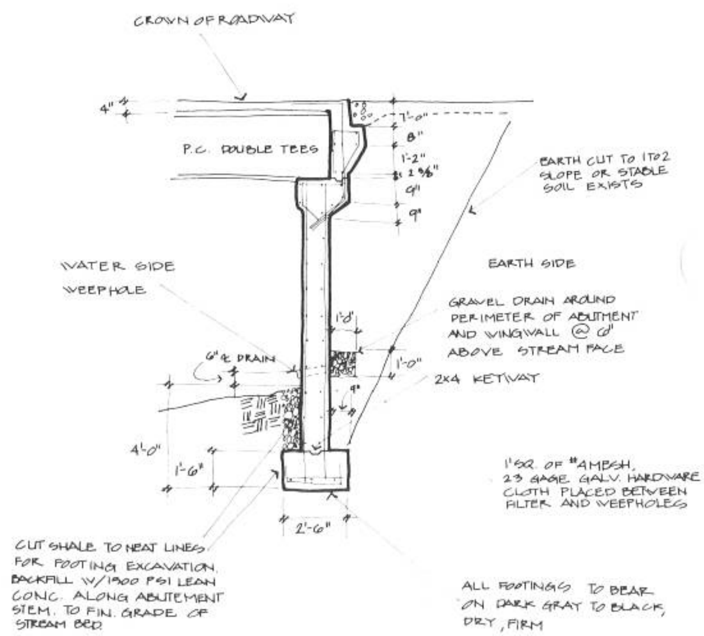
Plan of complete bridge



Wingwall section



Simple views of abutment



Abutment section

under the main abutment. Other designs might easily differ from this due to variations in soil conditions. If the excavation were neatly done, the footing might be poured without requiring formwork.

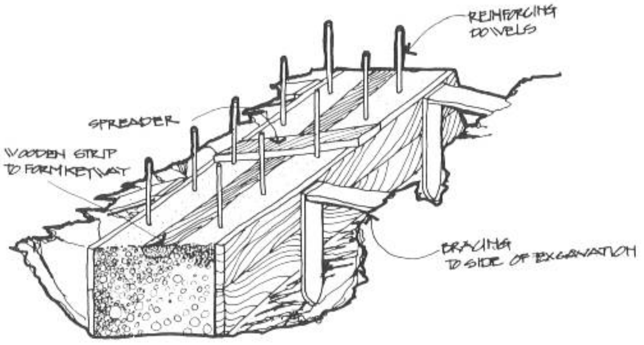
Prepare Forms. Actually, the footing would need to be poured before other forms were erected but at this time all the formwork will be discussed as a group.

This section should begin with a strong caution to use adequate bracing when building forms. A form which holds concrete having any great depth must withstand terrific outward side pressures. Wet concrete weighs approximately 150 pounds per cubic foot. This means that an abutment having a pour or fill depth of 8 feet would have a side load of 1,200 pounds per square foot at the bottom. Once the forms have begun to distort or sag, it is almost impossible to force them back without removing a good deal of the wet concrete. Thus some extra time and effort building and bracing strong forms will prevent higher failure costs during the pouring phase.

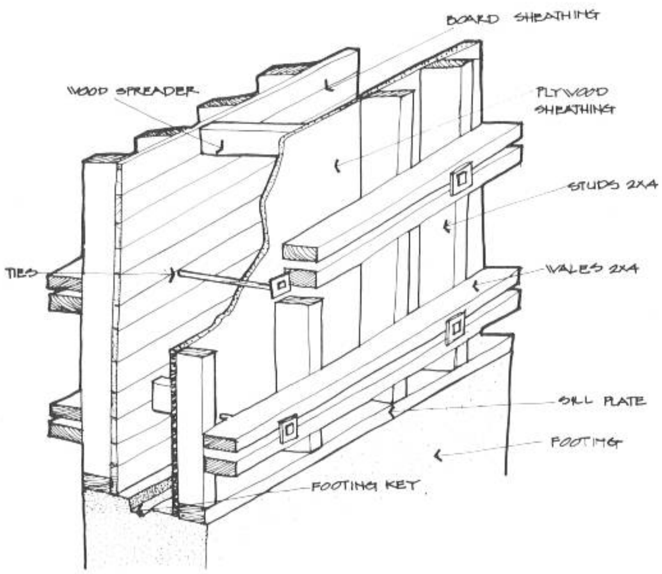
Forms for footings usually require a strip to be added to the top as the pour made to form the keyway, which makes a non-slip contact with the next pouring of concrete. The following figure illustrates how this may be done in a simple manner.

A typical formwork for a wall section is illustrated below. This also presents the common terminology used for the various form components.

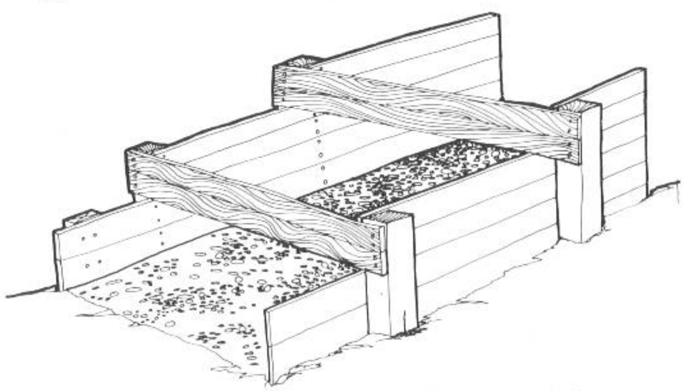
When a wingwall is to be poured, it may be necessary to slope the top of the wingwall. One simple method of doing this is illustrated below. The lower edges of the cross pieces are aligned to conform to the slope, and the concrete is spread to connect them evenly.



Example of formwork on a simple footing



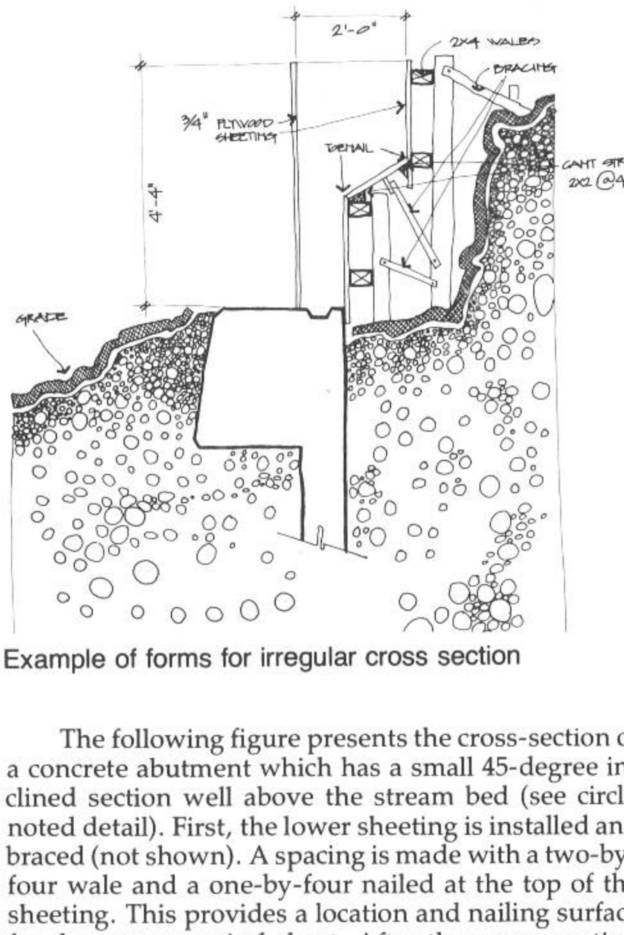
Typical form for a vertical wall



Construction of simple formwork stepped down to match the existing slope

Some abutments or deck seats have unusual cross sections which will require special consideration in form construction. These sections have usually been designed this way in order to save concrete although there may have been some other important considerations. Let's look at an example.

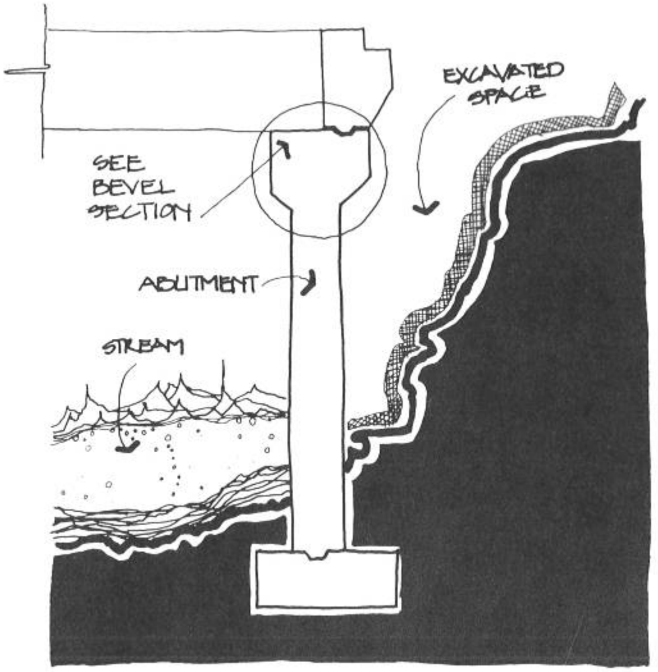
The figure below presents an example of formwork to support a cantilevered cross-section which has a 45-degree increase in section. Stakes are driven to support the two vertical sections of plywood sheeting. These stakes provide support to the wales (two-by-fours) which run the length of the cross-section. The tops of the stakes are further braced for support against the side-loading at the top. The inclined section is formed by a plywood sheet which has a two-by-four wale to provide stiffness. This sheet is cut at 45 degrees on the ends to match with the vertical and horizontal faces. A cant strip can be cut from a two-by-two and nailed to the upper vertical sheet and to the top of the lower vertical sheet. This serves as a locator and nailing surface for the 45-degree sheet. Finally a brace is run from the wale on the 45-degree sheet down to the base of the nearby stake.



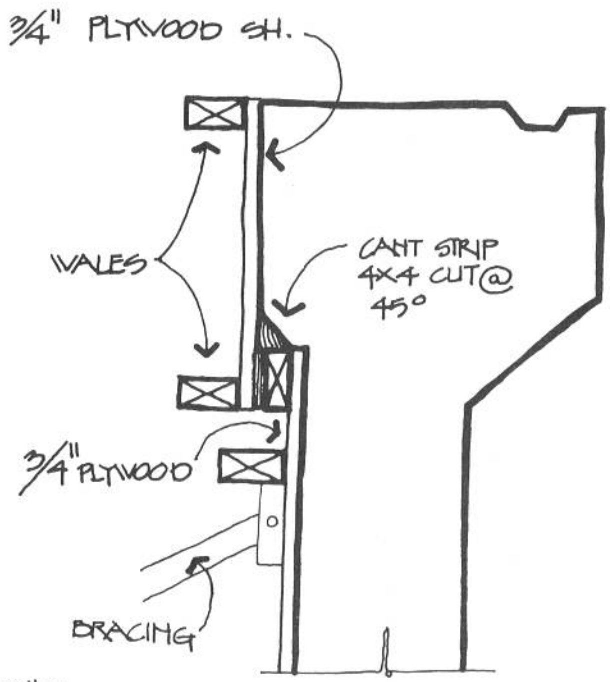
Example of forms for irregular cross section

The following figure presents the cross-section of a concrete abutment which has a small 45-degree inclined section well above the stream bed (see circle noted detail). First, the lower sheeting is installed and braced (not shown). A spacing is made with a two-by-four wale and a one-by-four nailed at the top of the sheeting. This provides a location and nailing surface for the upper vertical sheet. After the upper vertical sheet is located and nailed to the spacer (with wales already attached) it must be braced to stakes in the streambed (not shown). Finally a cant strip is cut from a four-by-four, sawing it at 45 degrees on the diagonal. This strip is nailed in the corner to form the 3-inch Champhes section.

Each job will have its own unique problems, but techniques such as these can be used to match the form requirements to the surrounding terrain. The steps in constructing the formwork are still generally similar.



Example of forms of irregular cross section.



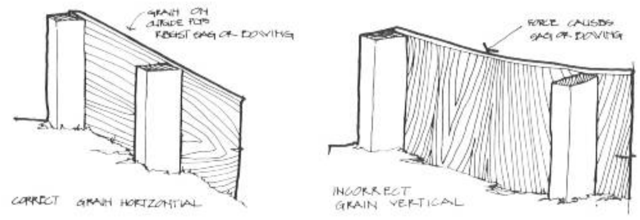
Section

Locate and drive initial stakes.

Locate and attach sheets which provide the shape to be poured (Provide studs and wales for strength and stiffness).

Locate and drive additional stakes and add braces to assure adequate strength.

Wood Materials. Most forms built for local bridge footings, abutments, deck seats (caps) and wingwalls will be constructed from lumber and plywood supplied from the local market. Partially seasoned



Correct and incorrect forming

lumber (two-by-fours, two-by-sixes, etc.) is usually used for formwork, since fully dried lumber swells excessively when it becomes wet while green lumber will dry out and warp during hot weather, causing alignment problems.

In Oklahoma, plywood is commonly used for form sheathing. Moisture resistant glues allow this material to be used with wet concrete. For larger sections, a ¾-inch plyform is normally used to provide strength and resistance. As a minimum, exterior grade plywood should be used. Grade B-B is most often used for formwork and has a smoothly sanded solid sheet veneer with circular repair plugs and tight knots allowed. A standard for commercial plywood has been established by the U.S. Department of Commerce.* The standards require that plywood marked for concrete form grade be edge sealed and mill oiled. Mill oiling does not eliminate the need for oiling or coating on the job, but mill oiled plywood gives better service than when it is only treated on the job. Edge sealing protects the glue line from moisture.

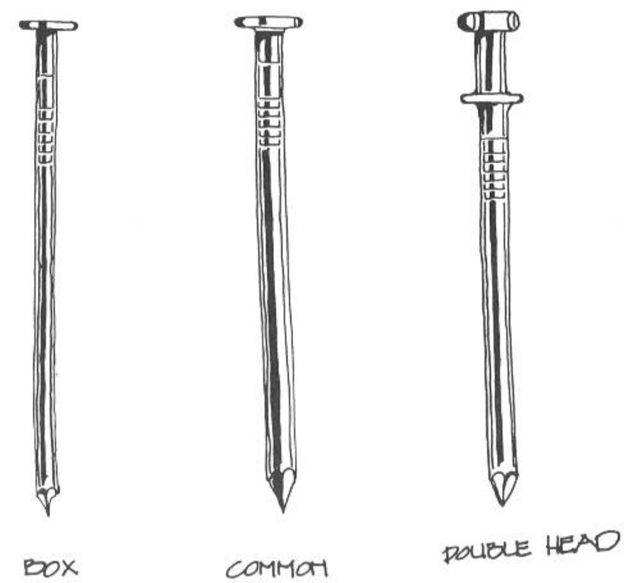
Plywood has greater stiffness, thus reducing bulging between braces if it is installed with the grain on the outside sheets perpendicular to the braces.

Fasteners and Hardware. Nails are the most common method used to construct wooden forms and bracing. Since the form structure should be strong, nail size selection must be appropriate as too small a size will not hold while nails that are too large may split and/or weaken the lumber. Nails for constructing forms are available in box (a more slender nail), common, and double head. The size is normally specified in "penny" designations depending on the length of the nail.

Double headed nails are used on braces and reinforcing for wales, stakes etc. They provide the holding strength of a common nail and still allow easy removal.

Common nails are recommended for constructing form panels and other assemblies when it is not necessary to remove the nails to facilitate form stripping from the concrete. They have great holding power and are difficult to remove. Their head size is larger than the box nail and may leave an impression in the concrete surface if used on forms facing the poured area.

*U.S. Product Standard PSI-66 for Softwood Plywood Construction and Industrial issued by Products Standards Division, National Bureau of Standards.



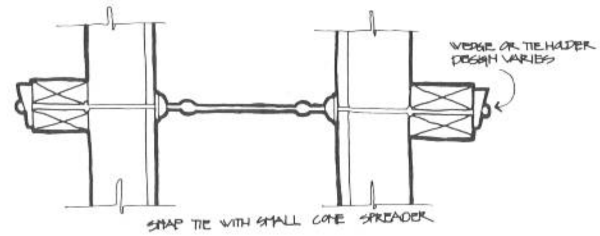
Standard nails

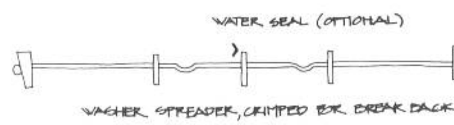
Box nails are recommended for attaching sheeting to studs, etc. These have thin heads and leave the smallest impression in a concrete surface. For built-in-place forms, box nails are often used because the thinner shank will pull loose more easily and thus allow easier disassembly. In addition, the thinner shank is less likely to cause splitting of sheets, etc. The size needed depends upon the thichness of the sheeting. For ⅝-inch and thicker plywood, 6 penny(d) nails are recommended.

Nails that are driven into the end grain of lumber have a low holding power (low resistance to pulling out). **Toenailing** is an important technique used in that it provides a stronger alternate in form building. (Approximately ⅔ of the resistance to pulling out of a cross-grain nail and approximately 5/6 of the lateral load capacity). For best results, start the nail at ⅓ the length of the nail from the end of the piece and at a 30-degree angle to the face of the piece in which it is started.

Compared to standard lumber, plywood has a greater resistance to splitting when nailed near the edge. This advantage is offset somewhat by the lesser resistance to nail withdrawal (approximately 70 to 85 percent).

Ties - A concrete form tie is used to hold the formwork against the side pressures of wet concrete. Some ties have features which provide the means for spacing the sheets at a pre-set distance. Some ties are designed with breakaway ends, leaving the internal portion within the concrete. Most ties are tightened by wedges although some have threaded fasteners. Some typical ties are shown below.

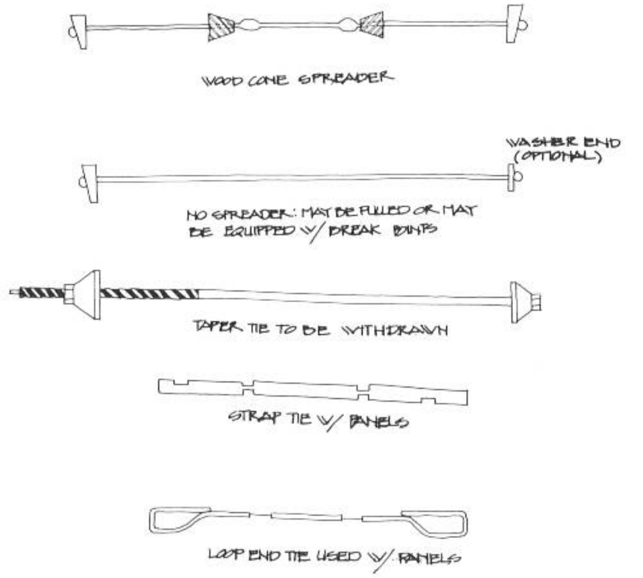




Nail Sizes and Measurements

	COMMON NAILS Flat head, diamond point			SMOOTH BOX NAILS Large flat head, diamond point			DOUBLE HEAD NAILS Diamond point, double head		
Size (penny)	Length,* in.	Gage No.	Diameter of head, in.	Length,* in.	Gage No.	Diameter of head, in.	Length under lower head, in.	Gage	Distance between heads, in.
2*d*	1	15	11/64	1	15½	3/16	—	—	—
3*d*	1¼	14	13/64	1¼	14½	7/32	—	—	—
4*d*	1½	12½	1/4	1½	14	7/32	—	—	—
5*d*	1¾	12½	1/4	1¾	14	7/32	—	—	—
6*d*	2	11½	17/64	2	12½	17/64	1¾	11½	1/4
7*d*	2¼	11½	17/64	2¼	12½	17/64	—	—	—
8*d*	2½	10¼	9/32	2½	11½	19/64	2¼	10¼	1/4
9*d*	2¾	10¼	9/32	2¾	11½	19/64	—	—	—
10*d*	3	9	5/16	3	10½	5/16	2¾	9	5/16*
12*d*	3¼	9	5/16	3¼	10½	5/16	—	—	—
16*d*	3½	8	11/32	3½	10	11/32	3	8	3/8
20*d*	4	6	13/32	4	9	3/8	3½	6	3/8
30*d*	4½	5	7/16	4½	9	3/8	4	5	7/16
40*d*	5	4	15/32	5	8	13/32	—	—	—
50*d*	5½	3	1/2	—	—	—	—	—	—
60*d*	6	2	17/32	—	—	—	—	—	—

*Length from underside of head to tip of point.



Preparation for Pouring. After cleaning forms of all dirt, dust, chips, and miscellaneous foreign materials, the inside form surfaces should be oiled or coated with a satisfactory release agent that will not stain or soften the concrete. This coating prevents the sticking of the concrete to the form, easing the stripping job. It may also prevent or retard absorption of water from the concrete. For wood forms, most of the commercial oils are satisfactory, for example diesel fuel. Some plywood comes mill oiled for this purpose.

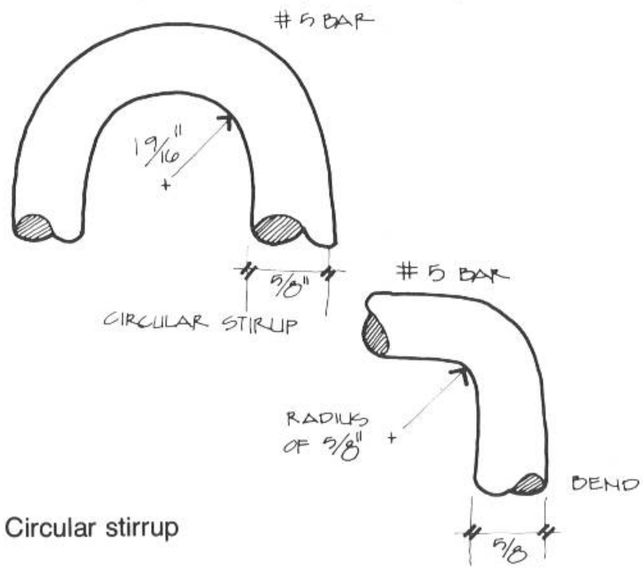
Place and Tie Reinforcing Steel. Reinforcing bar is available for concrete work in a variety of standard diameters. Your plans should specify both the shapes to be bent and the placement of all steel. Quantities of wire mesh and steel rods should be specified as well as the sizes of rods to be used. Bar size is denoted by number. Each number represents 1/8 inch of diameter. Thus a #3 bar is 3/8 inch in diameter while a #8 bar is 8/8 inch or 1 inch in diameter. On many plans, there will be a table specifying lengths for the various bar used. A typical example is given below.

The designation of groups of bars as BH1, BH2, BH3, BS, etc. is simply a convenient way of grouping bars that are to be used in the same appropriate location in the bridge. They do not represent any different types of steel or material. Thus, BH-1 bars may be horizontal bars used in the wingwalls of an abutment.

Bars should be bent to the specified shapes when cold. *Do not* heat the bars with a welding torch for ease of bending as this changes the metal structure and makes them weaker. The bends should be smooth curves and not sharp angled bends. For example, bends for stirrups and ties should have a radius on the inside of the bend of at least one bar diameter. A #5 bar has a 5/8-inch diameter and should be bent with a curve on the inside of the bend having a 5/8-inch radius.

When bending bars for a hook, the curvature of the bend should be even less. Guidelines are given below.

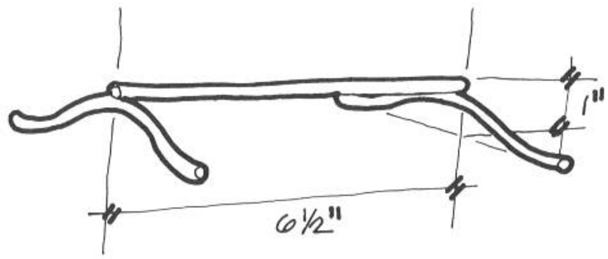
Bar Size	Minimum Radius (Inches)	Bar Size	Minimum Radius (Inches)	Bar Size	Minimum Radius (Inches)	Bar Size	Minimum Radius (Inches)
3	15/16	6	2¼	9	4½	14	8¾
4	1¼	7	2⅝	10	5	18	11¼
5	1 9/16	8	3	11	5½		



Circular stirrup

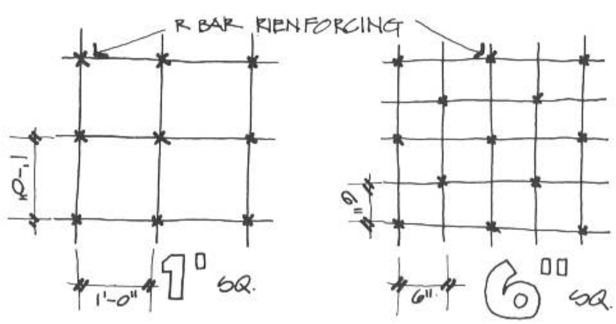
Reinforcing Steel

BH1-Bars			BH2-Bars			BH3-Bars			BS-Bars		
SIZE	NO.	LENGTH	SIZE	NO.	LENGTH	SIZE	NO.	LENGTH	SIZE	NO.	LENGTH
#4	2	26′-3″	#4	2	29′-9′	#4	8	32′-10″	#4	34	9′-5″
#4	2	30′-3″	#4	2	33′-9′	#4	8	36′-10″	#4	38	9′-5″
#4	2	34′-3″	#4	2	37′-9′	#4	8	40′-10″	#4	42	9′-5″
#4	2	38′-3″	#4	2	41′-9′	#4	8	44′-10″	#4	46	9′-5″



Slab spacer

When the steel reinforcing steel is placed in the formwork, it should be clean and free of dirt, paint, oil, loose scale, and bad rust spots. It is important to be sure that it is accurately placed in the positions shown on the plans. To maintian this distance from the forms, use stays, blocks, hangers, ties, or other approved supports. Blocks for holding reinforcement from contact with the forms should be precast mortar blocks or approved metal "chairs." The same types of blocks may be used to separate layers of reinforcing bars. You should not use pebbles, broken stone or brick, metal pipe, or wooden blocks to space or hold up reinforcing bars or wire mesh. If metal is to be in contact with an outside surface it should be galvanized. Bars are tied with soft steel wire ties at all intersections unless the spacing is less than 1 foot in each direction. In this case, every other intersection should be tied.



Reinforcing patterns

Pouring the Concrete. When pouring concrete, try to deposit it as near as possible to its final position. Moving concrete along a form tends to produce segregation. A second rule to follow is to deposit the concrete in an abutment in horizontal layers. A layer at 12 inches or less is recommended. The fresh concrete should be vibrated immediately after depositing to assure a complete form fill. By placing it in layers, it is easier to compact and fully vibrate the fresh concrete.

Forms should not be removed until the concrete has cured sufficiently to obtain strength for self-support. For small abutments, at least 24 hours should be allowed and longer times for heavy sections. A slab which must be fully self-supporting may require up to 7 days. If high-early strength cement is used, this time may be reduced.

Sample Calculations For Estimating Pile Bearing Values

Gravity Pile Driver

$$P = \frac{2WH}{S + 1.0}$$

P = Safe bearing capacity, pounds
W = Weight of falling hammer and parts, pounds
H = Height of fall, feet
S = *Average* penetration per blow for last 5 to 10 blows for gravity hammer or last 10 to 20 blows for steam hammer, inches/blow

Example:

Gravity pile driver
Hammer, 2500 pounds
Height of fall, 12 feet
Penetration last 10 blows, 1/2"

$W = 2500$
$H = 12$

$$S = \frac{1/2}{10} = 0.05$$

$$P = \frac{(2)\ (2500)\ (12)}{0.05 + 1.0} = \frac{60,000}{1.05} = 57142 \text{ pounds or } 28.5 \text{ tons}$$

Steam Pile Driver (Single Action)

$$P = \frac{2WH}{S + 1.0}$$

Example:

Hammer, 4000 pounds
Height of fall, 4 feet
Penetration last 16 blows, 2"

$W = 4000$
$H = 4$

$$S = \frac{2}{16} = 0.125$$

$$P = \frac{(2)\ (4000)\ (4)}{0.125 + 0.10} = \frac{32,000}{0.225} = 142,222 \text{ pounds or } 71 \text{ tons}$$

Road and Street Repair

This chapter describes techniques for routine repair on existing roads and streets. Asphalt and asphalt derivatives are the primary materials used for most repairs, so the discussion centers on what asphalt is and how it can be used most effectively for repair of county facilities.

Asphalt Paving Materials

Asphalt is man's oldest engineering material. It was in use as an adhesive and waterproofing agent more than 5,000 years ago. At the dawn of civilization, natural deposits of asphalt were used for waterproofing in ship building and water tanks and as cement for masonry and highway construction. While natural deposits still are present in many areas of the world, almost all asphalt produced and used in the United States is refined from petroleum. The asphalt produced is of many types and grades, from solids to thin liquids. Most crude petroleums contain some asphalt, and some crude oil may be almost entirely asphalt. However there are some crude oils (paraffin base) that contain no asphalt.

Asphalt Cement

Petroleum asphalt for use in pavements is usually called paving asphalt or asphalt cement to distinguish it from asphalt made for nonpaving uses such as roofing. At normal temperatures, paving asphalt is a sticky, semi-solid, highly viscous material. It is composed chiefly of complex hydrocarbon molecules. Because of its adhesive quality, it sticks to aggregate particles and can be used to bind them into asphalt concrete. Paving asphalt is waterproof and is unaffected by most acids, alkalies, and salts. It is a thermoplastic material, softening as it is heated and hardening as it cools. The unique combination of characteristics and properties of asphalt make it the world's most versatile construction material.

Cutback Asphalt

Rapid-curing (RC), medium-curing (MC), and slow-curing (SC) are designations of cutback asphalt types. Rapid-curing (RC) cutback asphalt is manufactured by blending asphalt cement with a specific amount of solvent (cutter stock) which will rapidly evaporate after using, leaving only the asphalt cement. The solvent (cutter) used in producing RC cutback is a material with a low boiling point such as gasoline or naphtha. Medium-curing (MC) cutback asphalts are produced by blending asphalt cement with an intermediate boiling point solvent such as kerosene. The kerosene solvent evaporates more slowly than the gasoline solvent used in (RC) cutback, thus, the designation medium-curing. Slow-curing (SC) cutback asphalts may be produced by blending asphalt cement with a high boiling point gas oil or may be extracted as a residual material during the petroleum refining process. Note: Recent Environmental Protection Agency policy will result in minimal use of cutbacks in the near future. This is based on pollution/energy conservation consideration.

Emulsified Asphalt

Emulsified asphalt is a combination of water, asphalt cement, and an emulsifying agent. Since asphalt cement will not dissolve in water, it exists in small (1/25,000-inch to 1/2,500-inch diameter) globules suspended in the water-emulsifying agent mixture. The emulsifying agent (commonly soap) prevents the asphalt spheres from coalescing. When an emulsion is mixed with an aggregate or spread thinly on a surface, the interfacial balance is disturbed, and the water and asphalt phases separate. On aggregate, the asphalt globules coalesce into a continuous film that cements the aggregate particles together while the water drains off and/or evaporates. There are two types of emulsified asphalt: (1) Anionic emulsified asphalt is an alkaline, water phase product in which the surface of the asphalt droplets carry a negative change. Best results are obtained when this type of emulsion is used with electro-positive aggregates such as limestone and dolomite, (2) cationic emulsified asphalt is acidic and the asphalt droplets carry a positive charge; therefore, best results are attained when used with electro-negative aggregates such as sand and other silicious aggregates. Some emulsions require that the aggregates be prewet. Anionic and cationic emulsions are incompatible and cannot be mixed or stored together.

Aggregates

In an asphalt-aggregate mixture used in paving, aggregates normally constitute 90 to 95 percent by weight of the total mixture and asphalt 5 to 10 percent. It is fairly obvious that the nature and quality of the aggregate will have a considerable effect on the resulting pavement. Hard, durable aggregate is required for strong, high-quality wearing courses on an asphalt pavement when wheel loads are concentrated and stresses are high. Aggregates of lower quality can often be used in asphalt base courses where strength requirements are not as high as for the surface course. Locally available and lower cost aggregates can be used in base courses and, thus, reduce the pavement cost. Particles of aggregate larger than about ¼-inch (particles retained on a ¼-inch sieve), called coarse aggregate, are normally obtained from crushing rock or from crushing and screening gravel. Particles smaller than about ¼-inch, called fine aggregate, are obtained from natural sand or fine screenings from rock crushing operations. Sometimes a mineral filler such as rock dust is added to the fine aggregate.

Types of Asphalt Pavement Construction

Plant Mix. Asphalt paving mixtures prepared in a central mixing plant are known as plant mixes. Asphalt concrete is considered the highest quality type of plant mix. It consists of well-graded, high-quality aggregate and asphalt cement. The asphalt and aggregate are heated separately from 250 to 325 degrees Fahrenheit, carefully measured and proportioned, then mixed until the aggregate particles are coated with asphalt. Mixing is done in the pug-mill unit of the mixing plant. The hot misture, kept hot during transit, is hauled to the construction site, where it is spread on the roadway by an asphalt paving machine. The smooth layer from the paver is compacted by rollers to proper density before the asphalt cools.

Asphalt concrete is but one of a variety of hot-asphalt plant mixes. Other mixes, such as sand asphalt, sheet asphalt, and coarse-grade mixes, are prepared and placed in a similar manner. However, each has one common ingredient—asphalt cement.

Asphalt mixes containing liquid asphalt also may be prepared in central mixing plants. The aggregate may be partially dried and heated or mixed as it is withdrawn from the stockpile. These mixes are usually referred to as cold mixes, even though heated aggregate may have been used in the mixing process.

Asphalt mixtures made with emulsified asphalt and some cutback asphalts can be spread and compacted on the roadway while quite cool. Such mixtures are called cold-laid asphalt plant mixes. They are hauled and placed in normal warm-weather temperatures. To hasten evaporation of emulsification water or cutback solvents, these mixtures, after being placed on the roadway, are sometimes processed or worked back and forth laterally with a motor grader before being spread and compacted.

Mixed-In-Place (Road Mix). Emulsified asphalt and many cutback asphalts are fluid enough to be sprayed on and mixed with aggregate at moderate to warm-weather temperatures. When this is done on the area to be paved, it is called mixed-in-place construction. Although mixed-in-place is the more general term, and is applicable whether the construction is on a roadway, parking area, or airfield, the term "road mix" is often used when construction is on a roadway.

Mixed-in-place construction can be used for surface, base, or sub-base courses. As a surface or wearing course, it usually is satisfactory for light and medium traffic rather than heavy traffic. However, mixed-in-place layers covered by a high-quality asphalt plant mix surface course make a pavement suitable for heavy traffic service. Advantages of mixing-in-place include:

1. Utilization of aggregate already on the roadbed or available from nearby sources and usable without extensive processing.
2. Elimination of the need for a central mixing plant. Construction can be accomplished with a variety of machinery often more readily available, such as motor graders, rotary mixer with revolving tines, and traveling mixing plants.

Surface Treatments and Seal Coats

A sprayed-on application of asphalt to a wearing surface, with or without a thin layer of covering aggregate, is called an asphalt surface treatment. By definition, such treatments are one inch or less in thickness. Sometimes these surface treatments are included in original construction. More often, they are applied to old pavements after a period of service and before deterioration from traffic wear and weathering proceeds too far. The sprayed-on asphalt serves to improve or restore the waterproof conditions of the old pavement face. Also, it serves to arrest any scuffing or raveling of the wearing surface. The addition of a cover of aggregate over the sprayed-on asphalt restores and improves the skid resistance of the wearing surface. Multiple surface treatments consist of two or more alternate layers of sprayed-on asphalt and aggregate cover. Surface treatments that have waterproofing or texture improvement, or both, as their main purposes are called seal coats.

Single or multiple surface treatments with aggregate cover also may be placed on granular-surface roads to upgrade them for traffic. The treatment eliminates dust, protects the road by shedding water, and provides a smoother riding surface. It is a useful, low-cost, all weather imrpovement of a granular-surfaced road, but it has limited traffic capacity and should be used only where traffic is light or where the period of expected service is limited.

Tack Coats and Prime Coats. Tack coats are light applications of liquid asphalt to an existing paved surface to insure bond between the old surface and the superimposed construction.

When an asphalt pavement or asphalt surface treatment is to be placed on a granular base, it is desirable to treat the top surface of the base by spraying on a liquid asphalt that will seep into or penetrate the base. This is called priming, and the treatment is called a prime coat. Its purpose is to serve as a transition from the granular material to the asphalt layer and bind them together. A prime coat is different from a tack coat as to type and quantity of asphalt used. However, both are spray applications.

Emulsion Slurry Seal. An emulsion slurry seal is a mixture of slow-setting emulsified asphalt, fine aggregates, mineral filler, and water. It is used to fill cracks and to improve scaled areas of old but sound pavements to restore a uniform surface texture. It also seals the surface and prevents moisture intrusion into the pavement. It should be used as a repetitive maintenance tool.

Plant Mix Surface Treatment. Plant mix surface treatments are a hot or cold plant mix asphalt placed on structurally sound asphalt surfaces, new or old. These are thin courses, ½ to ¾ inch thick, and do not appreciably correct weaknesses in the pavement surface. These treatments may be referred to as: friction courses, plant-mix seals, thin overlays, carpet coats or plant mix surface treatments.

Penetration Macadam. This is an older type of asphalt pavement construction. While many miles of asphalt penetration macadam pavement are still in service, relatively little is used in new construction. Briefly, an asphalt penetration macadam pavement consists of one or more layers of large-sized broken stone and rock chips interlocked by rolling. Fluid asphalt is sprayed on each layer, and it seeps into or penetrates the layer to bind the stones together. An asphalt surface treatment or asphalt mixture of some kind is usually put on the top of a penetration macadam pavement to serve as a wearing surface.

The following table shows the principal uses of various types of asphalt. This table and the majority of the information contained in this section are through the courtesy of the Asphalt Institute.

Principal Uses for Grades of Emulsified Asphalt

*ASTM Nomenclature**	*Principal Use*
MS-1, MS-2, MS-2h CMS-2, CMS-2h, HFMS-2h	Early rain resistant types of coarse aggregate mixing grade emulsified asphalts. Used for surfaces and bases.
SS-1, SS-1h, CSS-1, CSS-1h	Stable system used with dense-graded aggregates for bases, surface courses, and slurry seals. Also diluted with water for seals, dust palliative, and tack coat.
RS-1, RS-2, CRS-1, CRS-2	Chip Seals

*ASTM uses RS to designate "rapid set," MS to cover "medium set," SS to describe "slow set," and HFMS to describe "high float medium set."

Some user agencies specify an additional cationic sand mixing grade designated CMS-2s. The CMS-2s is used for sand and silty sand mixes; it contains a small amount of cutter stock.

Storing and Handling of Emulsified Asphalts

Storing Emulsified Asphalt

Storage procedure. Emulsified asphalt, being a dispersion of fine droplets of asphalt cement in water, has both the advantages and disadvantages of the carrier medium, water. When storing emulsified asphalts:

Do store as you would fluid water — between 10°C (50°F) and 85°C (185°F), depending on the use.

Do use hot water as the heating medium for coiled storage tanks. Steam also may be used, with temperature controlled on the coil surface to not more than 85°C (185°F).

Do store at the temperature specified for the specific grade. For spray applications, the emulsions are stored at higher temperatures than for mixing with aggregate. For example, the higher viscosity Rapid Set spray grades are stored at 50°C to 85°C (125°F to 185°F) since they are usually applied in this temperature range. The lower viscosity grades are stored at lower temperatures. The following table shows the normal storage temperature ranges. For mixing applications store the mixing grades at the lower end of the temperature ranges as shown in the table.

Do not permit the emulsified asphalt to be heated above 85°C (185°F). Elevated temperatures boil off the water, resulting in an asphalt layer in the tank. The material can no longer be used as intended and it will be difficult to empty the tank.

Do not let the emulsion freeze. This breaks the emulsion, separating the asphalt from the water. The result will be two layers in the tank, neither suited for the intended use, and the tank will be difficult to clean.

Do not allow the temperature of the heating surface to exceed 100°C (212°F). This will cause premature breakdown of the emulsion on the heating surface.

Do not use forced air to agitate the emulsion. It may cause the emulsion to break.

Storage Facilities. For protection from freezing and best utilization of heat, storage tanks should be insulated. Tall, vertical tanks are best as they expose the least amount of emulsion to air. The area exposed also can be minimized by keeping horizontal tanks full to minimize the area exposed to air.

Side-entering propellers located about one metre (three feet) up from the tank bottom may be used to prevent surface skin formation. Large diameter, slow-turning propellers are best and should be used to roll the material over (avoid overmixing). Tanks may be circulated top to bottom with a pump (avoid over pumping). In tanks not equipped with propellers, or a circulating system, as above, a layer of kerosene or oil floating on the surface can be used to reduce skin formation. Emulsions that are rolled or circulated generally do not require a layer of kerosene or oil on the surface.

Storage Temperatures for Emulsified Asphalts

Grade	Temperature, °C (°F)	
	Minimum	Maximum
RS-1	20 (70)	60 (140)
RS-2, CRS-1, CRS-2	50 (125)	85 (185)
SS-1, SS-1h, CSS-1, CSS-1h, MS-1	10 (50)	60 (140)
CMS-2, CMS-2h, MS-2, MS-2h, HFMS-2h	50 (125)	85 (185)

Handling Emulsified Asphalts

While heating emulsified asphalts in tanks, transports, and distributors it should be agitated to eliminate or reduce skin formation.

Do protect pumps, valves, and lines from freezing in winter. Drain pumps or fill them with antifreeze according to the manufacturer's recommendations.

Do blow out lines and leave drain plugs open when they are not in service.

Do use pumps with proper clearances for handling emulsified asphalt. Tightly fitting pumps can cause binding and seizing.

Do use a *mild* heating method to apply heat to the pump packing or casing to free a seized pump. Discourage the use of propane torches.

Do warm the pump to about 65°C (150°F) to facilitate start-up.

Do when a pump is out of service for even a short period of time, fill the pump with No. 1 fuel oil to ensure a free start-up.

Do when diluting grades of emulsified asphalt, check the compatibility of the water with the emulsion. If possible, use warm water and *always* add the water to the emulsion (not the emulsion to the water).

Do avoid repeated pumping and recylcling, if possible, as the viscosity may drop.

Do guard against mixing different classes, types, and grades of emulsified asphalt in storage tanks, transports, and distributors. For example, if cationic and anionic emulsified asphalts are mixed, the blend will break and separate into water and coagulated asphalt that will be difficult to remove. Because it is difficult to determine visually the difference between various emulsified asphalts, always make a trial blend of the newly delivered emulsion and the stored emulsion before pumping off. Check the trial blend for compatibility.

Do discharge inlet pipes and return lines at the bottom of tanks to prevent foaming.

Do not use tight-fitting pumps for pumping emulsified asphalts; they may "freeze."

Do not apply severe heat to pump packing glands or pump casings; this may damage the pump and cause the asphalt to become even harder.

Do not dilute rapid setting grades of emulsified asphalt with water. Medium and slow setting grades may be diluted.

Do not recirculate emulsified asphalts for too many cycles. They tend to lose viscosity when subjected to several cycles of pumping.

Do not load emulsified asphalt into tank cars, tank transports, or distributors containing "heels" of incompatible materials.

Uses of Emulsified Asphalts

There are 16 grades of emulsified asphalts specified by ASTM (10 grades of Anionic and 6 grades of Cationic). The ASTM grades are designated as rapid setting (RS), medium setting (MS) and slow setting (SS). The cationics are designated by the prefix "C". Thus the CRS, CMS, and CSS grades are cationic and RS, MS, and SS are anionic. Cationic emulsions are for use generally with siliceous aggregates and anionic emulsions are used generally with limestone type aggregates.

Each emulsion type is further classified by viscosity and the base asphalt penetration. Low viscosity products are designated by the number "1", while higher viscosity products are "2". The asphalt penetration is identified by the letter "h". Emulsified asphalts with "h" have a residue penetration of 40-90, while those with no small letter are in the 100-250 penetration range.

Though ASTM recommends 10 grades of anionic asphalt and 6 cationics, some user agencies, such as those in the Pacific Coast states, specify an additional cationic sand mixing grade designated CMS-2s The CMS-2s is used for sand and silty sand mixes; it contains a small amount of cutter stock.

Emulsified asphalts are designed for each specific use. The rapid set (RS) grades (CRS-1, CRS-2, RS-1 and RS-2), are designed to react quickly with aggregate and revert from the emulsion state to asphalt. The medium setting (MS) grades (MS-1, MS-2, MS-2h, CMS-2, CMS-2h), are designed for mixing with coarse aggregate. They have a high viscosity to prevent runoff.

The slow setting (SS) grades (CSS-1, CSS-1h, SS-1, SS-1h) are designed for maximum mixing stability and are used with high fines content, dense graded aggregates. The SS grades have long workability times to ensure good coating of dense graded aggregates. SS-1h and CSS-1h have low viscosity that can be further reduced by adding water. These grades also are used for tack coats, fog seals, and as dust palliatives.

The SS products revert to asphalt by dehydration. If a faster setting rate is needed in mixtures, then portland cement or hydrated lime can be used. The recommended rate is one part cement for four or more parts of SS-1h or CSS-1h.

Mixes

It is essential to select the most suitable class and grade of emulsion for mixing with the aggregate selected for a construction project.

Do consult The Asphalt Institute or manufacturer of emulsions to determine what grades are available.

Do evaluate the available aggregates in a laboratory to determine the proper grade of emulsified asphalt and amount to be used for the proposed method of construction.

Do avoid using aggregates containing an excess of clay.

Do use the proper amount of mixing water. When premix water is required, the aggregate should be dampened *prior* to the addition of emulsified asphalt.

Do use just enough mixing water to obtain adequate coating. Adequate coating need not be 100 percent coating—it may be as low as 50 percent for base course construction (fine aggregate particles, however, should be well coated).

Do mix only long enough to disperse the emulsion throughout the aggregate.

Do to increase the rate of cure and add to early stability of a fresh mix, incorporate a low percentage of portland cement. Cement also retards drainage of emulsion from over-wet aggregates.

Do place the mixture in lifts of no more than 75 mm (3 in.).

Do place a seal coat on dense-graded emulsified asphalt surface mixtures to prevent raveling, but not so soon that mixing water or any distillates are entrapped.

Do be sure that the temperatures of aggregate and air are at least 7°C (45°F) and rising before beginning mixing operations.

Do not try to correct a mix that is too dry by adding water after the aggregate has been coated with the emulsion. (Always add the water first, and then the emulsion.)

Do not use excessive amounts of mixing water as this results in sloppy mixes subject to runoff and slow curing.

Do not use a deficiency of mixing water. as this causes balling of fines and stripping of asphalt.

Do not overmix as this may cause stripping.

Seal Coats

The asphalt in the rapid setting grades of emulsion bind aggregate particles in place. The water, however, also plays an important role in performance. Water serves three functions:

- It lowers application viscosity so the emulsion can be applied at a lower temperature than the asphalt cement from which it was made.

- It serves as a carrier for adhesion agents to ensure a good bond between the asphalt, pavement and cover aggregate.

- It effects a volume change to ensure a good bond and reduce the chance of subsequent bleeding. This volume change allows the use of emulsions at about the same total liquid application rate as asphalt cements or cutbacks. The emulsion level (film), immediately after application of the chips, is high on the aggregate; after setting, there is a 30 to 50 percent volume reduction (film collapse) due to the loss of water. This film collapse causes the asphalt to remain high on the aggregate but low in the spaces between the chips, thus preventing chip loss. The low asphalt film between chips greatly reduces or eliminates bleeding. This feature is particularly important where the chips imbed into the pavement due to heavy traffic.

Do apply rapid setting emulsion at about the same rate of application as for cutbacks and asphalt cement. At higher rates, the benefit of film collapse is reduced.

Do apply the chips as soon as possible after the spray application (emulsion still brown in color) to ensure maximum imbedment into the emulsion.

Do use clean, angular chips for best durability and to prevent roll over and raveling.

Do roll with a pneumatic-tired roller as soon as possible. This imbeds the chips in the asphalt emulsion and orients them to the most stable poisiton while the emulsion still is fluid.

Do provide traffic control. Rapid acceleration, high speeds, and braking action will dislodge the chips until the seal coat is fully cured.

Do perform sealing work during the warm, dry summer months when weather conditions are most conducive to success.

Do use pre-coated chips for late season work (if it must be done) to ensure better construction.

Do use damp aggregate (not dripping wet) to ensure better construction.

Do not use excessive cover aggregate as it normally will be retained only one stone deep. Excess chips act as grinding agents and loose chips can pose a safety hazard.

Do not use dusty or dirty chips. Asphalt does not adhere to the chips and this causes early raveling.

Do not attempt to construct seal coats when the pavement and air temperatures are below 20°C (70°F).

Types of Failures

Cracks

Causes and Repair of Cracks. Cracking appears in many forms. Simple crack filling may be the right treatment in some cases. In others, complete removal of the affected area and the installation of drainage may be necessary before effective repairs can be carried out. To make proper repairs, causes of the cracking must first be determined.

The cracking pattern is frequently the same for various causes and for various stages of distress. Types of cracks maintenance crews commonly encounter are:

Alligator cracks	Reflection cracks
Edge cracks	Shrinkage cracks
Joint cracks	Slippage cracks

Alligator Cracks are interconnected cracks forming a series of small blocks resembling an alligator's skin or chicken wire. They are usually associated with a granular untreated base that has failed or with a resilient subgrade. Since alligator cracking is probably caused by a saturated base or subgrade, correction should include removing the wet material and installing drainage. A hot mix asphalt placed full-depth provides a strong patch. If hot mix asphalt is unavailable, new granular material compacted in layers, primed and surface treated may be used.

Skin patches can be used for a temporary repair. In any event, repairs should be made promptly so that further damage to the pavement does not occur.

Edge Cracks are longitudinal cracks a foot or so from the edge of the pavement with or without transverse cracks branching towards the shoulder. Usually, edge cracks are caused by lack of lateral or shoulder support for the asphalt pavement. They may also be caused by settlement or yielding of the base material underlying the cracked area. This in turn may be the result of poor drainage, frost heave, or shrinkage from drying out of the surrounding earth.

For repair, edge cracks may be filled with asphalt emulsion slurry or liquid asphalt mixed with sand. If the edge of the pavement has settled, the surface may be brought to grade with a hot plant mix patching material.

Joint Cracks. There are two types of joint cracks. One is the edge-joint crack, which occurs between the pavement and the shoulder. The other is the lane-joint crack, which occurs between two adjoining paving lanes.

Alternate wetting and drying or freezing and thawing beneath the shoulder surface is a common cause of edge-joint cracking. It usually results from poor drainage where water is trapped or ponded in depressions over the pavement shoulder joint.

Lane-joint cracks, on the other hand, are usually caused by a weak seam or poor bond between adjoining spreads in the pavement.

Where water is a contributing factor to cracking, drainage should first be corrected. The cracks are filled with a light grade of liquid asphalt mixed with fines and/or asphalt-emulsion slurry seal. Special asphalt compounds or heavier bodied asphalts may be used to fill larger cracks.

Reflection Cracks occur in asphalt overlays. These cracks reflect the crack pattern in the pavement structure underneath. They are most frequently found in asphalt overlays over portland cement concrete and cement treated bases.

Reflection cracks are caused by vertical or horizontal movements in the pavement beneath the overlay resulting from traffic loads, temperature, and earth movements.

If the cracks are less than 1/8 inch wide, it may be wise to ignore them unless water can enter and cause further damage. In this case they may be filled by a squeegee technique, using cutback or emulsified asphalt covered with sand. Cracks wider than 1/8 inch are filled with an asphalt emulsion slurry or a light grade of liquid asphalt and fine sand.

Shrinkage Cracks are interconnected cracks forming a series of large blocks, usually with sharp corners or angles. Often it is difficult to determine whether shrinkage cracks are caused by volume change in the asphalt mix or in the base or subgrade. Frequently, they are caused by volume change in fine aggregate asphalt mixes that have a high content of low penetration asphalt. Lack of traffic hastens shrinkage cracking in these pavements.

Shrinkage cracks should be filled with asphalt emulsion slurry followed by a surface treatment of a slurry seal over the entire surface.

Slippage Cracks. Slippage cracks are generally crescent-shaped cracks resulting from horizontal forces induced by traffic. They are caused by a lack of bond between the surface layer and the course beneath. Lack of bond may be due to dust, dirt, oil, or even the absence of a tack coat.

The only proper way to repair a slippage crack is to remove the surface layer from around the crack to emulsion slurry or liquid asphalt mixed with sand. If the edge of the pavement has settled, the surface may be brought to grade with a hot plant mix patching material.

Distortions

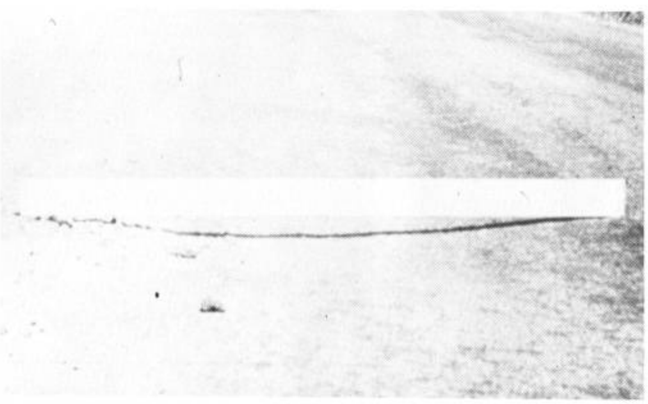
Causes and Repair of Distortions. Pavement distortion is any change in the pavement surface from its original shape. It is usually caused by such things as too little compaction of pavement courses, too many fines in surfacing mixtures, too much asphalt in the mix, swelling of underlying courses, or settlement. Like cracks, distortions take a number of different forms:

1. Channeling,
2. Corrugations,
3. Shoving,
4. Depressions, and
5. Upheaval.

As with any other defect, the type of distortion has a cause and this cause must be determined before correct remedy can be applied. Repair techniques range from leveling the surface by filling with new material, to complete removal of the affected area and replacing with new material.

Channeling, grooving, or rutting are channelized depressions that develop in the wheel tracks of asphalt pavements. Channeling may result from consolidation or lateral movement under traffic in one or more of the underlying courses, or by displacement in the asphalt surface layer itself. It may develop under traffic in new asphalt pavements that had too little compaction during construction, or from plastic movement in a mix that does not have enough stability to support traffic.

Corrective action may be taken by leveling the pavement or by filling the channels with hot mix asphalt. A thin hot mix asphalt overlay should then be placed over the entire surface.



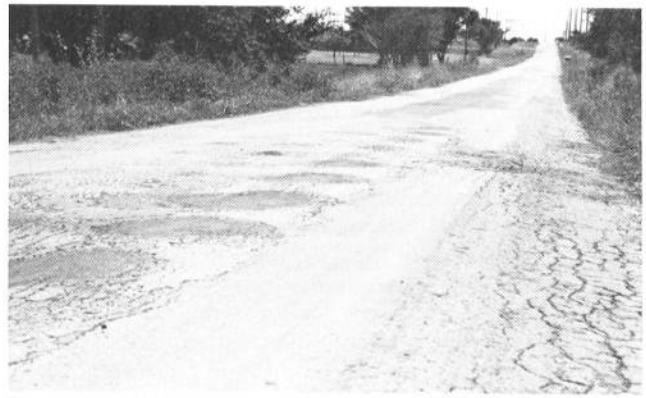
Channeling, grooving or rutting.

Corrugations and Shoving. Corrugation, or washboarding, is a form of plastic movement typified by ripples across the asphalt pavement surface. Shoving is plastic movement resulting in localized bulging of the pavement surface. Both corrugation and shoving usually occur at points where traffic starts and stops, or on hills were vehicles brake on the downgrade.

Corrugations and shoving also usually occur in apshalt pavement mixtures that lack stability. This may be the result of too much asphalt, too much fine aggregate, or round or smooth textured coarse aggregate. In the case of liquid asphalt mixes, it may be due to a lack of aeration.

If the corrugated pavement has an aggregate base with a thin surface treatment, the surface should be scarified, mixed with the base, and recompacted before resurfacing. If the surface is more than 2 inches thick, shallow corrugations can be removed with a pavement planning machine called the heater planer. The planed area is then given a seal coat or a plant-mix surface.

For effective repair, shoved areas should be removed and patched.



Corrugation or washboarding.

Depressions are localized areas of limited size that may or may not be accompanied by cracking. Water collects in depressions, and then becomes not only a source of pavement deterioration, but a hazard to motorists. Depressions are caused by traffic heavier than that for which the pavement was designed, by poor construction methods, or by consolidation deep within the subgrade.

Depressions should be filled with hot mix asphalt and compacted to restore the area to the same grade as the surrounding pavement.

Upheaval is the localized upward displacement of a pavement due to swelling of the subgrade or some portion of the pavement structure. It is most commonly caused by ice expansion in the granular courses beneath the pavement or in the subgrade. Upheaval may also be caused by the swelling effect of moisture on expansive soils.

Correction should include removing the loosened material and installing needed drainage. Hot mix asphalt material can then be used for the full depth for a strong patch.

Disintegration

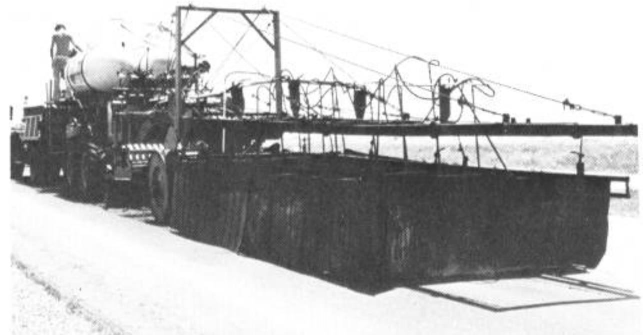
Disintegration is the breaking up of a pavement into small, loose fragments. This includes the dislodging of aggregate particles. If not stopped in its early stages, disintegration can progress until the pavement requires complete rebuilding. Pot holes and ravelling are two of the more common types of early stage disintegration. Repair ranges from simple seals to deep patches.

Pot holes are bowl-shaped holes of various sizes in the pavement resulting from localized disintegration. They are usually caused by weakness in the pavement resulting from too little asphalt, too thin an asphalt surface, too many fines, too few fines, or poor drainage.

Pot holes frequently appear when it is difficult to

Shoving.

Water delineates depressed area.



Planing with a heater-planer.

Upheaval.

make a permanent repair and emergency measures have to be taken. Temporary repair usually involves cleaning out the hole and filling it with a premixed asphalt patching material. Permanent repair is made by constructing a deep patch.

Raveling is the progressive loss of surface material by weathering and/or traffic abrasion. Usually the fine aggregate wears away first, leaving little pock marks in the pavement surface. As erosion continues, larger particles eventually break free and the pavement soon has the rough and jagged appearance typical of surface erosion. Raveling is caused by poor construction methods, inferior aggregates, or poor design. An early application of a fog seal when raveling is first detected will generally stop progressive deterioration.

Dry and weathered surfaces usually require a surface treatment. Emergency measures include a fog seal applied over the roadway surface. Surface treatments include slurry seal, sand seal, aggregate seal, or plant mix surface treatment, depending on the surface condition and traffic.

Slippery Surfaces

Excess Asphalt. Bleeding or flushing is the presence of excess asphalt or a film of asphalt on the pavement surface. Pavement courses having rich asphalt mixes, improperly constructed seal coats, or too heavy a prime or tack coat result in bleeding and flushing. Overweight traffic can force or flush the asphalt to the surface of the pavement in hot weather.

In many cases, bleeding can be corrected by repeated applications of hot sand or rock screenings to blot up the excess asphalt. If the bleeding is light, a plant mix surface treatment or an aggregate seal coat using absorptive aggregate may be the only treatment needed.

A pavement planing machine, such as the heater planer, will remove excess asphalt from the surface. In cases of heavily over-asphalted surfaces, the surface should be completely removed.

Polished Aggregate. Aggregate particles in the surface of a pavement may be worn smooth under the abrasive action of traffic. This includes both naturally smooth uncrushed gravels and crushed rock that wear quickly under the action of traffic. Some aggregates, particularly some types of limestones, become polished rather quickly under traffic. Others, such as some types of gravel, are naturally polished, and if they are used in a pavement surface without crushing they become a skid hazard. Polished aggregates are quite slippery when wet.

The only effective way to repair a pavement with polished aggregates is to cover the surface with a skid-resistant treatment. A hot asphalt plant-mixed thin overlay, a sand seal, or an aggregate seal should be applied. The aggregate must be hard and angular, such as slag, silica sand, or other proven nonpolishing materials.

Loss of cover aggregate is the chipping-off of aggregate under traffic from a surface treated pavement,

Pot hole.

Raveling.

Bleeding or flushing.

Polished aggregate.

Loss of cover aggregate.

Longitudinal streaking.

leaving the asphalt. Several things can cause the loss of cover aggregate, such as:

1. Aggregate spread after asphalt has cooled too much;
2. Aggregate too dusty or wet when spread;
3. Wrong asphalt pump speed;
4. Asphalt too cold or too high in viscosity; and,
5. Pump pressure too low.

About the only satisfactory repair for longitudinal streaking is to plane off the streaked surface and apply a new surface treatment. It is much easier to prevent longitudinal streaking than to correct it. Careful adherence to the manufacturer's recommendations for the asphalt distributor before it is used and while it is being used will prevent streaking.

Transverse streaking is alternating lean and heavy lines of asphalt running across the road that may result in corrugations in the pavement surface. It is caused by spurts in the asphalt spray from the distributor spray bar. These spurts may be produced by pulsation of the asphalt pump due to worn or loose parts, by improper pump speed, or by a miss in the motor.

Again, about the only satisfactory repair is to plane off the streaked surface and apply a new surface treatment.

Patching Potholes

Potholes, those bowl-shaped holes of various sizes in the pavement, occur and multiply rapidly, particularly after a period of wet weather. Potholes are usually caused by weaknesses in the pavement. Once the surface is broken, deterioration continues at an accelerated rate.

Pothole maintenance is a continuing problem and usually appears at a time when it is difficult to make permanent repairs. Too often the solution consists of a few shovelfuls of premixed asphalt patch material deposited in the hole with the hope that traffic will provide compaction. To achieve proper pothole maintenance it is necessary to take into consideration the following important items:

Weather
Trained personnel
Identification of the problem
Use of suitable materials

Best results will be achieved by scheduling repair work during dry, warm weather. However, the problem is usually most urgent during wet weather. This requires greater care and proper equipment to insure success. Personnel assigned to pothole repairs should be aware of material limitations during cold and wet weather.

It is easy to blame material for failure, but even the best available materials will fail when improperly used. Therefore, the most important item to pothole maintenance is providing sufficiently trained personnel to identify the problem and to apply an appropriate technique to make the repair.

A properly trained operator will recognize the cause and plan the repair to eliminate recurrence. Failure to provide proper drainage is one of the most common causes of failure. In emergency situations temporary measures may be necessary, but even then a little extra attention will increase the level of success. All pothole crews should be equipped to blow out, sweep, or otherwise remove water and should have the equipment to dry and prepare the hole.

Material used for patching may be either cold mix asphalt materials, hot mix asphalt materials, concrete, or other suitable patching material. The design of asphalt paving mixes is controlled by locally available raw materials which may be proportioned to obtain an economical blend of graded aggregates mixed with the proper amount of asphalt to provide the following characteristics:

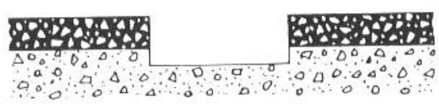
All aggregate particles coated with asphalt
Sufficient workability to permit handling and placement
Stable under load and traffic
Dense enough to prevent water from flowing through to the base.

Due to variation in materials each area mix must be designed around the available aggregate supply. Use of the "Asphalt Plant Manual" published by The Asphalt Institute will assist in selecting the proper mix.

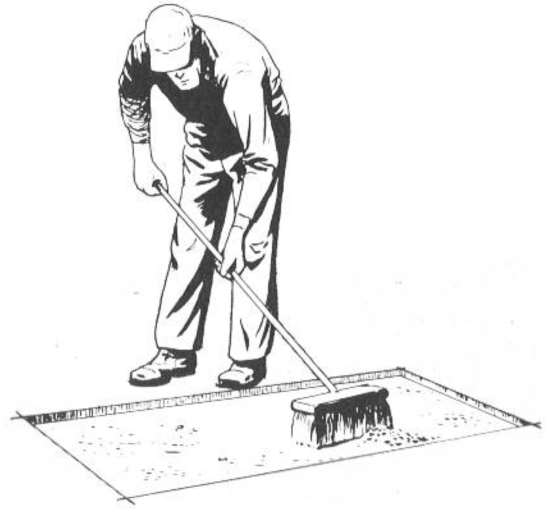
In all cases some compaction should be made immediately to prevent raveling and washing out. A portable vibratory plate compactor can be used.

Permanent repairs should be made as follows:

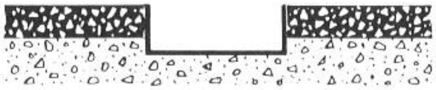
Clean hole of loose material and water.



Cut out to solid material on all sides and bottom.



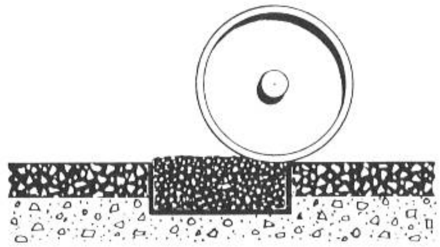
Cleaning surface of exposed layer

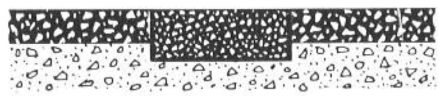


Apply tack coat, particularly around cut edges.

Placing plant-mix in cut

Leveling patch mixture





Compact thoroughly with roller or vibratory plate compactor.

Place premixed asphalt patching material full depth with particular attention to placing along side vertical face and bottom corners. Place enough material to make the surface even with the surrounding pavement after compaction. Level the patch material carefully to prevent segregation. Compact thoroughly with a roller or a vibratory plate compactor.

In most instances the materials available for patching are suitable for the particular area, but in all cases the method of repair is responsible for a successful repair.

Best results will be achieved by assigning a lead man or foreman the responsiblity of patching potholes. This person should be given basic training in patching. He should be provided adequate equipment and have a suitable source of supplies available.

Pothole patching is usually done under traffic conditions. The safety of working personnel and the traveling public is of utmost importance. Maintenance personnel should work from the center of the road to the shoulder to avoid stepping into the opposite traffic lane and should be equipped with reflective clothing. Personnel should be trained in traffic safety as well as safe use of all equipment.

Surface Treatment

Successful surface treatments are easily constructed, provided the correct amounts and kinds of asphalt and aggregate are placed on a sound foundation with good equipment and under the right weather conditions. Careful planning and preparation, followed by proper care and timing, will insure a waterproof surface that will give economical and satisfactory service for many years.

This chapter tells the what, the why, and the how in the construction of successful surface treatments of all kinds.

Survey of Project

Before any work is started a thorough surface examination should be made to determine needed repairs and to evaluate requirements for the treatment.

Soft spots that may result in failures later as well as variations in width, cross-section, and profile that would leave the road unsightly should be noted. Side drainage defects, especially, should be noted. If an old surface is being reconditioned, look for

Pot holes	Depressions
Raveling	Broken edges
Badly cracked areas	Absorbent surface
Corrugations	Bleeding asphalt

After the project is surveyed, necessary repairs and corrections must be made so the road will be in sound condition before the treatment is begun. For a more uniform surface, repairs should be completed in sufficient time before surface treating to insure proper consolidation under traffic.

Repair of Defects

Granular Base Course. Where the existing base is narrow or the cross-section or profile is out of shape, the road should be scarified and new material added. To avoid thin layers that may flake off after the surface treatment has been placed, the new material should be mixed with the scarified material. Then it should be compacted in layers not exceeding six inches each.

Material in soft spots should be removed to the full depth and width necessary and new basic material added and compacted to a density equal to that of the surrounding base.

Existing Asphalt Surface. Some old pavements do not need repairs before they are resurfaced. Others may require complete scarifying, mixing, and recompacting along with removal of bad material. Most pavements fall between these extremes, with repairs ranging from minor patching to removing excess asphalt. The paragraphs that follow discuss the repair of the more common defects.

Pot holes, or chuck holes, are bowl-shaped cavities usually caused by weakness in the pavement. They should be cleaned out, sides and bottom, to solid adjacent material before they are filled. The holes should be shaped to make square shoulders in the direction of traffic, with all sides nearly vertical. Then they should be primed and filled. Where the pavement to be treated is of substantial thickness, the best way to make repairs is by the premixed method—preferably several weeks before surface treatment to obtain traffic compaction.

The premixed material can be hot or cold. Hot-mix is preferable becuase it contains no cutter stock which must evaporate before the patch becomes solid.

If the hole is over two inches deep, the material is placed and compacted in layers not exceeding two inches each. Compaction may be performed by heavy hand tampers, vibratory plate compactors or, on large patches, conventional steel wheeled rollers. The finished patch is left ¼ to ½ inch above the level of the pavement to allow for further compaction by traffic.

Raveling is the progressive separation of aggregate particles in a pavement from the surface downward or from the edges inward. It may be caused by wear and tear of traffic, by too little asphalt binder, or by faulty distributor operation where one or more nozzles did not spray fully.

Raveling usually can be repaired by slightly increasing the amount of asphalt over that ordinarily required for the surface treatment. There are cases, however, when it may be prudent to apply a slurry seal on the old surface before applying the surface treatment.

Cracks do not all look alike and are not caused by the same thing, nor are they repaired in the same way. For these reasons the cause or causes must be determined before the correct repair can be made. The common causes and suggested repair of transverse and longitudinal cracks, alligator cracks, shrinkage cracks, and slippage cracks are discussed in the following paragraphs.

Transverse and Longitudinal Cracks. As their names imply, these cracks run either across the pavement or in the direction of the length. They usually are caused by base or subgrade movement, pavement shrinkage, or by shrinkage, swelling, or heaving of certain types of soils. They are repaired by applying crack filler or slurry seal before the surface treatment is placed.

Alligator Cracks. These are interconnected cracks forming a series of small polygons resembling an alligator's skin. In most cases, alligator cracking is caused by unstable support and is accompanied by deformation of the pavement surface. The affected areas usually are not large and they can be repaired by hand methods.

Since unstable support usually is the result of saturated bases or subgrades, correction should include removing the wet material, installing needed drainage and compacting in new granular base material in layers not exceeding six inches each. The new base then should be primed and patched.

Shrinkage Cracks. These are interconnected cracks forming a series of large polygons, usually with sharp corners or angles. Shrinkage cracks are caused by faults in the pavement mixture, such as volume change from drying out, low asphalt content, or brittle asphalt. Sometimes they are caused by shrinkage of base, subbase, and subgrade. A slurry seal usually is all that is needed to correct shrinkage cracking. A slurry seal also should be applied before any other surface treatment is placed.

Slippage Cracks. Sometimes crescent-shaped cracks appear which point in the direction of the thrust of traffic. These slippage cracks are found in plant-mixed pavements and are associated with a lack of bond between the surface course and a smooth-textured leveling or base course. Dust or moisture, or both, between the layers together with too thin courses or mixes of low tensile strength frequently cause this type of cracking.

Adequate repair means removing the slipping layer from around the crack to the point where good bond between the layers is found and patching the area with premixed material.

Corrugations (washboarding) are undulations consisting of alternate crests and valleys at close, regular intervals in the surface of a pavement. They are caused by lack of stability in an asphalt pavement or lack of cohesion in an untreated road. Excess asphalt, improper aggregate gradation, or too rounded aggregate particles all may contribute to the cause. Inadequate compaction also may be a factor.

A satisfactory correction is to scarify the surface, mix it with the base and recompact the mixture before applying the new surface treatment. The corrugated surface also can be heater-planed before applying the surface treatment, but this does not correct the cause. If the corrugations are due to surplus asphalt, the surface should be removed and the area reconstructed.

Depressions are road surface distortions caused by consolidation of base or subgrade. Depressions may or may not be accompanied by cracking, but in either instance they usually create a rough spot and permit water to accumulate. If the road cannot be reconstructed, it should at least be leveled with asphalt pre-mix material before the surface treatment is placed.

Broken edges of a pavement are usually the result of insufficient thickness of the mat, lack of shoulder support or saturation of the base. Edges are repaired by filling the cracks and sealing the outer edge of the pavement. And to minimize future trouble, ditches should be cleaned and the shoulder bladed down and compacted to proper cross-section.

Absorbent surfaces will soak up fresh asphalt for new surface treatments, leaving too little to bind the cover aggregate. This condition usually is caused by high permeability of the pavement, but may be caused by porous aggregate such as slag, or by badly worn or excessively rough-textured areas in the old surface. A fog seal, applied before placing the other surface treatment, will correct the condition.

Bleeding asphalt is the result of too much asphalt for the aggregate. The excess must be eliminated or the condition will recur soon after the new surface treatment is placed. The surest way to correct the condition is to remove and reprocess the pavement mixture with added aggregate, or by heater-planer treatment. After this, the surface treatment can be placed.

Preparation For Construction

General. When all needed repairs have been made within the project limits, there are still several steps to coordinate before the surface treatment operation can start. The weather has to be right, the surface must be cleaned, the material must be on the job, and the equipment must be in good working order.

Weather has an important role in the success of surface treatments. A time of year should be selected for the surface treating program when weather conditions are most likely to be hot and dry during, and for some weeks after, the treatment.

Many specifications require that the air temperature in the shade be at least 50 degrees F. before surface treatment operations can begin. Some are even more realistic and require that the temperature of the surface of the road be above 80 degrees F. before work can start—the sound reasoning being that no matter how hot the asphalt is when sprayed, it will cool to the temperature of the pavement surface within one minute or less.

Surface treating should never be started while the surface is wet or when it is threatening to rain. The combination of water, fresh surface treatment, and traffic will result in loss of most of the cover aggregate.

Cleaning the Surface. The surface to be treated must be cleaned immediately before the asphalt is sprayed. All hardened mud and other foreign matter must be removed and the surface thoroughly swept with power brooms.

Material on the Job. The delivery of materials to the job should be coordinated so that there will be no delays after the work starts. If the aggregate source is not within a short distance of the project, a sufficient number of trucks should be used to assure a continuous supply or enough aggregate to finish the whole job should be stockpiled near the job site. The stockpile should be built well enough in advance of starting work so that excess water will have drained from the aggregate.

Asphalt delivery should be arranged so that there is enough on the job to complete each day's work without delays.

Equipment in Good Order. Before work starts, all pieces of equipment should be examined to make certain they are in good working condition. The distributor operator should make sure that the spray bar is the correct height above the surface and that all nozzles are clear and spraying freely—even if they have been checked the night before. The aggregate spreader should be checked to be sure that it is working properly.

At the end of each day's operation the equipment should be inspected and cleaned. All necessary preventive maintenance should be performed at this time, too. Clean equipment that seldom breaks down on the job not only saves money, it promotes pride of workmanship.

The Surface Treatment Operation

General. The asphalt in high quality surface treatments will hold the aggregate and, without overfilling the voids, will waterproof and airproof the surface. To do this, a thin membrane of asphalt must be sprayed over the surface without streaking, drilling, or distortion of any kind.

The cover aggregate should be uniformly spread in less than one minute after the asphalt application. This requires enough trucks loaded with the aggregate to be standing by to cover completely the asphalt in the specified time. Careful timing and coordination are absolutely necessary to produce the desired results. Immediately after application, the aggregate should be set in place by rolling to produce a smooth, tight surface of even texture. As soon as the asphalt has a definite set or hardening, rolling should be discontinued or the bond between the surface and aggregate may be broken by the roller. Traffic should be detoured or controlled to a speed of less than seven miles per hour until the asphalt initially sets. This time will vary according to weather conditions.

The first phase of the operation should not begin until the entire operation is ready to be completed without any delays.

Priming is the initial incorporation of asphalt into the surface of a non-asphalt base course for the following purposes:

To waterproof the surface of the base
To plug capillary voids
To coat and bond loose mineral particles
To harden or toughen the surface
To promote adhesion between the base and the surface treatment

In the priming process, from 0.2 to 0.5 gallon per square yard of low viscosity liquid asphalt is sprayed on the prepared surface of the base and allowed to penetrate as far as possible. If the asphalt is not entirely absorbed by the base within 24 hours, the excess should be blotted with just enough sand to prevent pickup under traffic. Before beginning the surface treatment all of the asphalt prime volatiles must have evaporated and all loose sand should be swept from the base.

Spraying the Asphalt. Before the surface treating operation starts, a line should be placed along the edge of the road to guide the driver of the distributor truck. This can be done by establishing about two feet outside the area to be surfaced a line of markers. (Rocks will do.) On city streets, the gutter line or the curb line can be used as a guide. The distributor operators must be very careful to match the curb or gutter line and not cut it short or overlap it. It is desirable to protect the curb and gutter from splash or overlap with a shield or building paper.

Each length of spread should be determined before beginning each asphalt application. The length of spread should be based mainly on the number of loaded aggregate trucks on hand when operations begin. Another important factor is elapsed time between the spraying of asphalt and the spreading of the aggregate. No more asphalt should be applied than can be covered with aggregate within one minute. Other considerations in setting the length of spread are the amount of traffic to be controlled and intersections with other roads.

After all the adjustments and checks are made, including heating the asphalt to proper spraying viscosity, application at the correct rate should present no problems. The distributor driver merely has to maintain the preset speed that is indicated on the dial of the bitumeter.

Checks on the amount of asphalt used should be made after each run with the distributor. This can be done quickly and easily by calculating the gallons per square yard applied using, in the formula below, the length and width of spread and gauge stick measurements made in the tank before and after the run.

$$R = \frac{9T}{WL} \times M$$

Where—

R = Rate of application in gallons per square yard
T = Total gallons spread from the distributor at spraying temperature = (Gauge stick reading before spread) − (Gauge stick reading after spread)
W = Width of spread in feet
L = Length of spread in feet
M = Multiplier for correcting asphalt volume to basis of 60°F. (from appropriate table in Appendix G)

Example:

Gauge stick reading before spread = 960 gallons
Gauge stick reading after spread = 504 gallons
T = 456 gallons

W = 12 feet
L = 0.9456 (from Table G-2 for Group 1 asphaltic materials and temperature of 200° F.)

Then—

$$R = \frac{9T}{WL} \times M$$

$$R = \frac{9 \times 456}{12 \times 1335} \times 0.9456$$

$$R = 0.236 \text{ gallon per square yard}$$

Transverse Joints. Rough and unsightly transverse joints can be avoided by starting and stopping the asphalt and aggregate spread on building paper. The paper should be placed across the lane to be treated and it should be placed so that the forward edge is at the desired joint location. The distributor, traveling at the correct speed for the desired application rate, should start spraying on the paper so that when it reaches the exposed surface the spray bar is making a full, uniform application. A second length of building paper should be placed across the lane at the predetermined cut-off point for the distributor. This will give a straight, sharp transverse joint. After the aggregate spreader has passed over it, the paper should be removed immediately and destroyed.

For the next application, the leading edge of the paper should be placed on the previously laid treatment so it will be within one-half inch of the cut-off line. This will prevent a gap between the two spreads.

Longitudinal Joints. Full width applications of asphalt and aggregate will eliminate longitudinal joints, but in most surface treatment work traffic must be maintained and the joint is necessary. In addition, full width coverage of asphalt should never be done unless the distributor can apply full pressure to all parts of the spray bar and advance provisions are made to follow immediately with full width coverage of aggregate.

In order to prevent aggregate from building up on the longitudinal joint, the edge of the aggregate spread should coincide with the edge of the full thickness of applied asphalt. This will allow a width which can be overlapped when the asphalt is applied in the adjacent lane. Then, when the aggregate is spread for the full width in the next lane there will be no build-up at the joint. The width of the asphalt strip left exposed will vary, depending on whether the height of the spray bar is set for a double or a triple lap and on the spacing of the nozzles.

If at all possible, the longitudinal joint should be along the center line of the pavement being treated. An established guide line should be used to assure a straight longitudinal joint.

Note

It is highly important that the aggregate be spread immediately after application of the asphalt.

Spreading the Aggregate. All aggregate needed for the planned spread should be on hand before starting. When the distributor moves forward to spray the asphalt, the aggregate spreader should start right behind it. It is essential that the asphalt be covered within one minute or the increase in viscosity that takes place within that time may prevent good wetting and binding of the aggregate. It also is important that the aggregate be spread uniformly and at the proper rate. In a single application, aggregate normally will not stick more that one particle thick to the asphalt, so it is useless and wasteful to apply it at a rate greater than a single layer in thickness.

A high degree of control is possible with mechanical spreaders pushed by a truck or with self-propelled spreaders. A uniform application rate can be assured with a properly adjusted spreader if a tachometer is used to maintain uniform speed. Another help in controlling distribution rates is laying off the length which each truck load of aggregate should cover.

Excess aggregate, if placed in some areas, should be removed immediately with square end shovels. In areas where application is insufficient, additional aggregate should be added. With properly adjusted and operated aggregate spreaders, however, hand work should not be necessary.

Rolling seats the aggregate in the asphalt and thus promotes the bond which is necessary to resist traffic stresses.

The Asphalt Institute recommends that a pneumatic-tired roller be used on all surface treatment jobs. While both pneumatic-tired and steel-wheeled rollers have been used successfully, the former will give a uniform pressure over the entire area while the steel-wheeled roller will hit only the high spots. In addition, the contact pressures of the pneumatic-tired roller can be lowered to prevent crushing of soft aggregate. In any case, two self-propelled rollers should be used with each aggregate spreader.

Rolling should begin with a pneumatic-tired roller immediately after distribution of the cover material and continue until the aggregate is properly seated in the binder. As soon as the asphalt has a definite set or hardening, rolling should be discontinued or the bond between the surface and aggregate might be broken by the roller. Rolling should begin at the outer edge of the treatment and proceed in a longitudinal direction, working toward the center of the road. Each trip should overlap the previous trip by about one-half the width of the front wheels or roll.

Brooming. Properly distributed aggregate will require no redistribution and drag brooms should be prohibited. Broom dragging tends to shift the smaller particles to the bottom and prevents adhesion of the larger particles. Drag brooms also tend to displace the stuck aggregate by turning the asphalted side up so that the wheels of passing traffic will pick it up.

Removing Excess Aggregate. In spite of all precautions, there usually will be some loose aggregate on the road surface after the rolling operation is completed. Before the adjacent lane is covered with asphalt, loose aggregate should be swept from along the joint and, if necessary, from the rest of the uncovered lane.

Aggregate which does not stick creates a problem since tires on fast-moving vehicles will pick up the loose particles and throw them against following vehicles, often damaging headlights, windshields, and finish. This loose aggregate may be removed by lightly brooming with a rotary power broom during the cool of early morning, after final set of the asphalt has occurred.

Traffic Control. Control of traffic through the work area is important to high quality work. High speed traffic over a fresh surface treatment displaces the aggregate and produces a slick, black surface. Traffic should be detoured or allowed only in the lane not under construction. When work is completed and initial asphalt set has occurred, traffic should be controlled to less than 25 miles per hour until final asphalt set. The time until final set will vary with the weather. Traffic should be directed through the work area in a manner designed to provide maximum safety for the workmen and the least possible interruption of the work. Traffic control should be maintained throughout the job. The best way to control traffic is with warning signs, flagmen, and a pilot truck, leading vehicles past the work.

Traffic control also should extend to the hauling equipment. The aggregate trucks should be routed to the aggregate spreader in a direction opposite to the progress of the surface treatment operation. This prevents them from turning on the freshly placed treatment. All trucks should be required to turn around at a designated spot away from the new work for their return trip to the stockpile.

Multiple Surface Treatments. For pavements required to carry increasing volumes of traffic or when a greater thickness of mat is desired on new construction, double and triple surface treatments may be used. This type of construction will produce surfaces with thicknesses up to about 1½ inches which, if placed on a good base, can carry rather large traffic volumes for long periods.

When multiple applications are used, it is essential that each succeeding aggregate nest with the layer previously placed so that the completed construction will form a compact mass with a dense, tight surface. The success of this type of construction depends upon this nesting of the particles and the distribution of the asphalt through the mass.

The largest size aggregate is placed in the lower course with succeeding courses using smaller aggregate. A good general rule is that the second course aggregate should be about half the size of the first course aggregate, and the third course aggregate about half the size of the second.

For example, if the first course aggregate is predominantly one inch to one-half inch in size, the second course should be one-half inch to one-quarter inch and the third course one-quarter inch to one-eighth inch (No. 6 sieve). The total thickness, using normal aggregate, for a double surface treatment with the first two aggregates would be about one inch and for a triple surface treatment using the three sizes about 1⅛ inches. With large percentages of flat particles in the aggregate, thicknesses would be less.

The quantity of each size of aggregate for a multiple surface treatment is that amount required to cover the surface one stone thick. This spread quantity should be determined with no allowance being made for spreading inaccuracies.

Construction procedures for multiple surface treatments are essentially the same as those for single surface treatments except that the process is repeated either two or three times. The procedure for a double surface treatment consists of the following steps:

Placing first course asphalt
Placing first course aggregate
Rolling first course aggregate
Placing second course asphalt
Placing second course aggregate
Rolling second course aggregate

There should be proper curing between each treatment.

For a three course surface treatment steps 4, 5, and 6 are repeated for the third course.

Slurry Sealing

A slurry seal is a mixture of well-graded fine aggregate, mineral filler (if needed), emulsified asphalt, and water applied to a pavement as a surface treatment. It produces a smooth attractive black surface that contrasts excellently with traffic paint.

Emulsified asphalt slurry seal is effective in both the preventive and corrective maintenance of asphalt pavement surfaces. Its timely application will prevent surface distress caused by oxidation of the asphalt, loss of matrix, and embrittlement of the pavement mixture. Applied to surfaces of older pavements that are showing distress, it will seal surface cracks, stop raveling and loss of matrix, make open surfaces impermeable to air and water and, with proper aggregate, improve skid resistance.

Three basic aggregate gradations, suggested by the International Slurry Seal Association, cover most uses of slurry seals. They are:

Type I—Fine: Maximum Nominal Size Aggregate = 2.36 mm (No. 8)
Type II—General: Max. Nominal Size Aggregate = 4.75 mm (No. 4)
Type III—Coarse: Max. Nominal Size Aggregate = 4.75 mm (No. 4)

Type I is used for maximum crack penetration and surface sealing in low traffic density area. Type II is used for preventive maintenance applications, to correct severe raveling, oxidation, and loss of matrix, and to improve skid resistance in areas of moderate to heavy traffic. Type III is used as the first course in multicourse applications, to correct severe surface conditions, and to impart skid resistance on pavements with heavy traffic loadings.

This type of surface treatment has a number of advantages, including:

- Rapid application
- No loose cover aggregate
- Excellent surface texture for paint striping
- Ability to correct minor surface irregularities
- Minimum loss of curb height
- No need for man-hole and other structure adjustments
- In many cases, the relatively low cost of the treatment makes practical importing special aggregates for special surface effects, such as high skid resistance, color contrast, and sound reduction.

Materials

Emulsified Asphalt. The emulsified asphalt most commonly used has been a slow-setting type, either anionic or cationic, with grade 1 or in selected, depending on type of application, traffic, and climatic conditions. In recent years, quick-setting (QS) emulsified asphalts have been developed for slurry seal applications where rapid opening to traffic is necessary: These emulsified asphalts usually require the use of small percentages of powdered or liquid additive to control the setting time of the slurry mixture. The additive initiates set for anionic quick-set and retards set for cationic quick-set emulsified asphalts.

Aggregate. The aggregate is the key material as it is the largest component in the slurry system. The aggregate must be clean, angular, durable, well graded, and uniform. In general, any fine aggregate fulfilling the requirements for use in an asphalt concrete surface course is satisfactory for a slurry mixture. Normally, they include natural or manufactured sand, blast furnace slag, crusher fines, or a combination of two or more of these materials. An aggregate blend for a slurry system should meet the following requirements:

- Sand equivalent = 45 minimum (AASHTO* T 176 or ASTM† D 2419)
- Abrasion loss = maximum 35 percent (AASHTO T 96 or ASTM C 131, gradings C or D)

The three generally accepted combined aggregate gradations being used for slurry mixtures are shown in the following table.

Slurry Mixture Gradings

Type of Slurry	I	II	III
General Usage	Crack filling & fine seal	General seal, medium textured surfaces	1st and/or 2nd application, two-course slurry, highly textured surfaces
Sieve Size (USA Standard Series)		Percent Passing	
12.5 mm (½ in.)			
9.5 mm (⅜ in.)		100	100
4.75 mm (No. 4)	100	90-100	70-90
2.36 mm (No. 8)	90-100	65-90	45-70
1.18 mm (No. 16)	65-90	45-70	28-50
600 um (No. 30)	40-60	30-50	19-34
300 um (No. 50)	25-42	18-30	12-25
150 um (No. 100)	15-30	10-21	7-18
75 um (No. 200)	10-20	5-15	5-15
Residual Asphalt Content, % Dry Mass of Aggregate	10-16	7.5-13.5	6.5-12
Application Rate, kg/m² (lb/yd²), based on mass of dry aggregate	3-5.5 (6-10)	5.5-8 (10-15)	8 or more (15 or more)

*American Association of State Highway and Transportation Officials

†American Society for Testing and Materials

Mineral fillers such as limestone dust, portland cement, and fly ash are considered part of the blended aggregate. The filler should comply with the requirements of *Standard Specification for Mineral Filler for Bituminous Paving Mixtures*, ASTM D 242.

Water is an important element in the slurry mixture and should be clear, potable, and compatible with the slurry mixture.

Mix Design

The main items of design in emulsified asphalt slurry seals are aggregate gradation, emulsified asphalt content, and consistency of the mixture. The aggregates, emulsified asphalt, and water should form a creamy textured slurry that, when spread, will flow in a wave ahead of the strike-off squeegee. This will allow the slurry to flow down into the pits and cracks in the pavement and fill them before the strike-off passes over.

Slurry mixtures must be adapted to each job. Although a precise design procedure has not yet been developed, the following steps will result in an entirely acceptable slurry mixture.

The initial step in mix design should be a review of design considerations. These considerations include a description of the pavement to be treated, the objectives of the treatment, and evaluation and selection of the materials to be used.

The next step should be preparation of a job mix formula. This includes appropriate tests on the aggregate and emulsified asphalt to estimate, by calculated surface area and desired film thickness, the percentage of residual asphalt needed to meet the objectives of the treatment.

Then, laboratory prepared trial mixes should be used to estimate the optimum water content and filler requirement (if any); followed by compatibility and consistency tests, determination of mix and set time, physical tests of the cured slurry mixture, and, finally, selection of the optimum asphalt content.*

Equipment

A slurry machine is a type of traveling mixing plant, truck mounted with a towed-type spreader box attached. All machines have separate tanks for emulsified asphalt and water along with pumps for these materials. The aggregate is volumetrically controlled by feeding it from a hopper by a belt with an adjustable gate opening or auger (screw) system. The hopper generally is charged with a wheeled front-end loader but on some large slurry seal projects, a belt conveyor system has been mounted on the slurry machine to transfer aggregate from dump trucks into the hopper as the machine moves along.

The slurry machine has a continuous flow mixing

*International Slurry Seal Association, 1730 Pennsylvania Avenue N.W., Suite 1150, Washington, D.C. 20006.

unit, either single or double pugmill, capable of delivering accurately a predetermined proportion of aggregate, emulsified asphalt, and water to the mixing chamber and discharging the thoroughly mixed slurry on a continuous basis. The mixing unit also includes a metering device or method that introduces, if needed, a predetermined proportion of mineral filler into the mixer at the same time the aggregate is fed.

The spreader box is equipped with flexible squeegees and has an adjustable width and pavement pressure capability. When quick-set (QS) emulsified asphalt are used, some spreader boxes are equipped with hydraulic powered augers to keep the slurry in motion as well as to help distribute the mixture evenly across the box.

If the slurry machine is calibrated correctly for proportioning aggregate, mineral filler, water, and emulsified asphalt, many of the problems that have been associated with slurry sealing will not occur. Proper presetting of the aggregate feeder gate requires a knowledge of the moisture content of the aggregate being used and the effect of moisture changes on the specific weight of that particular aggregate. When using a quick-set (QS) emulsified asphalt, accurate control of the powdered or liquid additive to control slurry setting time is essential. Also with QS slurry, the mixture must be kept in motion with the agitation device in the mixing chamber and stagnant areas prevented in the spreader box.

Miscellaneous. Other equipment may include any or all of the following: (1) for surface preparation—power broom, power blower, vacuum sweeper, air compressor, water truck, high-pressure water blaster, powered wire brush for vegetation removal, and asphalt distributor; and (2) for spreading operation—wheeled front-end loader, shovels, hand squeegees, and pneumatic-tired roller.

Preparation of the Surface

Immediately prior to slurry application, all structurally failed areas and major depressions should be repaired, wide cracks filled, and dust, dirt, and other foreign material removed from the surface. Any standard cleaning method can be used. Also, removal of the top 13 to 20 mm (½ to ¾ in.) of old asphalt pavements by heater-scarifier may be used to get rid of surface contaminants and obliterate cracks. (Reflective cracking may be delayed in this way.)

A tack coat of diluted emulsified asphalt of the same type and grade specified for the slurry is recommended for all pavement surfaces, except clean asphalt mixes that are only a few days old.

Placing Slurry

General. It is very important in the placing procedure to keep a close watch on the spreader box itself and to observe that the slurry is rolling in one continuous mass and is evenly distributed across the box to the end of a pass. A problem may arise with even distribution when placing slurry in areas of high crown or on superelevated curves. The slurry should be constantly diverted to the high side of the box, as gravity will keep the low side filled. The operator should keep the box in the desired lateral position and the driver should maintain a straight line using a chain on a pipe mounted at the front of the machine to align the edge of the spreader box behind.

When approaching the end of a pass, the operator should cut the machine off in time to have as little slurry left in the mixer as possible and none left in the spreader past the finish line. Overmixing, whereby trapped air and overbeating of the emulsion causes a puffy, malt-like appearance, can occur if, at the end of a pass, the operator fails to shut off the mixer with the slurry still inside. If the surface is being pre-wetted by water fogging, the spray bars must be cut off to prevent puddles any time the slurry machine stops and restarted when the operation proceeds.

Grades of 8 percent or more call for some adjustment in the slurry mixture. The adjustment differs depending on whether the direction of placing is uphill or downhill.

Uphill placings: It is easier to hold the slurry in the spreader box because the direction of movement forces it through two sets of squeegees before it leaves the box. Therefore, a more fluid slurry is used to avoid placing a thick layer.

Downhill placing: A slurry of ordinary consistency often will overflow, push out under the front squeegee, or both, and flow ahead of the machine. Consequently, it must be thickened somewhat for downhill operations.

Because it is less trouble, some operators prefer to place the slurry in the uphill direction whenever possible.

Joints. The slurry should be placed in such a manner that all lane widths and longitudinal joints will conform to the existing traffic lanes. There are normally two ideal times for making a joint—when the slurry is still in a completely uncured, semi-fluid condition or in a completely cured condition. The time in between these two conditions is the most troublesome because of possible tearing and scarring. When making both transverse and longitudinal joints with this latter condition, the area overlapped should be *lightly* wetted just ahead of the box being dragged over it (hand hose or spray bar).

With a previous pass still in a semi-fluid and workable state, it generally is advisable to make a new transverse joint some 3 to 5 metres (10 to 15 feet) back from the end of the previous pass. When the previous spread is fully cured with no overmixing, the machine is positioned with the rear squeegee sitting just barely on the cured pass. With longitudinal joints, the use of a drag (burlap or some form of carpeting) pulled along the joint seam itself will help the fresh slurry to be evenly distributed. Although considerable lateral overlap of the spreader box on a previously placed pass can be tolerated with the finer slurry aggregate gradations (particularly Type I) extensive overlapping with the two coarser gradations will produce ridging and/or streaking along the longitudinal joint. Therefore, with the coarser gradations, the spreader box widths should be planned and adjusted to give passes with almost no lateral overlay, i.e. a true abutting type longitudinal joint similar to that used for asphalt concrete paving.

Handwork. This type of slurry placement should be minimized as much as possible, but there will always be some fill-in and small areas of repair requiring handwork. The area to be handworked should first be lightly dampened with the slurry machine hand hose and the slurry worked immediately and quickly after dumping into small piles. With quick-set slurry, the time for working the mix is particularly critical. A longer working time can be obtained for QS slurry by adjusting the amount of additive in the mix. No slurry should be overworked by hand as this can cause foam to develop and adversely affect the quality of the handworked areas. When doing handwork in small areas, especially fill-in behind the slurry machine, the material always should be squeegeed in the direction of the machine pass. If it is placed "cross-grain," the patch stands out rather than blends with the machine-placed material.

Rolling. Generally, where normal traffic will iron out the slurry and close any hair-line cracks of dehydration, it is not necessary to roll a normal thickness [6.3 mm (1/4 in.) or less] of slurry seal. However, there are instances where the somewhat lattice-like structure of the slurry should probably be densified by pneumatic-tired rolling to improve durability, such as in the areas subjected to severe power. Slurry seals on taxiways, runways, truck terminal yards, and intersections of heavily traveled roads and streets are examples where rolling is desirable. Also, pneumatic-tired rolling on applications that appear to be "tender" usually will correct the condition. The rolling should start as soon as clear water can be pressed out of the slurry mixture with a piece of newspaper without discoloring the paper.

Traffic Control. Sufficient traffic control should be exercised to adequately protect the fresh slurry seal with the time of protection required dependent on the thickness of the slurry, type of emulsified asphalt, and climatic conditions. At airports and parking lots, it is usually possible to completely barricade the area being slurry sealed. With multilane roads and streets, the general practice, however, is to complete one lane only from end to end of the project using traffic cones, signs and even pilot vehicles to control traffic. A narrow unslurried slot is temporarily left at intersections for through traffic. As with other types of surface treatment, inadequate traffic control is often the downfall of an otherwise successful slurry sealing project.

Climatic Limitations. A slurry should not be applied until either the pavement or air temperature is 10°C (50°F) and rising, nor should it be applied when rain is threatening. Slurry placed at lower temperatures usually will not cure properly (poor dehydration and poor asphalt coalescence will result).

Special Problems and Correction

Oversized Aggregate. Oversized aggregate will pass through the mixer into the spreader box but will catch under the back squeegee leaving streaks in the slurry. Quite often the aggregate is contaminated with overground. This problem can be overcome by putting the stockpile on a clean, paved surface. This situation has also been overcome with SS-type emulsified asphalt slurry mixes by placing a 12.5 mm to 19.0 mm (1/2 in. to 3/4 in.) screen on the spreader box where the slurry enters from the mixer to catch the oversized aggregate. This procedure apparently cannot be used with QS slurries as the mix sets up on the screen which blocks passage into the spreader.

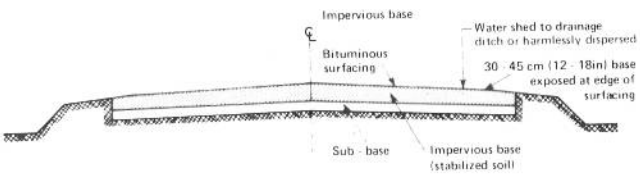
Segregation of the Mix. This often-encountered condition may appear in the form of a black, fat-appearing, slick surface or skin; a tendency for the slurry to pick up on tires; or a lack of early adhesion to the existing pavement. Segregation is usually the result of operating with an excessive amount of water in the slurry mix—an easy but *incorrect* way to compensate for unstable slurry. Segregation can also be caused by too little mineral filler, poor-overall aggregate gradation, or improper proportioning of the mix components. If a downward adjustment in water content does not correct the problem, then the other possible causes should be investigated.

Drainage

Drainage is almost always the most important factor in determining the performance of a road. When a road fails, it is often because of inadequate drainage. Failure can happen when shoulders and embankments are damaged during heavy storms or floods, or less noticeably when surface cracks permit water to penetrate into the subgrade and weaken it so that it is no longer strong enough to support traffic. Frequently, the surface treatment is blamed for failure when the real culprit is inadequate drainage. It is not uncommon to be concerned with pavement while paying little or no attention to subdrainage. Recurring spring maintenance problems, such as potholes and broken pavement, result from freeze/thaw action of ground water. A dollar spent on sub-base preparation and drainage will return more than two dollars spent on surface treatment in terms of reduction of future maintenance requirements.

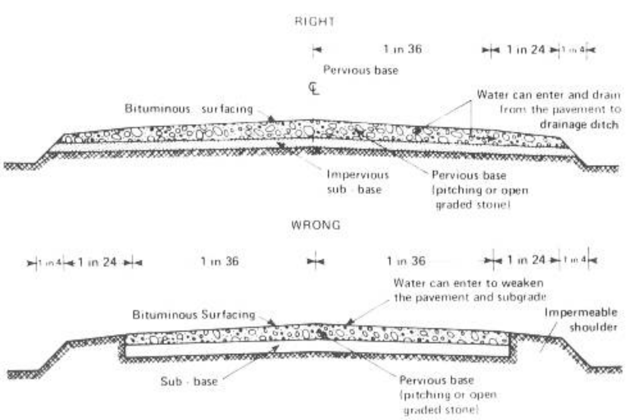
Roadbed Drainage

If a road is to perform satisfactorily, it must have sufficient crown to remove the surface run-off and must also have provisions for removal of any water which may gain access to the lower layers of the road. If a road is properly crowned with a permanent type surface, most of the water will run off. However, water can infiltrate and scour the shoulders on the way to the drainage ditches. Since it is impossible to prevent all infiltration, the base should be dense enough to prevent excess water accumulation in the base. The following figure shows an acceptable design using an impervious base.



Base should resist water accumulation.

Much of the rural road construction in Oklahoma is done with open textured permeable material. In such cases, the open trench type of construction (shallow excavation between impermeable clay shoulders) should be avoided. The wrong and right ways to construct a road with a pervious base material are illustrated below. As shown, the shoulders should be constructed as an integral part of the sub-base. This is good practice even when using a dense paving material with dense base.

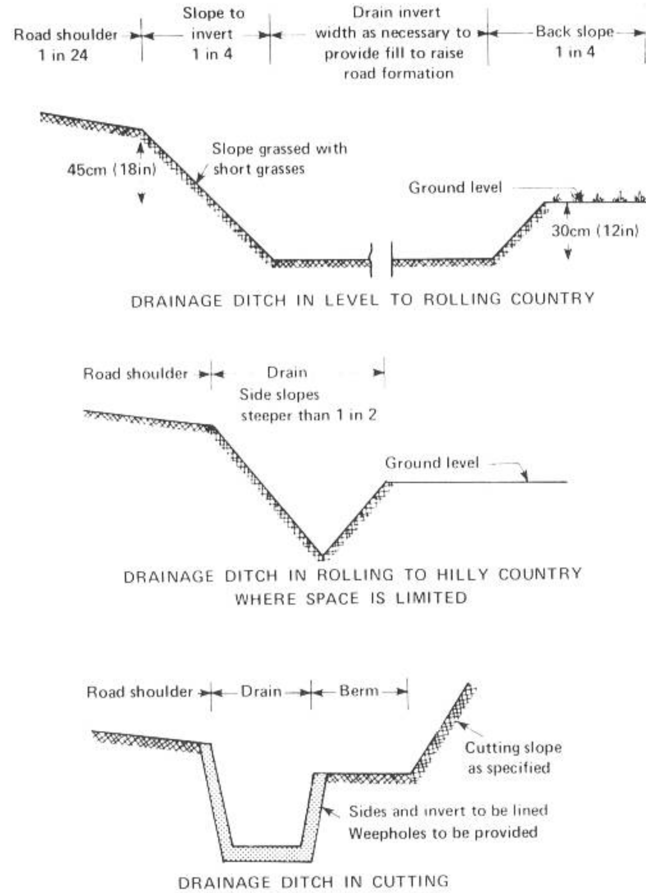


Good and poor drainage design.

Erosion Control

The susceptibility of soils to erosion depends on the properties of the soil, the length of the slope, the gradient and vegetative cover. Since vegetation dissipates the energy of wind and water, it is an important factor in erosion control.

The faces of embankments, road surfaces and shoulders and drainage ditches are the places most vulnerable to water erosion. Embankments with a slope of no more than 1½ horizontal to 1 vertical and well-compacted soil can be safe from excessive erosion to a height of 25 feet, once proper vegetation is established. For embankments higher than 25 feet, runoff from the road should be carried to selected points and discharged down the embankment by means of a lined drainage ditch. The ditch may be lined with concrete, asphalt or turf.



Drainage ditch design varies with terrain.

Drainage ditches should be lower than the roadbed they drain and should provide a suitable channel to carry water away from the roadbed. Ditches should be shaped to minimize the hazard to traffic and to insure that the discharge from the ditches does not cause erosion. The slopes on the sides of drainage ditches should not exceed 1 in 4 to minimize erosion of the ditches. It is desirable to have at least 1 percent longitudinal fall to insure proper flow in the ditches.

Culverts

A culvert must have adequate strength to support the weight of the fill material above it, as well as the other loads placed on it. It must be durable and have sufficient hydraulic capacity to carry away a predetermined quantity of water in a given time. If the culvert is too small, flooding of the roadway will result. If the culvert is too large, it is unnecessarily expensive. However, generally it is better to design a culvert oversized than undersized.

Culverts usually consist of concrete or corrugated metal pipes. Larger installations may be concrete box culverts, concrete arches or timber. Culverts commonly range from 12 to 36 inches in diameter, but sizes as large as 120 inches are available. The minimum diameter recommended for a roadway cross culvert is 18 inches.

Culverts should be designed to carry maximum anticipated quantities of water for areas in which they are constructed and should be placed to take advantage of existing contours, placing the culvert in the existing channel, if possible. The gradients should provide a velocity of approximately 2.5 feet per second to prevent the accumulation of sediments in pipes. Pipe culverts should have at least 12 inches of cover for sizes smaller than 24 inches in diameter and not less than one-half the diameter for larger sizes. Culverts other than pipe should have a minimum of 12 inches and preferrably 18 inches of cover.

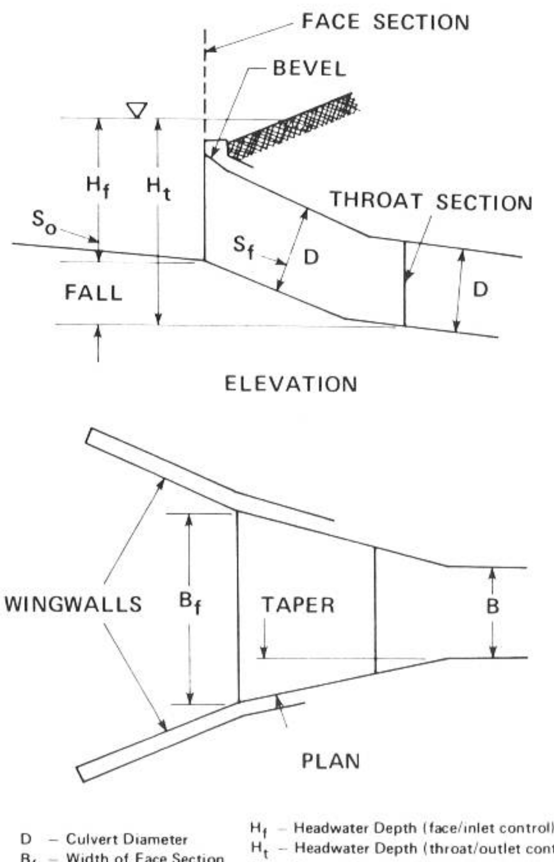
The cheapest culvert to construct may *not* prove least expensive in the long run. Locations that will eventually require excessive maintenance or expensive protective features may eat up savings resulting from a choice based on low installation cost.

The capacity of culverts can often be improved by altering the entrance configuration. By simply beveling the edge of the inlet, capacity can be increased significantly. Additional increases in capacity can be obtained by having side-tapered inlets, and further improvement can be accomplished with slope-tapered inlets. Figures are provided to show the designs of these inlets.

Subsurface Water

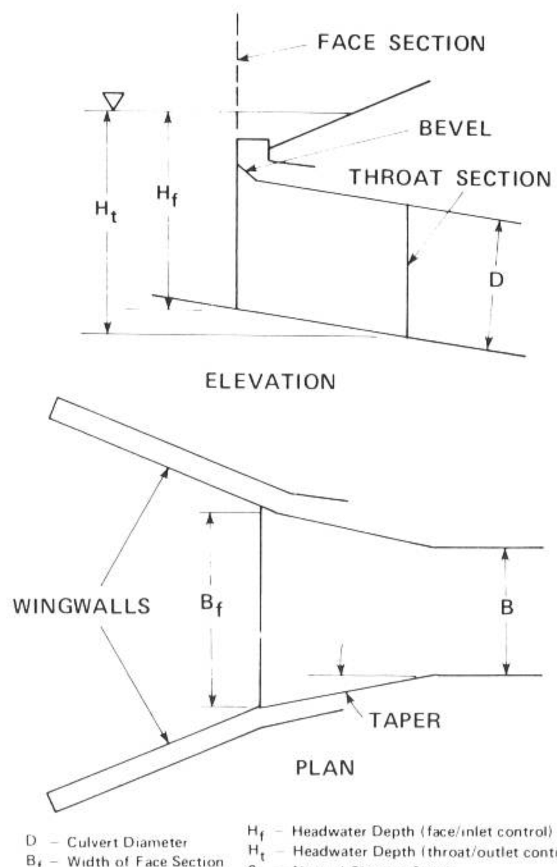
When a high water table causes problems with the roadway, the road may be raised, or drainage arrangements may be made to lower and dispose of the

In most rural roads, sub-drainage can be maintained with properly shaped shoulders and ditches that prevent the water table from rising in the roadway. Where this is not possible, drains should be installed not more than six feet below profile grade in a trench filled with pervious filler material and capped with impervious material such as clay to prevent surface water from entering. Shallow installations, not less than 18 inches deep, along the roadside will usually drain sub-grade and base. The decision as to whether the roadbed should be raised or subsurface drains installed is an engineering problem that must be solved at a specific site, taking into account availability and cost of fill versus cost of excavation and installation of drains.



D – Culvert Diameter
B_f – Width of Face Section
B – Barrel/Culvert Width
H_f – Headwater Depth (face/inlet control)
H_t – Headwater Depth (throat/outlet control)
S_o – Natural Channel Slope
S_f – Inlet Slope

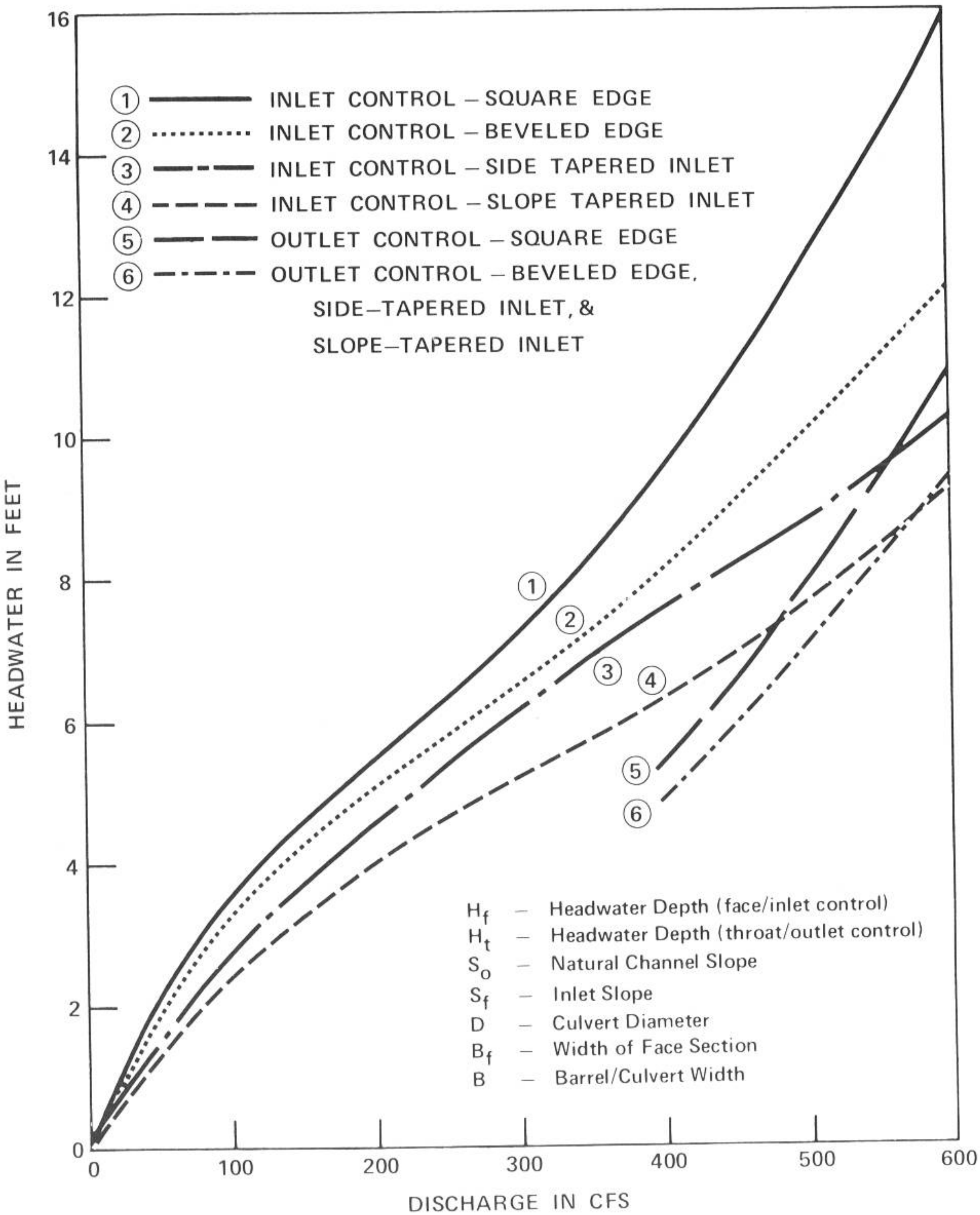
Slope-tapered inlet design.



D – Culvert Diameter
B_f – Width of Face Section
B – Barrel/Culvert Width
H_f – Headwater Depth (face/inlet control)
H_t – Headwater Depth (throat/outlet control)
S_o – Natural Channel Slope
S_f – Inlet Slope

Side-tapered inlet design.

PERFORMANCE CURVES FOR SINGLE 6′ X 6′ BOX CULVERT, 90° WINGWALL



Discharge capacities of 6′ x 6′ box culvert with various inlet designs.

Road Construction

All road construction and nearly all road improvements involve a considerable amount of earthwork. Soil is the foundation material for all roads and highways, whether it be in the form of undisturbed subgrade materials, transported and reworked base, or embankment material. Pavement loads must be transmitted to the base and sub-base. If adequate support does not exist, the road will rapidly deteriorate. A good road requires a suitable foundation which in turn requires material stability.

A material is stable if it has little or no volume change and resists deformation under repeated or sustained loads whether the material is wet or dry. Before considering methods to improve the stability of soils, we will look at soil characteristics of various types of soil. (See table). The divisions and classification prefixes used are as follows:

A. Coarse-grained soils.
 1. Gravels and gravelly soils, prefix G.
 2. Sands and sandy soils, prefix S.

The gravels and sands are subdivided into the following:
 (a) Well graded soils with little or no fines, suffix W.
 (b) Medium graded soils, with little or no fines, suffix M.
 (c) Poorly graded soils with little or no fines, suffix P.
 (d) Poorly graded soils with appreciable fines, or well graded soils with excess fines, suffix F.

B. Fine-grained soils.
 1. Inorganic silt soils, prefix M.
 2. Inorganic clay soils, prefix C.
 3. Organic silts and clays, prefix O.

Two subdivisions to the fine-grained soils:
 (a) Soils whose liquid limits are less than 50 percent, and which have low compressibility, suffix L.
 (b) Soils whose liquid limits are greater than 50 percent, suffix H.

C. Fibrous soils.
 1. Peat and swamp soils, prefix Pt. There are no subdivisions of the fibrous soils.

The table on Page 53 provides information for each classification on the usefulness of the type soil for road foundations and bases. It also gives the potential frost action, compressiblity, and drainage characteristics and suggests the appropriate mechnaical compaction equipment for each type of soil.

The degree of stability for a satisfactorily compacted material is primarily a function of resistance to lateral flow. Because of their particle size, well-keyed granular materials have a high resistance to lateral flow. Water has little effect on the internal friction (resistance to lateral flow) or volume change on these larger sized particles. However, in fine grained materials such as the clays so prevalent in Oklahoma, the stability is very much moisture dependent. Stabilizing materials are used to obtain and maintain desired moisture and increase the cohesion, to produce a cementing action, and to act as a waterproofing material.

Stabilized soil mixtures lend themselves to "stage construction," which involves the gradual improvement of the road as traffic demands increase. A properly designed stabilized soil mixture might serve as a wearing surface, then receive a thin bituminous surface treatment as traffic increases, and eventually serve as a support for a high-quality pavement which will serve a heavy volume of traffic.

To select the proper stabilizing agent, an understanding is required of both the soil and agent to be used. The additive must be of the correct type and in the correct quantity to produce the satisfactory end-product desired.

Asphalt Stabilization

Asphalt materials are used with soils for two general purposes. They may act as a cohesive agent in sand or sand soils or they may be used to waterproof a soil mixture. Asphalt stabilization has its greatest use in sandy soils; it finds limited use in stabilizing clay soils due to the difficulty in obtaining adequate dispersal of the asphalt.

The designation of the asphalt material to be used for stabilization is normally made by penetration grade. The most suitable grades appear to be 80-100 and 120-150 penetration. The asphalt may be mixed with the soil by specifically designed machines or it may be added to a windrow on the roadway. The soil (or sand) asphalt mixtures should be designed in the lab using some type of stability test. Usually 4 to 6 percent of asphalt by weight is added to the soil. After mixing the soil and asphalt, the mixture must be aerated to remove moisture and hydrocarbons. This can be accomplished by moving the windrow back and forth across the roadway using a grader. After aeration, the mixture should be spread and compacted. Compaction may be done with a sheepsfoot roller, followed by pneumatic rollers and steel-wheeled rollers. The compaction should be done in 2- to 4-inch courses.

Calcium Chloride

Calcium chloride is used to get maximum performance from properly graded quality aggregates; it is not used to change the characteristics of poor or questionable materials. Calcium chloride possesses the ability to attract and retain moisture from the air. It is used to expedite the compaction process by slowing the rate of evaporation of moisture from the mixture during compaction and to aid in the retention of moisture during the service life of the soil-aggregate

Table 1. Soil Characteristics

Major Divisions (1)	(2)	Ltrs. (3)	Name (4)	Foundation Value When Not Subject To Frost Action (5)	Value As Base Directly Under Bituminous Pavement (6)	Potential Frost Action (7)	Compressibility and Expansion (8)	Drainage Characteristics (9)	Compaction Equipment (10)	Unit Dry Weight lb/ft³ (11)	Field CBR (12)
Coarse Grained Soils	Gravel and Gravelly Soils	GW	Well-graded gravels or gravel-sand mixtures, little or no fines	Excellent	Good	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment, steel-wheeled roller	125-140	60-80
		GP	Poorly graded gravels or gravel-sand mixtures, little or no fines	Good to excellent	Poor to fair	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment, steel-wheeled roller	110-130	25-60
		GM	Silty gravels, gravel-sand-silt mixtures	Good to excellent	Fair to good	Slight to medium	Very slight	Fair to poor	Rubber-tired equipment, sheepsfoot roller; close control of moisture	130-145	40-80
				Good	Poor	Slight to medium	Slight	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	120-140	20-40
		GC	Clayey gravels, gravel-sand-clay mixtures	Good	Poor	Slight to medium	Slight	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	120-140	20-40
	Sand and Sandy Soils	SW	Well-graded sands or gravely sands, little or no fines	Good	Poor	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	110-130	20-40
		SP	Poorly graded sands or gravelly sands, little or no fines	Fair to good	Poor to not suitable	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	100-120	10-25
		SM	Silty sands, sand-silt mixtures	Good	Poor	Slight to high	Very slight	Fair to poor	Rubber-tired equipment, sheepsfoot roller; close control of moisture	120-135	20-40
				Fair to good	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	105-130	10-20
		SC	Clayey sands, sand-clay mixtures	Fair to good	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	105-130	10-20
Fine Grained Soils	Silts and Clays LL < 50	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Fair to poor	Not suitable	Medium to very high	Slight to medium	Fair to poor	Rubber-tired equipment, sheepsfoot roller; close control of moisture	100-125	5-15
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Fair to poor	Not suitable	Medium to high	Medium	Practically impervious	Rubber-tired equipment, sheepsfoot roller	100-125	5-15
		OL	Organic silts and organic silt-clays of low plasticity	Poor	Not suitable	Medium to high	Medium to high	Poor	Rubber-tired equipment, sheepsfoot roller	90-105	4-8
	Silts and Clays LL > 50	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils elastic silts	Poor	Not suitable	Medium to very high	High	Fair to poor	Sheepsfoot roller	80-100	4-8
		CH	Inorganic clays of high plasticity, fat clays	Poor to very poor	Not suitable	Medium	High	Practically impervious	Sheepsfoot roller	90-110	3-5
		OH	Organic clays of medium to high plasticity, organic silts	Poor to very poor	Not suitable	Medium	High	Practically impervious	Sheepsfoot roller	80-105	3-5
Highly Organic Soils		Pt	Peat and other highly organic soils	Not suitable	Not suitable	Slight	Very high	Fair to poor	Compaction not practical		

mixture. Small amounts of calcium chloride will, in many instances, result in increased density for a given compaction effort. Initial application is at the rate of approximately one-half pound per square yard, per inch of thickness.

Cement Stabilization

Cement stabilization is often referred to as soil-cement. Soil-cement is a mixture of soil, cement, and water tightly packed to high density in a moist condition. When cured, the soil-cement mixture forms a hard, rigid base course. Soil-cement may serve as a base for a thin wearing surface which will have light or medium traffic or as a support for a high-type flexible or rigid pavement. Portland cement in amounts of 3 to 16 percent by volume of the compacted mixture is added to the natural soil. Nearly all soils may be stabilized through the use of portland cement, but silts and heavy clays require large percentages of cement for successful stabilization. Cement stabilization differs from other types of stabilization in that it actually hardens the soil material and structural strength is obtained from the cementing action rather than from waterproofing or cohesion. There are three fundamental control factors for soil-cement: proper moisture content, adequate compaction, and proper cement content. These should be determined by laboratory testing of representative soil samples.

Pulverized soil is mixed with the correct amount of portland cement and enough water to permit maximum compaction. Costs vary considerably, but a typical 6-inch soil-cement base course may cost about 85 cents per square yard.

Lime Stabilization

This type of stabilization involves the use of quicklime or hydrated lime to improve plastic clay soils. Lime is a strong alkaline base which reacts chemically with clay forming complex silicates or other cementing materials. Either high calcium or dolomitic lime can be used, but pulverized limestone is *not* suitable since it is relatively inert chemically. The use of lime permits the upgrading of marginal and sub-marginal soils into satisfactory base and sub-base materials. It also improves the workability of plastic soils making them easier to pulverize. Lime tends to waterproof the soil to some extent and allow it to dry out more quickly when saturated, thus speeding construction.

Determination of the quantity of lime to use is based on lab testing. However, the amount used in subgrade treatment is generally from 3 to 6 percent. Subgrade soil is scarified and pulverized to a depth of 6 inches followed by spreading of lime, usually with a mechanical spreader. Enough water is added to bring the moisture content to 5 percent or more above optimum. The lime-soil mixture is allowed to cure for periods from 1 to 7 days. Mixing and pulverizing then continues until all the material will pass a one-inch sieve and 60 percent will pass a Number 4 sieve. Compaction is done by pneumatic rollers or vibrator compactors. The compacted layer is allowed to cure from 3 to 7 days before the next layer is placed. During the curing period, it is desirable to keep heavy traffic off the roadway. Total stabilization cost averages 45 to 50 cents per square yard per 6-inch thickness.

Salt Stabilization

The sodium ions present in salt stabilization react with clay particles, giving greater dispersions of some clays. This may make it possible to obtain desired compaction with less effort. It also provides a weak bond between soil particles. After curing and the re-crystallization of the unreacted salt within the void has taken place, a firm, stable layer is formed, increasing the strength and load bearing capacity.

Salt has considerable use in stabilizing the surface of dirt roads with low traffic volume. Salt, soil, and water are mixed; and the mixture is compacted while the salt is dissolved. When the mixture dries, the re-crystallized salt makes the resulting surface dense and hard. The salt binds the smaller soil particles to the larger particles "cementing" them together.

Salt may be mixed with the soil either in a pug mill or in place using a road grader. If mixed in a pug mill, 20 pounds of salt per ton of soil (note: one cubic yard of soil weight about 1.5 tons) will suffice. If mixed in place, 1 to 2 pounds per square yard per inch of compacted depth should be added. Water should be added to obtain a moisture content within 1 to 2 percent of optimum. The salt crystals should be completely dissolved and the mixture should barely stick to equipment tires.

The mixture should then be spread with a grader and rolled with a pneumatic tired roller from the shoulder to the center of the road forming a crown sloped at one-half inch per foot of lane width. The road surface should have a glazed look, but no moisture should appear on the surface.

Other Stabilization Materials

Other materials that have been used for stabilization are: phosphoric acid, calcium acrylate, anilinefurfural, lignins and resins, sodium silicates, sucrates, dioctadecyl demethyl ammonium chloride, aliphatic organic chemicals, lime fly ash and many commercial products.

Summary

If economic designs of highway pavements, embankments and subgrades are to be obtained, and subsequent maintenance cost reduced to a minimum, it is essential that the soil in these road components be brought to a satisfactory state of stability during the construction work. In many cases this can be best accomplished by the use of an additive to the soil. Because of the variety of soils encountered in nature, a sound engineering approach is required to assure successful results in any given case.

Maintenance of Aggregate Surfaced Roads

Many of the county and city roads in "rural" Oklahoma are aggregate surfaced roads. Aggregate surfaced roads represent a large portion of the total road mileage in Oklahoma. These roads are relied upon for all-weather passage of low-volume traffic.

This section will provide a description of various types of aggregate road materials and tips on maintaining these materials on the road. It is hoped that this information will be used to help reduce the cost of maintaining aggregate roads.

Materials used for building roads should provide a road that is passable in all kinds of weather. The materials available for road building differ. the soils that are used may break into fine pieces under heavy traffic, may swell when wet, or may be so hard they are difficult to work. These problems need to be corrected before a hard surface is placed on the road.

Aggregates

Aggregates are coarse soils or mineral particles. In road building it is best to use aggregates that are very hard and not easily broken up. Aggregate types are:

- Crushed stone or rock, usually limestone.
- Gravel and natural sands. These can be found in natural deposits in river beds or old streâm beds.
- Burnt clay or expanded shale, an industrial by-product or commercially produced as aggregate material.

There may be other materials that are locally available that make good road aggregates. Experience will tell you how desirable these materials are.

Blending Aggregates

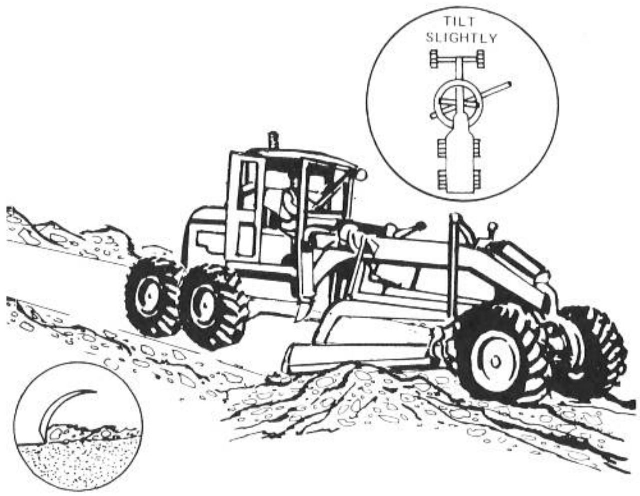
Aggregate surfaced roads are usually the most economical for carrying low volumes of traffic because of the usual local availability of aggregate. To achieve a road that can be used in all types of weather a proper blend of different size aggregates is necessary.

The wearing surface is made up of different size aggregates blended together. Blending different sizes allows the pieces to lock and pack (compact) together to make a strong tight surface. Usually the size of aggregate is ¾ inch and down.

The fine material acts as a binder. It is an important part of the mixture because with the addition of water it acts as a cement to hold the aggregates together. Moist aggregate will not dry to form a hard wearing surface without the proper amount of fines. When an aggregate road has dust blowing from it, the dust is the fines and, therefore, the binder is being lost.

Maintaining Aggregate Surfaces

To keep a road in good condition, the road surface and shoulders must be maintained. This will involve smoothing and reshaping which is usually done with a motor grader.

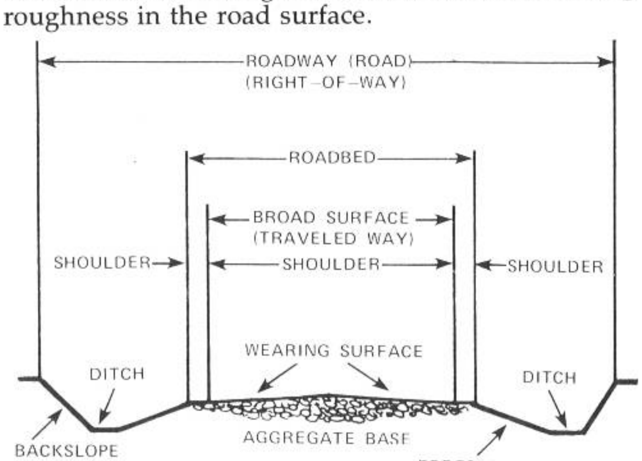


Tilt moldboard to get dragging action.

Smoothing of the road surface is done by dragging the surface with a grader blade. This should be done when the aggregates and fines are moist. When smoothing is done in dry weather, care should be taken not to disturb the crust. This dragging operation also rolls the aggregate and helps compact the road surface as it is blended.

Properly blended aggregates and fines will dry to form a hard crust that provides a wearing surface. The crust carries the traffic load and sheds water until it is broken. Traffic and climatic conditions will completely break down the crust over time and reshaping will be necessary to rebuild the crust.

The speed at which a grader operates or can blade effectively will depend on the type of grader, its tire pressure, and the condition of the road surface. Going too fast will cause the grader blade to bounce, creating roughness in the road surface.



Typical section of aggregate surfaced roadway.

Reshaping

Reshaping is necessary when the road cannot be smoothed to an acceptable riding surface. The entire aggregate base, 4 to 8 inches in depth, may have to be reworked to eliminate large potholes, deep ruts, and flattened crown.

Reshaping involves remixing the aggregate base to get a proper blend of fines and different size aggregates and blading and compacting this blended material into a properly crowned road surface. When remixing, it may be necessary to add more aggregate or fines. The art of proper blending is a cut-and-try propostion, experience is the best guide to correct blending. The quality of the crust and its length of useful life depend on the skill used in blending coarse and fine materials and moisture to form the desired crust.

After the aggregate base is remixed, it is reshaped by blading to restore a proper crown and smooth surface. A proper crown has the center of the road higher than the shoulders and a straight, uniformly sloped line from the center of the road down to the shoulder edges on either side. This is an A-type crown and is the most desirable for good road life but is the hardest to maintain.

Keeping a crown on the road is probably the most important part of blading. Without a proper crown, water will stand and soak and soften the road surface.

The amount of crown or cross slope in the road should be ⅓ to ½ inch for each foot of width measured from the center of the road to the outside edge or shoulder. This amount of crown should allow good drainage of surface water without washing of surface materials. This slope may vary in special cases.

The most common crown found on aggregate roads is a parabolic crown that is relatively flat across the center of the road. This crown occurs naturally due to traffic traveling down the center of the road and destroying the A-type crown. Parabolic crowns should be worked as soon as possible by reshaping.

Shoulders

The shoulders are the additional width along the outside edge of the roadway. These will be either aggregate or grass covered on most rural aggregate surfaced roads. The slope of the shoulder from road edge to ditch foreslope must be equal to or slightly greater than the road surface cross slope. This will allow for good drainage of surface water from the roadway.

The shoulders should be maintained periodically. When reshaping the roadway, the shoulders should also be worked in the same manner.

Summary

An aggregate surfaced road will provide a good all weather roadway when it has been properly constructed and maintained. The materials available for aggregate surface roads will depend upon local availability and budget. The material used should be suitable for use as a base for future hardsurfacing. By putting down good base in the beginning, the weak spots can be found over a period of years and corrected before applying a permanent hard surface when the traffic count increases.

The mixture of aggregate materials for the roadway will depend upon the experience of the road superintendent and will have to be adjusted for different aggregates. The road surface will need blading occasionally to retain a smooth surface. Reshaping will be necessary from time to time to correct potholes, transverse corrugation or "washboard" effect, and rutting. The shoulders should also be maintained when reshaping.

Recycling Asphalt Pavement

Recycling of existing paving materials is becoming necessary partially due to the growing scarcity of select virgin materials at a reasonable cost and availability within easy hauling distance. Also the price and availability of high quality binders such as asphalt havebeen dramatically affected by the continuing energy crisis. It is also becoming more important to conserve dollars. Most dollars spent are public dollars and these dollars must be stretched even more today.

Methods now being used to reclaim or reuse paving materials from old and deteriorated pavements will be discussed. Both asphalt and portland cement concrete pavements are being recycled but only asphalt pavement will be discussed here.

The ability to recycle old or discarded asphalt pavements can be of significant value in conserving energy, natural resources, and in the preservation of natural landscape.

Some of the more obvious benefits are enumerated below:

- Reduction of the need for exploring and developing new aggregate sources and conservation of existing aggregate sources.
- Elimination of the necessity of locating disposal sites for discarded pavements.
- Conservation of expensive and scarce asphaltic products. Recycled asphalt pavement requires about 75% less new asphalt cement than do virgin materials.
- Distressed pavements can be recycled in lieu of placing thin overlays that are especially prone to reflective cracking.
- The structural value of a distressed pavement can be increased by recycling a portion of the underlying base material along with the bituminous pavement.
- A distressed section of a pavement can be recycled without disturbing the pavement that is in good condition.

The several methods of recycling used for asphalt pavements that will discussed are hot-mix recycling, cold recycling with chemical options, and surface recycling.

Hot-Mix Recycling

Hot mix recyling involves recycling the old pavement into a high-type asphalt concrete by recapturing the original investment in asphalt binder and aggregates. The basic operation consists of scarification and removal of the pavement, crushing and processing, followed by conventional lay-down.

Removal is achieved by ripping up the asphalt surfaces with a motor grader or dozer-mounted ripper. The material is then loaded and hauled to a processing location. Care is taken not to remove or disturb the base during this process.

Processing consists of crushing the removed material to a minus five-eighth's inch size. This is done by using a rock crusher. The material is then passed through a heat exchanger type of rotating dryer and heated to 260-280°F. New aggregate and asphalt cement are added to meet the required specifications.

Some of the new cold planing machines are capable of removing (cutting) the existing pavement in a size and gradation that does not require further crushing or processing. Heat during the remix operation breaks down the larger parts and facilitates addition of "new" materials and the final mixing process. Economics will dictate the preferred method of removal. More information on cold removal is provided under the section, "Cold Planing".

The material is then returned to the roadway and placed through a conventional paving machine. This method will necessitate closing the recycled section of roadway to traffic for several days. A savings of about 25 percent over the cost of conventional hot-mix is achieved with this process.

The problem with recycling materials through any hot-mix operation is the reduction in production rate. The productivity of the plant is reduced at least 50 percent and this causes problems at the lay-down machine.

Another problem with hot-mix recycling has been meeting emission requirements for clean air at the plant. When old asphalt pavement is placed in a conventional asphalt plant, the result is smoke that pollutes the air and materials that stick to the equipment.

There has been work done using conventional pugmill type plants for old pavements. Crushed pavement is added to new aggregates that have gone through the dryer and heated to approximately 450° F. When these products are mixed in the conventional pugmill the heat from the new aggregates is transfered to the crushed asphalt pavement and softens the asphalt cement contained therein. New asphalt cement is also added at the rate of approximately 1½ percent by weight of the mix. The only modification required to a conventional plant is the addition of a conveyor to deliver the crushed asphalt pavement to the weigh bin. The asphalt pavements should be crushed to minus one-half inch size before being added to the new aggregates. This slight modification will allow the plant to be operated in the conventional mode or in the recycle mode. When using this type of plant arrangement a mix of 75 percent recycled material and 25 percent new aggregate with 1 to 1½ percent new asphalt cement will give an acceptable mix. Trial runs are needed to achieve the optimum mix.

It is now reasonable to require the stockpiling of old bituminous pavements for future use rather than diposal in fills as has been the custom. This material is a valuable resource and should be handled as such.

Hot-mix recycling has its main applications on highway jobs and in large cities, yet materials in rural areas could be accumulated in stockpiles for future use.

Cold-recycling with Chemical Options

Recycling old pavement by scarifying, in-place pulverizing or removal for central plant crushing, adding additional aggregates and chemicals as desired, mixing, and relaying as a stabilized base are cold-recycle chemical options. This low-cost process includes numerous options as to the chemicals used to rejuvenate or increase the stability of the recycled materials.

This technique has been used for many years as a maintenance tool. Streets that were built up from oil mats, chip and seal, thin overlays, and other methods used over the years to obtain all weather roads have huge amounts of aggregates and asphaltic cements contained in them. These materials are still usable and can be reclaimed.

To make use of these materials, it is required to scarify the road surface materials. Scarifying teeth mounted on a motor patrol or crawler tractor do a good job of ripping up the road. A chemical softener added to the surface material will soften the hardened asphaltic binder so that thorough mixing can be achieved. A pulverizer is then used to reduce the material to a usable size, usually minus one-inch size.

It is very important to understand that any base problems will need to be corrected when the surface is removed. If these problems are not corrected, they will show up or reflect through the new surface.

The pulverized surface material should be spread back over the roadway and mixed in-place with new asphalt binders to hold the material together. Asphalt emulsions are gaining in popularity for this type of application. After the surface material has been mixed and compacted, it is advisable to seal the surface with a chip and seal or fog-coat application.

Rejuvenators are also used on existing pavements. Rejuvenators can be applied to the pavement surface to "rejuvenate" the surface which has become oxidized. Caution should be exercised in the use of these products due to their tendency to make the pavement surface slick if applied too heavily. Normally, an application of 0.10-0.20 gallon per square yard is used. More about rejuvenators will be presented under heater techniques.

Surface Recycling

Surface recycling involves recycling in-place by heating, scarifying, adding additional materials if required, mixing, and relaying the top inch of a surface distressed pavement. Applications are for increasing skid resistance, removing ruts, and correcting flushed or oxidized surfaces.

Surface recycling can be achieved in many ways, and some of these will be discussed. There are many new techniques being developed every day, and this tends to make it difficult to stay abreast of the state-of the-art.

It is important to remember that surface recycling techniques will not correct base problems in the roadway. Before any technique can give the proper results it will have to applied to a sound base. Correcting base problems should be the first step in any surface recycling program.

Of the various surface recycling techniques only heater planer, heater scarifier, and cold planing methods will be discussed.

Heater-Planer

"The unit shall be a self-contained machine specifically designed to heat and plane the irregularities from the asphaltic pavements. The planed surface shall be free from soot, oil film and other imperfections of workmanship. The planed cuttings shall be bladed into a windrow from which they can be picked up."

The preceding is a typical short specification for a heater-planer job. The heater-planer is used on jobs where the removal of asphalt pavement (high quality type) is necessary. The method is not suitable on low quality type surfaces such as single or double treated chip overlays or soil/sand asphalt. This could be necessitated by the need to regain curb height, reduce overlay load on a structure, increase clearance under a structure, or smooth a rutted or corrugated pavement.

The planer uses heat to soften the pavement and a planer blade to remove the softened surface material. The heater heats the pavement surface to about 250° F. The pavement is usually softened to a depth of one and one-fourth inches to two inches. One factor to consider is whether the heater can heat the pavement without burning trees, killing lawns and scorching the asphalt in the pavement. The heated-planed material can be used to surface secondary roads, parking areas or pavement shoulders. The material is picked up from the pavement while hot and placed immediately. This material cannot be stored conveniently, since it becomes cemented in mass upon cooling.

Two types of heating are available, radiant heating and direct flame. The best results have been from radiant heaters. This work is generally performed by contractors at a cost of $0.75-$1.00 per square yard for one and one-half inches of removed surface. This technique is particularly useful when the removed material is to be used in a hot-lay application.

Heater-Scarifier

The heater-scarifier heats the pavement surface like the planer, then mixes the top three-fourth's inch of the pavement. The mixing is done by spring mounted spike teeth that rip up the heated pavement and mix the oxidized top one-fourth inch with one-half inch of the underlying pliable paving material.

This operation is performed on badly oxidized pavements that have small surface cracks. The scarification and heating will seal the upper three-fourths inch of the crack and thereby seal out surface water. The operation also smoothes surfaces that are becoming raveled and slightly rutted. This technique can only give good results if it is performed on a pavement with a good strong base.

It is common practice to use a rejuvenating agent following the scarification to restore flexibility and ductility to the pavement. At this point the pavement can be compacted to the desired density and then surface sealed or overlayed with a thin overlay.

A word here about rejuvenators—rejuvenators are cationic maltene emulsions which are used to restore some of the ductility and penetration of a hardened asphalt pavement. The emulsion is made from selected oil and resin components from asphalt that have had the asphaltines removed.

On pavements that are overlayed following a heater-scarifier rejuvenator treatment a thinner overlay can be used. A pavement which receives a two-inch overlay normally can be overlayed with a one-inch thickness of asphalt overlay, approximately $0.27 per square yard. The savings comes from the fact that curb height is saved. Actual use has proven that a longer life pavement is obtained and reflective cracking is delayed.

Paving trains are also being developed which heat the paving, pick it up, add new oils and asphalt mix and lay the new mix down similar to typical hot-lay operations. The use of this system minimizes the time required for a street to be closed and gives a new surface with a minimum of new materials.

All of the above heater-type work is generally performed by contractors. Contractors have the expertise and equipment to do the work much more efficiently than local governments can. Usually, contractors will give competitive bids on jobs over 10,000 square yards. It is a good practice to talk to more than one contractor and to check the references of each.

Cold Planing

This method of pavement removal or profiling has been developing rapidly in the past 5 years. Today, there are machines on the market which will plane concrete or asphalt paving at a much faster rate than the heater techniques. These machines can remove the surface defects of a pavement for a more uniform overlay or they can remove the pavement to the base material.

The material obtained from these machines is a crushed paving material that can be used for bases, secondary roads, new surface pavement or patching mixes. By reusing these materials, a savings is realized in aggregates and oil which help offset the cost of the planing operation. Also by using these machines to establish a uniform profile, the amount of asphalt overlay material needed to obtain a one-inch or two-inch overlay is reduced to a minimum.

One machine that is presently available consists of a thirty-inch diameter drum mounted on a motor grader chassis. This drum rotates against the paving as the grader moves forward and cuts the pavement with high strength steel or carbide steel bits. The cut material is swept up after each pass and loaded for future use. The planer is especially useful in regaining curb height by removing a deep section of material at the curb and feathering the cut towards the crown of the road. This machine is also useful in bridge deck repair in removing salt damaged concrete, or restoring the crown or grade, or removing a "slick" surface.

Another type of machine on the market is a large planer that cuts a five-foot or wider path. This machine is track mounted, self-contained and usually has the capability of loading the cut material on trucks for transport. These machines also use a large rotating steel drum that has steel or carbide steel bits for cutting.

The cold planers available today have the ability to perform one or more of the following basic pavement removal, maintenance, and resurfacing functions:

(1) Pavement removal down to the subgrade of old pavement will allow the existing pavement to be used again. Removed asphalt may be used on secondary roads, recycled through a processing plant for incorporation into a high quality mix, or stockpiled for later use.

(2) Traffic can be maintained through the area, and at the end of the day the entire roadway can be opened to traffic.

(3) Pavement profiling of structurally sound pavements that are deteriorated on the surface will restore good, comfortable, safe riding surfaces. No further work is required, and the profiled surface is suitable for traffic immediately.

(4) Pavement removal for overlays can return the pavement to near design profile and suitable slope and curb sections can be reestablished. Washboards and tire ruts can be removed, thereby reducing the quantity of overlay material required. By planing to regain these features the full compacted base is left intact.

(5) Skid resistance and surface texture can be regained by a light high-speed pass with a cold planer. This application is especially useful at intersections, on curbs, and on bridge decks.

Summary

The recycling of old and discarded asphalt concrete is a significant technical achievement in the field of asphalt paving technology. It has been determined that a product comparable to that derived from new materials can be attained through the hot-mix recycling process. Test results relative to the asphalt flow characteristics, bituminous mixture stability, and aggregate gradation show that recycled material can meet the specifications for new materials.

Cold recycling brings the recycling option to cities and counties who need to upgrade streets but are forced to use their own equipment and labor. This method is also less expensive but still provides a good riding surface and road structure. Cold recycling can be combined with maintenance programs and will provide for road upgrading.

Heater techniques and cold planing provide inexpensive methods to upgrade a road surface without causing drainage problems or reducing curb height. Also, surface deformations can be corrected so that a uniform overlay can be placed with a minimum amount of materials.

The most significant fact is the savings obtained in energy and natural resources. The ability to reuse aggregates coupled with an approximate 75 percent savings in petroleum products should generate great interest and demand on a nationwide basis in the years ahead.

Bases

The base course of an asphalt pavement structure is the layer of material immediately beneath the binder course. It may be composed of crushed stone, crushed slag, crushed or uncrushed gravel and sand, or combinations of these materials, and may be asphaltic or nonasphaltic. However, asphaltic bases are highly advantageous and they are often more economical to build and will perform more satisfactorily than nonasphaltic bases. Some locally available materials otherwise unsuitable for use as base material may be up-graded by the addition of an asphaltic binder and serve satisfactorily as a base.

Asphalt Bases

Asphalt bases may be asphalt concrete, asphalt macadam, asphalt plant-mix or mixed-in-place.

Such asphalt bases are of superior quality as a result of the waterproofing and bonding action of the asphalt. When liquid asphalts are used in such base construction, care should be taken to insure that they are properly cured before placing the asphalt wearing surface.

Thickness and Quality Requirements for Non-Asphaltic Bases

Thickness and quality requirements for base courses depend primarily upon the volume and axle loading conditions of traffic and, to some extent, upon the quality of the material to be placed beneath. Thickness and quality requirements for these materials are outlined below.

Where in-place materials meet the requirements for base, as specified, they may be used for the base provided they are scarified, thoroughly mixed at optimum moisture content, and recompacted for the full depth required.

Detailed requirements for non-asphaltic base courses are as follows:

Light Traffic. The base course should be of material classified "Good Subbase" or better.

Compaction should be accomplished so the compacted layers do not exceed 6 inches in depth.

When a surface treatment is to be used as the asphalt pavement surface, however, the base course should be of material classified as "Medium Base" or better, meeting the compaction requirements outlined above.

The minimum thickness of non-asphaltic base should be such that the total thickness of base and pavement is not less than 5 inches. Where the required total thickness of the asphalt pavement structure exceeds the 5-inch minimum thickness of such base, binder and surface courses, additional base material may be used or, if more economical, a subbase may be included to provide the required total thickness.

Medium Traffic. The base course should be of material classified as "Excellent Base."

Compaction should be accomplished so that compacted layers do not exceed 6 inches in depth.

The minimum thickness of non-asphaltic base should be such that the total thickness of base, binder, and surface courses is not less than 6 inches. When the required total thickness of the asphalt pavement structure exceeds the 6-inch minimum thickness of such base, binder, and surface courses, additional base materials may be used or, if more economical, a subbase may be included to provide the required total thickness.

Heavy Traffic. The base course should be of material classified as "Excellent Base."

Compaction should be accomplished so that compacted layers do not exceed 6 inches in depth.

The minimum thickness of non-asphaltic base should be such that the total thickness of base, binder and surface courses, is not less than 8 inches. Where the required total thickness of the asphalt pavement structure exceeds the 8-inch minimum thickness of such base, binder and surface course, additional base may be used or, if more economical, a subbase may be included to provide the required total thickness.

For parking lots to be used only by passenger cars and light trucks of 6,000-lb axle load or less, the required minimum total thickness of non-asphaltic base and asphaltic binder and surface courses may be reduced to 6 inches with compaction requirements the same as noted above.

Very Heavy Traffic. Base course should be of material classified as "Excellent Base." Compaction should be accomplished so that compacted layers do not exceed 6 inches in depth.

The minimum thickness of non-asphaltic base should be such that the total thickness of base, binder and surface courses, is not less than 10 inches. Where the required thickness of the asphalt pavement structure exceeds the 10-inch minimum thickness of base, binder, and surface courses, additional base may be used or, if more economical, a subbase may be included to provide the required total thickness.

Asphalt-Treated Bases

Where asphalt-treated bases are used, a reduction may be made in the required thickness of base, and in the overall asphalt pavement structure. One inch of high-quality asphalt base may be regarded as equivalent to 1½ inch of non-asphalt base, provided the maximum reduction in total design thickness does not exceed 15 percent or 3 inches, whichever amount is greater. Further, surface and binder thickness may be reduced by substituting asphalt-treated base of comparable strength on an inch-for-inch basis provided the surface thickness is not reduced to less than 2 inches.

Regardless of the amount of reduction, total thickness must not be less than that shown in the following Table.

Minimum Thickness Requirements for Surface, Binder and Base Courses'

Minimum Thickness in Inches

Traffic Classification	Total Asphalt Surface and Binder Course[2]	Asphalt Base Course[2]	Total Thickness Using Asphalt Base	Non-Asphalt Base Course	Total Thickness Using Non-Asphalt Base
Very Heavy	4	4	8	6	10
Heavy	3	3½	6½	5	8
Medium	3	2	5	3	6
Light	2	2	4	3	5

Surface thickness may be reduced by substituting asphalt-treated base of comparable strength on an inch-for-inch basis.

Quality and Thickness Requirements for Subbases and Improved Subgrades

Local materials are usually available near the construction site which are superior in quality to the subgrade material over which the asphalt pavement structure is to be built. These materials, however, may not meet the requirements for base course materials. Such local materials are usually available at a fraction of the cost of high-quality base materials and they may be entirely satisfactory for use in the lower portion of the asphalt pavement structure. These local materials may be used as a "subbase" and materially reduce the cost of the pavement structure.

Where an asphalt pavement structure is to be built for heavy concentrations of traffic and/or high axle loadings over a very weak subgrade, a substantial thickness of subbase may often be used. In some instances it may even be economical to consider two types of subbase material, one of quality superior to the other. In such instances, the superior quality material is placed immediately beneath the base and above the poorer quality subbase. Where two such subbases are used the upper one is usually referred to as the "subbase" and the lower may be designated as "improved subgrade." The designer must often "balance out" thicknesses of base, subbase and improved subgrade to achieve the most economical utilization of available materials.

Requirements for Subbase Materials

Having determined the required total thickness of the asphalt pavement structure and the thickness of base, binder, and surface courses, the subbase should next be considered, if suitable materials are available for this purpose. If the subbase material of the required quality is not economically available to fulfill these needs, it will be necessary to increase the base thickness as required.

Materials for the Subbase Course

Such materials must be selected with regard to their strength to support loads and, in frost areas, with regard to their susceptibility to frost action. Susceptibility to water and water vapor is equally important in all areas. In considering moisture effects, rain water, ditch water, and underground moisture seams (these sometimes found in cuts) are not as important as capillary water or condensed water vapor often trapped under pavements. The former can usually be diverted by drainage but the latter occurs almost universally even in desert regions. Generally, any granular materials which are non-frost susceptible are adequate for the subbase course, when properly drained and where granular materials are economically available, and otherwise satisfactory, except for high plasticity, consideration should be given to waterproofing and stabilization with asphalt.

Well-graded aggregate, while desirable for any course, is not essential for the subbase courses. Other limiting factors shown in this part may govern the selection of such materials. The maximum size of aggregate used in any subbase course should not exceed about ¾ the thickness of the lift. If a course made up of large, coarse aggregate containing only a small percent of fines is used over an underlying course containing plastic material, a blanket course, two to four inches thick, of stone or slag screenings or clean sand should be placed to prevent infiltration of the plastic material into the coarse aggregate of the overlying course. Since subbase materials usually come from pits of considerable irregularity, care should be taken that design tests are made on the poorest materials in the pit.

Improved Subgrade

Under conditions of heavy concentrations of traffic, high axle loadings, and very weak subgrades, it may be desirable to consider the use of an "improved subgrade" material in addition to the subbase material.

Materials for Improved Subgrade

In selecting materials for improved subgrade, a most important factor in cold climates is frost susceptibility. Generally, any non-frost susceptible material will have adequate load carrying capacity for this course. Any materials previously described as suitable for base and subbase will also be suitable for improved subgrade.

Where deep frost is a problem, fine-grained soils which have proven to be non-frost susceptible can be used in the improved subgrades, in addition to those noted above. Requirements for such materials and the depths at which they may be used on heavy-duty highways are shown below. For lighter traffic, thickness may be reduced according to traffic and local practice.

Depth	*Silt*	*Fine Sand and Silt*
Within 24" from the pavement surface, not more than	40%	45%
Between 24" and 36" from pavement surface not more than	50%	60%

Frost susceptibility is closely related to susceptibility to water. Hence either selection of materials, or treatment of materials, for resistance to the one will take care of the other.

Frost Considerations

In localities where freezing weather occurs, subbase and improved subgrade materials should be selected which are not susceptible to detrimental behavior upon freezing and thawing. Here, again, it should be recognized that the thickness design of subbase and improved subgrade materials may require some "balancing out" by the designer to utilize local materials most effectively.

Compaction

Adequate compaction of subbase, improved subgrade, and subgrade materials is essential to the satisfactory performance of the asphalt pavement structure. Compaction should normally be accomplished in layers not exceeding 6 inches in compacted depth.

Miscellaneous Design Details

The Asphalt Institute normally recommends that the base and subbase courses be placed to the full width of the roadway structure. An asphalt-paved shoulder is an excellent safety feature, and provides high lateral support which enhances the strength of the pavement proper. Increasingly, it is the practice to extend the same material used in the subbase, base, and in some cases the surface of the pavement completely across the shoulder to the ditch slope during original construction.

This permits uniform consolidation from ditch to ditch and eliminates possible settlement and infiltration of water at the pavement edge. Moreover, it greatly facilitates widening operations should they become necessary at some later date.

Of late, increasing importance has been given to full width construction because of the effect of "trench" or partial width construction in trapping water at low and level points of the grade. Such water may remain in place for weeks and months and progressively attack subgrade, base, and subbase materials and even pavement.

In order to take proper advantage of full width construction, the side slopes must be maintained free of impervious covering materials above the subbase elevation.

Shoulders

Design of shoulders depends upon volume and intensity of traffic. On heavy-duty highways, it is essential that shoulders be of ample width to accommodate the largest vehicles and strong enough to support their loads withouh deformation or ravelling. Some consider that shoulders should be surfaced with material different in texture from the pavement proper to prevent use as an additional traffic lane. Experience has shown, however, that it may be desirable to carry the same surface material completely across the shoulder. A solid painted band along the edge of the pavement proper affords sufficient demarcation of the shoulder. If rumble is desired, coarse aggregate can be rolled into the surface course of asphalt concrete on the shoulder area. If further contrast is desired it may be easily obtained by a surface treatment on the shoulder portion using colored aggregate.

Shoulder construction should not be considered a minor problem for the reason that slow-moving and standing loads such as shoulders frequently support are actually more severe on a pavement structure than fast-moving loads. This tends to compensate in part for the relative infrequency of such loads.

For exceptionally wide shoulders and where base and/or subbase materials are costly, full width construction may be uneconomical. In such cases, consideration should be given to the use of locally available, free-draining material for the shoulder construction or to the use of drains which will properly remove free water from the base and subbase courses.

Drainage and Compaction

Good drainage and thorough compaction of all elements of the asphalt pavement structure are essential features for good service. Raised median areas between dual-lane roadways should not be used because such designs normally result in poor drainage conditions. Also they hamper snow removal.

Standards for Road Repair

The following are general standards which can be applied to most types of county road repair.

Right of Way

Width of right-of-way is determined by the construction anticipated and the maintenance required to keep the road in good condition. For instance, a right of way of approximately 60 feet is needed for a 24-foot road. Considering the road, shoulders, ditch, and maintenance clearance.

Road Width

Determined by the average daily vehicle traffic (ADVT) expected.

ADVT	0-50	50-400	400p750	750-1600	1600-6000	7600
WIDTH	18'	20'	22'	22'	24'	48'

Shoulder

Determined by the ADVT and road width

Road Width	18'	20'	22'	22'	24'	48'
Shoulder Width	2'	4'	6'	8'	8'	8'

Ditches

A depth of 18 inches is considered minimum. The actual depth and construction is dependent upon the terrain and run-off expected. Construction will vary from a single "V" 18 inches deep to a more complex 2 or more feet deep.

Base

The depth of the base is determined by the anticipated axle load of vehicles using the road as found in the engineers' road design manual. Construction is of Soil-Asphalt where possible. Coarse or fine aggregate is used otherwise.

Surface

Bituminous Asphalt is applied over a Soil-Asphalt base and Asphalt. Concrete over an aggregate base.

References

Books, Papers, Manuscripts

The Asphalt Institute, *The Asphalt Handbook,* College Park, Maryland.

The Asphalt Institute, *Asphalt in Pavement Maintenance,* Manual No. 16 (MS-16)

CMI Corporation, *Roto-Mill-Research Pays,* Oklahoma City, Oklahoma.

Federal Highway Administration, *Recycled Asphalt Concrete,* 75-5 Implementation Package, July 1975.

Godwin, Lenford N., "Slurry Seal Surface Treatments," *Instruction Report S-75-1,* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, June 1975.

Gore, Bill, "Heater-Scarifier Rejuvenator Cut Cost of Pavement Overlays," *Rural and Urban Roads,* October 1975.

Iowa Department of Transportation, *An Evaluation of the Roto-Mill Profiler on Concrete Pavement in Iowa, Special Report,* Division of Highways, Office of Materials, November 1976.

Jim Jackson Contractor, Inc., *Heater-Planing, Heater-Scarifying,* Little Rock, Arkansas.

National Association of Countries Research Foundation, *Blading Aggregate Surfaces,* NACE Training Guide Series, 1974.

Odier, L., Milliard, R. S., dos Santos, Pimentel, and Mehra, S. R., *Low Cost Roads,* Butterworth and Company, Ltd., London, 1967.

Pettibone, *Asphalt Recycling Program,* Texas Corporation.

Rural and Urban Roads, "Pavement Planning Speeds Up Milwaukee's Resurfacing Program," December 1976, pp. 38-39.

Young, R. T., Province, R. J., and Fiock, E. F., *Bituminous Slurry Surface Handbook,* Slurry Seal, Inc., Waco, Texas, 1973.

Organizations

American Road Builders' Association, 525 School Street, N.W., Washington, D.C. 20024

Angleo Beneditti, Inc., Heater-Scarifier Contractor, Cleveland, Ohio

The Asphalt Institute, College Park, Maryland 20746

Diamond Salt Company, St. Clair, Michigan 48079

Dow Chemical Company, Albert Road Building, Medland, Michigan 48640

The International Slurry Seal Association (ISSA), 1730 Pennsylvania Avenue, N.W., Suite 1150, Washington, D.C. 20006

Michigan Chemical Corporation, 500 N. Bankston Street, St. Louis, Michigan 48880

Morton Salt Company, 110 N. Wacker Drive, Chicago, Illinois 60606

Portland Cement Association, Old Orchard Road, Skokie, Illinois 60076

Poz-O-Pac Company, (G & W Corson, Inc., Parent Company), Plymouth Meeting, Pennsylvania 19462

Solvary Process Division of Allied Chemical Corporation, Box 1139R, Morrison, New Jersey 07960