Transportation Depth Topics

School of PE

Supplemental Notes

Code: CITESN-D **Spring 2015**

The NCEES list of Transportation design standards includes the AASHTO *Highway Safety Manual*, (HSM), 1st edition, Vol. 1, 2010 (for the April 2015 Civil PE Exam), and the NCEES Transportation depth exam specifications indicates the possibility of questions about *Accident Analysis* and *Highway Safety Analysis*. While the AASHTO HSM is an excellent resource, it is not the only source of information about these topics. The U.S. Department of Transportation, Federal Highway Administration (FHWA) has an extensive series of on-line articles about highway safety that provide guidance on these topics at no cost. The following notes are from several of these on-line sources.

http://safety.fhwa.dot.gov/intersection/resources/fhwasa09027/
http://safety.fhwa.dot.gov/intersection/resources/fhwasa09027/resources/Intersection%20Safety%20Issue%20Brief%2012.pdf
http://safety.fhwa.dot.gov/hsip/resources/fhwasa09029/sec3.cfm

Driving

In transportation, driver error is a significant contributing factor in most crashes. For example, drivers can make errors of judgment concerning closing speed, gap acceptance, curve negotiation, and appropriate speeds to approach intersections. In-vehicle and roadway distractions, driver inattentiveness, and driver weariness can lead to errors. A driver can also be overloaded by the information processing required to carry out multiple tasks simultaneously, which may lead to error. To reduce their information load, drivers rely on a priori knowledge, based on learned patterns of response; therefore, they are more likely to make mistakes when their expectations are not met. In addition to unintentional errors, drivers sometimes deliberately violate traffic control devices and laws.

Driving Task Model

Driving comprises many sub-tasks, some of which must be performed simultaneously. The three major sub-tasks are:

- **Control** – Keeping the vehicle at a desired speed and heading within the lane.
- **Guidance** – Interacting with other vehicles (following, passing, merging, etc.) by maintaining a safe following distance and by following markings, traffic control signs, and signals; and,
- **Navigation** Following a path from origin to destination by reading guide signs and using landmarks.

Figure 1 Driving Task Hierarchy (1)

Each of these major sub-tasks involves observing different information sources and various levels of decision making. The relationship between the sub-tasks can be illustrated in a hierarchical form, as shown in Figure 1. The hierarchical relationship is based on the complexity and primacy of each subtask to the overall driving task. The navigation task is the most complex of the subtasks, while eh control sub-task forms the basis for conducting the other driving tasks.

Collision Diagrams

The purpose of a collision diagram is to provide a graphical representation of crashes at a particular location within a given time period. A collision diagram indicates the crash type, severity, speed, light conditions, and road conditions for each individual crash report. After a collision diagram is drawn, one may be able to identify potential problem areas with the location through reoccurring patterns.

Collision Diagrams are just one of the many tools used to help develop a better understanding of the areas that may need to be looked at for a particular location Base mapping is one of the more critical parts of a collision diagram.

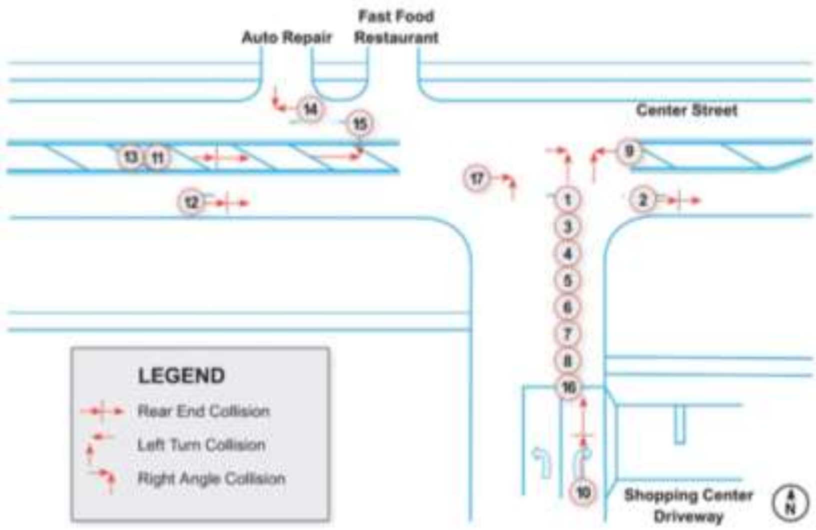

Figure 2. Example of an Intersection Collision Diagram (2)

A collision diagram simplifies the visualization of crash patterns. Crash clusters or particular patterns of crashes by collision type (e.g., rear-end collisions on a particular intersection approach) may become evident on the crash diagram that were otherwise overlooked.

As shown in Figure 2, crashes are represented on a collision diagram by arrows that indicate the type of crash and the direction of travel. Additional information associated with each crash is also provided net to each symbol. The additional information can be crash statistics, but often includes some combination (or all of) severity, date, time of day, pavement condition, and light condition. A legend indicates the meaning of the symbols, the site location, and occasionally other site summary information.

The collision diagram can be drawn by hand or developed using software. It does not need to be drawn to scale. It is beneficial to use a standard set of symbols for different crash types to simplify review and assessment. Example arrow symbols for different crash types are shown in Figure 3. These can be found in any safety textbooks and state transportation agency procedures.

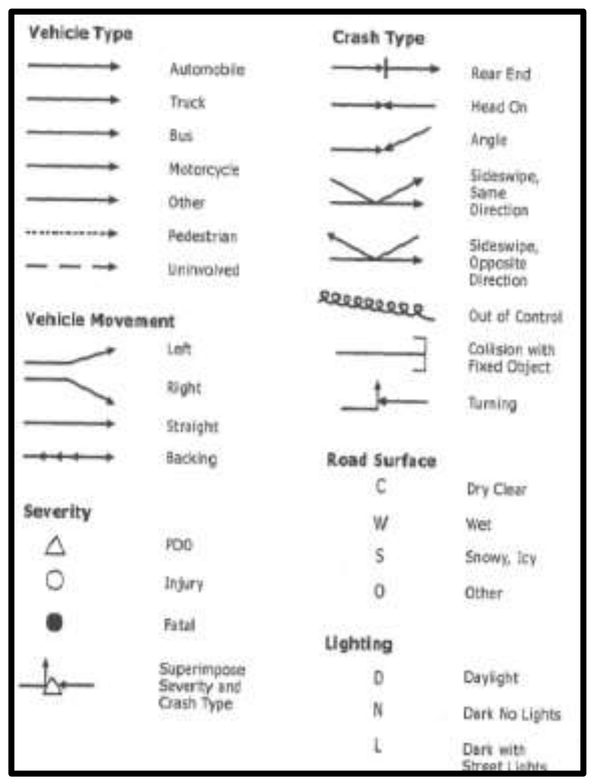

Figure 3. Example Collision Diagram Symbols (3)

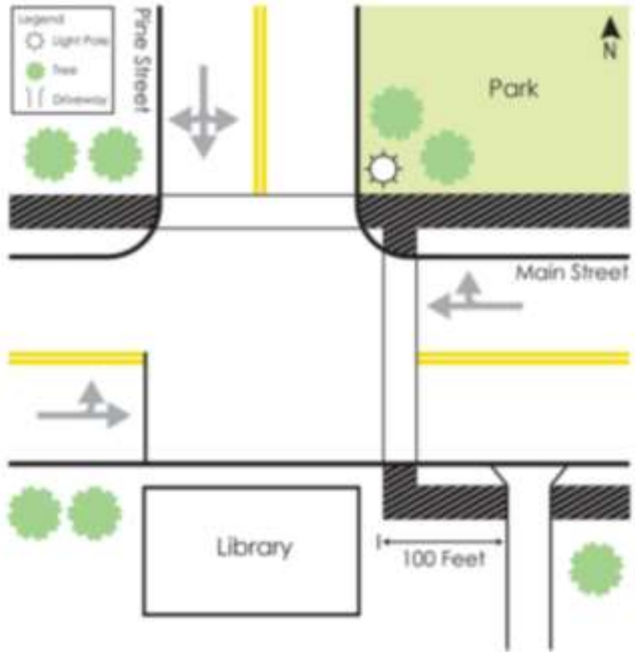

Figure 4. Example Condition Diagram (2)

Condition Diagram

A condition diagram is a plan view drawing of as may site characteristics as possible. Characteristics that can be included in the diagram are:

Roadway

- Lane configurations and traffic control;
- Pedestrian, bicycle, and transit facilities in the vicinity of the site;
- Presence of roadway medians;
- Landscaping; (possibly overgrown shrubs that could block sight lines.)
- Shoulder or type of curb and cutter; and,
- Locations of utilities (e.g., fire hydrants, light poles, telephone poles).
-

Land Uses

- Type of adjacent land uses (e.g., school, retail, commercial, residential) and;
- Driveway access points serving these land uses
- Pavement Condition
- Locations of pot holes, ponding, or ruts.
-

The purpose of the condition diagram is to develop a visual site overview that can be related to the collision diagram's findings. Conceptually, the two diagrams could be overlaid to further relate crashes to the roadway conditions.

Figure 4 provides an example of a condition diagram; the content displayed will change for each site depending on the site characteristics that may contribute to crash occurrence. The condition diagram is developed by hand during the field investigation and can be transcribed into an electronic diagram if needed. The diagram does not have to be drawn to scale.

The KABCO (4) scale is a measure of the functional injury level of the victim at the crash scene. The codes are selected based on the on-site judgment of the investigating police officer completing the crash report. "KABCO" injury scale also can be used for establishing crash costs. This scale was developed by the National Safety Council (NSC) and is frequently used by law enforcement for classifying injuries:

- **K –** Fatal;
- **A –** Incapacitating injury;
- **B –** Non Incapacitating injury;
- **C –** Possible injury;
- **O –** No injury Property Damage Only

Crash costs by severity level were estimated as part of the development of the HSM. These costs were developed based on the KABCO scale and are shown in Table 4.2. If a state has not developed their own crash costs, these costs could be used to calculate safety benefits.

Table 4.2 Crash Costs by Injury Severity Level

Injury Severity Level	Human Capital Crash Cost	Comprehensive Crash
Fatality (K)	$1,245,600	$4,008,900
Disabling Injury (A)	$111,400	$216,000
Evident Injury (B)	$41,900	$79,000
Fatal/Injury (K/A/B)		$158,200
Possible Injury (C)	$28,400	$44,900
PDO (O)	$6,400	$7,400

Source: Highway Safety Manual, First Edition, Draft 3.1, April 2009. (5)

Human capital crash cost estimates include the monetary losses associated with medical care, emergency services, property damage, and lost productivity.

Comprehensive Crash Costs include the human capital costs in addition to nonmonetary costs related to the reduction in the quality of life in order to capture a more accurate level of the burden of injury. Comprehensive costs are also generally used in analysis conducted by other federal and state agencies outside of transportation.

CRASH MODIFICATION FACTOR (CMF)
See HSM Page 3-19

Crash Modification Factor (CMF) is a measure of the safety effectiveness of a particular treatment or design element.

$$CMF = \frac{\text{Estimated Crashes WITH Treatment}}{\text{Estimated Crashes WITHOUT Treatment}}$$

$$CMF = \frac{\text{Expected Average Crash Frequency with Site Condition b}}{\text{Expected Average Crash Frequency with Site Condition a}}$$

NOTE – Site Condition ‘a’ is before the treatment and Site Condition ‘b’ is after the treatment.

A CMF less than 1.0 indicates a treatment has the potential to reduce crashes.

Interpretation Example – A CMF for total crashes for improving the pavement conditions on a rural road has been estimated to be 0.89. This CMF indicates that the frequency of total crashes with the treatment is estimated to be 89% of the estimated crashes without the treatment. In other words, the CMF indicates that there will be a 11 percent reduction in total estimated crash frequency for this road.

Problem 1
Estimated crashes for an existing four-way stopped intersection are to be 18 crashes per year. One of the alternate is considered replacing the four-way stopped intersection with a modern roundabout. The CMF for converting the four-way stopped intersection to a modern roundabout is 0.64. How many crashes are estimated with a modern roundabout?

Solution 1
Estimated Crashes with Modern Roundabout = CMF * Estimated Crashes with Four-way Stopped Intersection = 0.64 * 18 = 11.52 crashes per year

Problem 2
The current four-leg signalized intersection is estimated to have 8.4 crashes per year. Two types of treatments are proposed for this intersection. One treatment is including left turn lanes on the major street which is expected to result in CMF of 0.77. Second treatment is permitting right-turn-on-red which is expected to result in CMF of 1.08. It is assumed that the effects of these both treatments are independent on each other. How many crashes are estimated if both of these treatments are implemented?

Solution 2
NOTE – We have to multiply both CMF

Estimated Crashes with Both Treatments = 0.77 * 1.08 * 8.4 = 7 crashes per year.

Bibliography

(1) Report No. FHWA-TO-86-1 *Driver Expectancy in Highway Design and Traffic Operations* May 1986 http://ntl.bts.gov/lib/32000/32500/32510/FHWA-TO-86-1
(2) Improving Safety on Rural Local and Tribal Lands, Safety Toolkit, August 2014, USDOT, FHWA http://safety.fhwa.dot.gov/local_rural/training/fhwasa14072/isrltrst.pdf
(3) AASHTO Highway Safety Manual, 1st edition, 2010
(4) UmassSafe Traffic Safety Research Program, University of Massachusetts, Amherst, MA www.ecs.umass.edu/umasssafe/CODES%20WEBSITE/lane_Departure_FactSheet.pdf

http://safety.fhwa.dot.gov/tools/crf/resources/cmfs/docs/management.pdf

http://www.notesgen.com/upload_file/files/uploads/F2178F31-81F8-4248-83D2-1D2067CA80E2.pdf

Exercises

1. The intended outcome of a *diagnosis* is which of the following:
   A The identification of causes of the collisions and potential safety concerns or crash patterns that can be evaluated further.
   B A review of a transportation network that identifies and ranks sites from most likely to least likely to realize a reduction in crash frequency with implementation of a countermeasure.
   C The identification of countermeasures to reduce crash frequency or severity as specific sites.
   D An assessment of how crash frequency or severity has changed due to a specific treatment or a set of treatments or projects.

2. What is the approximate Comprehensive Crash Cost of an *Evident Injury*?
   A $10,000 to $30,000
   B $30,000 to $65,000
   C $65,000 to $150,000
   D $150,000 to $260,000

3. What is the Human Capital Crash Cost of a Head-on Collision at a Non-Intersection location?
   A $81,000 to $90,000
   B $91,000 to $100,000
   C $101,000 to $110,000
   D $111,000 to $130,000

4. The three major subtasks performed by drivers include which of the following?
   A Communication, Control, and Maneuvering
   B Guidance, Navigation, and Control
   C Guidance, Communication, and Control
   D Communication, Guidance, and Navigation

5. Which of the following is probably NOT a contributing factor to a Right-angle collision at a signalized intersection?
   A Narrow Lanes
   B Inadequate signal timing
   C Excessive speeds
   D Drivers running red light

6. Which of the following is probably NOT a contributing factor to a Rear-end collision at an unsignalized intersection?
   A High Approach Speed
   B Inadequate gaps in traffic
   C Excessive speeds
   D Large Number of Turning Vehicles

7. What type of crash would you expect on a roadway segment that has the following contributing factors: inadequate lane width, inadequate median width, poor delineation, and inadequate shoulder width?
   A Vehicle rollover
   B Rear-end
   C Opposite-direction sideswipe or head-on
   D Run-off-the-road

8. What type of crash would you expect at a signalized intersection that has the following contributing factors: inadequate signal timing, pedestrian or bicycle conflicts, conflict with right-turn-on red vehicles?
   A Nighttime
   B Rear-end or sideswipe
   C Left- or right-turn movement
   D Right-angle

9. On the KABCO scale, what does a "K" code represent?

   A Fatality
   B Incapacitating Injury
   C Possible Injury
   D Property Damage Only

The Pavement Evaluation & Maintenance Primer identifies common types of pavement distress, their causes, and remedies.

Five Primary Causes of Pavement Deterioration

1. **Traffic Loading.** This is the single most important consideration. Pavement performance is most directly affected by the load magnitude, configuration and number of heavy vehicle load applications. Load applications are measured in terms of 18,000 lb Equivalent Single Axle Load (ESAL). A pavement is designed to withstand a certain number of ESALs over its design life.

2. **Moisture.** Moisture can significantly weaken the support strength of natural gravel materials, especially the subgrade. Moisture can enter the pavement structure through cracks and holes in the surface, laterally through the subgrade, and from the underlying water table through capillary action. The result of moisture ingress is the lubrication of particles, loss of particle interlock and subsequent particle displacement resulting in pavement failure.

3. **Quality of Materials and Construction.** The actions taken during construction are crucial to the long-term performance of the pavement. Proper compaction and moisture content must be achieved during construction. In addition the quality of materials, and accurate layer thickness (after compaction) all directly affect pavement performance. These conditions stress the need for skilled workmanship and the importance of good inspection and quality control procedures during construction.

4. **Maintenance.** Pavement performance depends on what, when, and how maintenance is performed. No matter how well the pavement is built, it will deteriorate over time based upon the mentioned factors. The timing of maintenance is very important, if a pavement is permitted to deteriorate to a very poor condition, as illustrated by point B in Error! Reference source not found. then the added life compared with point A, is typically about 2 to 3 years. This added life would present about 10 percent of the total life. The cost however of repairing the road at point B is minimum four times the cost if the road had been repaired at point A. The postponement of maintenance hold further implications, in that for the cost of repairing one badly deteriorated road (Point B), four roads at point A would have to be deferred, which would mean that in a few years the rehabilitation cost could be 16 times as much. Thus, postpone

5. **Subgrade.** The subgrade is the underlying soil that supports the applied wheel loads. If the subgrade is too weak to support the wheel loads, the pavement will flex excessively which ultimately causes the pavement to fail. If natural variations in the composition of the subgrade are not adequately addressed by the pavement design, significant differences in pavement performance will be experienced.

Asphalt Pavement Deterioration Categories.

Pavement deterioration is the process by which distress (defects) develop in the pavement under the combined effects of traffic loading and environmental conditions. There are five major categories of pavement deterioration.

- **A.** Surface defects
- **B.** Surface deformation
- **C.** Cracking
- **D.** Disintegration
- **E.** Miscellaneous Distresses

A. Surface defects: Surface defects are related to problems in the surface layer. The most common types of surface distress are:

1. Raveling
2. Bleeding
3. Polishing
4. Delamination

1. **Raveling:** Raveling is the loss of material from the pavement surface. It is a result of insufficient adhesion between the asphalt cement and the aggregate. Initially, fine aggregate breaks loose and leaves small, rough patches in the surface of the pavement. As the disintegration continues, larger aggregate breaks loose, leaving rougher surfaces. Raveling can be accelerated by traffic and freezing weather. Some raveling in chip seals is due to improper construction technique. This can also lead to bleeding. Repair the problem with a wearing course or an overlay.

2. **Bleeding:** Bleeding (or flushing) is defined as the presence of a film of excess asphalt on the road surface which creates patches of asphalt cement. It usually creates a shiny, glass-like reflecting surface (as in the first photo) that can become quite sticky. Excessive asphalt cement reduces the skid-resistance of a pavement, and it can become very slippery when wet, creating a safety hazard. This is caused by an excessively high asphalt cement content in the mix, using an asphalt cement with too low a viscosity (too flowable), too heavy a prime or tack coat, or an improperly applied seal coat. Bleeding occurs more often in hot weather when the asphalt cement is less viscous (more flowable) and the traffic forces the asphalt to the surface. Excessive asphalt binder can cause HMA bleeding.

Possible Causes. Bleeding occurs when asphalt binder fills the aggregate voids during hot weather and then expands onto the pavement surface. Since bleeding is not reversible during cold weather, asphalt binder will accumulate on the pavement surface over time. This can be caused by one or a combination of the following:

- Excessive asphalt binder in the HMA (either due to mix design or manufacturing)
- Excessive application of asphalt binder during BST application (as in the above figures)
- Low HMA air void content (e.g., not enough room for the asphalt to expand into during hot weather)

The following repair measures may eliminate or reduce bleeding, but may not correct the underlying problem that caused it:

- Minor bleeding can often be corrected by applying coarse sand to blot up the excess asphalt binder.

Major bleeding can be corrected by cutting off excess asphalt with a motor grader or removing it with a heater planer. If the resulting surface is excessively rough, resurfacing may be necessary.

3. **Polishing:** Polishing is the wearing of aggregate on the pavement surface due to traffic. It can result in a dangerous low friction surface. A thin wearing course will repair the surface.

4. **Delamination.** Delamination is the discrete loss of the wearing course layer. There is usually a clear delineation of the wearing course asphalt and the course below. Possible causes of delamination include
   - Surface asphalt layer is too thin in relation to asphalt mix size. Inadequate cleaning or inadequate tack coat before placement of upper layers.
   - Seepage of water through asphalt to break bond between surface and lower courses.
   - Underlying surface is highly polished, or has a new or heavy application of line marking.

   If the delaminated surface layer is on a previously sealed surface, remove remaining unstable areas, clean exposed surface, tack coat and replace with an appropriate asphalt mix. (If unsealed, apply prime or primerseal.)

   Unstable areas should be removed, cleaned, tack coated and replaced. Consider crack sealing for other areas

B. Surface deformation: Pavement deformation is the result of weakness in one or more layers of the pavement that has experienced movement after construction. The deformation may be accompanied by cracking. Surface distortions can be a traffic hazard. The basic types of surface deformation are:

1. Rutting
2. Corrugations
3. Shoving
4. Depressions
5. Swell

1. **Rutting.** Rutting (or "channelization") is the displacement of pavement material that creates channels in the wheel path. Very severe rutting will actually hold water in the rut. There are four types of rutting:

   - Mechanical deformation or subgrade displacement of the asphalt pavement
   - Plastic deformation of the asphalt mixtures near the pavement surface
   - Consolidation or the continued compaction under the action of traffic
   - Surface wear, the actual wearing away of surface particles by traffic

   Rutting is usually a failure in one or more layers in the pavement. Rutting occurs at high-stress locations (i.e., intersections, grades, any places where heavy vehicles stop, start, turn or climb steep grades). The width of the rut is a sign of which layer has failed. A very narrow rut is usually a surface failure, while a wide one is indicative of a subgrade failure. Inadequate compaction can lead to rutting. Rutting can be due to subgrade Failure. Minor surface rutting can be filled with micropaving or paver-placed surface treatments. Deeper ruts may be shimmed with a truing and leveling course, with an overlay placed over the shim. If the surface asphalt is unstable, recycling of the surface may be the best option. If the problem is in the subgrade layer, reclamation or reconstruction may be needed.

2. **Corrugation.** Corrugation is referred to as wash boarding because the pavement surface has become distorted like a washboard. The instability of the asphalt concrete surface course may be caused by too much asphalt cement, too much fine aggregate, or rounded or smooth textured coarse aggregate. Corrugations usually occur at places where vehicles accelerate or decelerate. Minor corrugations can be repaired with an overlay or surface milling. Severe corrugations require a deeper milling before resurfacing.

3. **Shoving** Shoving is a permanent, longitudinal displacement of a localized area of the pavement surface caused by traffic loading. When traffic pushes against the pavement, it produces a short, abrupt wave in the pavement surface. This distress normally occurs only in unstable liquid asphalt mix (cutback or emulsion) pavements. Locations and causes of shoving are similar to those for corrugations. Shoves also occur where asphalt pavement abut PCC pavements. The PCC pavements increase in length and push the asphalt pavement, causing the shoving.

   The figure shows an example of shoving. Repair minor shoving by removing and replacing. For large areas, milling the surface may be required, followed by an overlay.

4. **Depressions.** Depressions are small, localized bowl-shaped areas that may include cracking. Depressions cause roughness, are a hazard to motorists, and allow water to collect, causing hydroplaning. Depressions are typically caused by localized consolidation or movement of the supporting layers beneath the surface course due to instability. Repair by excavating and rebuilding the localized depressions. Reconstruction is required for extensive depressions.

5. **Swell** A swell is a localized upward bulge on the pavement surface. Swells are caused by an expansion of the supporting layers beneath the surface course or the subgrade. The expansion is typically caused by frost heaving or by moisture. Subgrades with highly plastic clays can swell in a manner similar to frost heaves (but usually in warmer months). Repair swells by excavating the inferior subgrade material and rebuilding the removed area. Reconstruction may be required for extensive swelling.

C. Cracking: The most common types of cracking are:

1. Fatigue cracking
2. Longitudinal cracking
3. Transverse cracking
4. Block cracking
5. Slippage cracking
6. Reflective cracking
7. Edge cracking

1. Fatigue cracking (Alligator or Crocodile cracking): Fatigue cracking is commonly called alligator cracking. This is a series of interconnected cracks creating small, irregular shaped pieces of pavement. It is caused by failure of the surface layer or base due to repeated traffic loading (fatigue). Eventually the cracks lead to disintegration of the surface, as shown in Figure. The final result is potholes. Alligator cracking is usually associated with base or drainage problems. Poor drainage in the road bed is a frequent cause of this degradation of the base or subgrade. A heavy spring thaw, similarly to poor drainage, can weaken the base course, leading to crocodile cracking. Small areas may be fixed with a patch or area repair. Larger areas require reclamation or reconstruction. Drainage must be carefully examined in all cases.

2. **Longitudinal cracking:** Longitudinal cracks are long cracks that run parallel to the center line of the roadway. These may be caused by frost heaving or joint failures, or they may be load induced. Understanding the cause is critical to selecting the proper repair. Multiple parallel cracks may eventually form from the initial crack. This phenomenon, known as deterioration, is usually a sign that crack repairs are not the proper solution.

3. **Transverse cracking :** Transverse cracks form at approximately right angles to the centerline of the roadway. They are regularly spaced and have some of the same causes as longitudinal cracks. Transverse cracks will initially be widely spaced (over 20 feet apart). They usually begin as hairline or very narrow cracks and widen with age. If not properly sealed and maintained, secondary or multiple cracks develop, parallel to the initial crack. The reasons for transverse cracking, and the repairs, are similar to those for longitudinal cracking. In addition, thermal issues can lead to low-temperature cracking if the asphalt cement is too hard. Figure shows a low-severity transverse crack.

4. **Block cracking:** Block cracking is an interconnected series of cracks that divides the pavement into irregular pieces. This is sometimes the result of transverse and longitudinal cracks intersecting. They can also be due to lack of compaction during construction. Low severity block cracking may be repaired by a thin wearing course. As the cracking gets more severe, overlays and recycling may be needed. If base problems are found, reclamation or reconstruction may be needed. Figure shows medium to high severity block cracking.

5. **Slippage cracking:** Slippage cracks are half-moon shaped cracks with both ends pointed towards the oncoming vehicles. They are created by the horizontal forces from traffic. They are usually a result of poor bonding between the asphalt surface layer and the layer below. The lack of a tack coat is a prime factor in many cases. Repair requires removal of the slipped area and repaving. Be sure to use a tack coat in the new pavement.

6. **Reflective cracking:** Reflective cracking occurs when a pavement is overlaid with hot mix asphalt concrete and cracks reflect up through the new surface. It is called reflective cracking because it reflects the crack pattern of the pavement structure below. As expected from the name, reflective cracks are actually covered over cracks reappearing in the surface. They can be repaired in similar techniques to the other cracking noted above. Before placing any overlays or wearing courses, cracks should be properly repaired.

7. **Edge cracking** is the formation of crescent-shaped cracks near the edge of a road. It is caused by lack of support of the road edge, sometimes due to poorly drained or weak shoulders. If left untreated, additional cracks will form until it resembles crocodile cracking. Like wheel-path crocodile cracking, poor drainage is a main cause of edge cracking, as it weakens the base, which hastens the deterioration of the pavement. Water ponding (a buildup of water which can also be called puddling) happens more frequently near the edge than in the center of the road path, as roads are usually sloped to prevent in-lane ponding. This leads to excess moisture in the shoulders and subbase at the road edge. Edge cracking differs from crocodile cracking in that the cracks form from the top down, where crocodile cracks usually start at the bottom and propagate to the surface. At low severity the cracks may be filled. As the severity increases, patches and replacement of distressed areas may be needed. In all cases, excess moisture should be eliminated, and the shoulders rebuilt with good materials.

D. Disintegration The progressive breaking up of the pavement into small, loose pieces is called disintegration. If the isintegration is not repaired in its early stages, complete reconstruction of the pavement may be needed. The two most common types of disintegration are:

1. Potholes
2. Patches

1. **Potholes.** Potholes are bowl-shaped holes similar to depressions. They are a progressive failure. First, small fragments of the top layer are dislodged. Over time, the distress will progress downward into the lower layers of the pavement. Potholes are often located in areas of poor drainage, as seen in Figure. Potholes are formed when the pavement disintegrates under traffic loading, due to inadequate strength in one or more layers of the pavement, usually accompanied by the presence of water. Most potholes would not occur if the root cause was repaired before development of the pothole. Repair by excavating and rebuilding. Area repairs or reconstruction may be required for extensive potholes.

2. **Patches:** A patch is defined as a portion of the pavement that has been removed and replaced. Patches are usually used to repair defects in a pavement or to cover a utility trench. Patch failure can lead to a more widespread failure of the surrounding pavement. Some people do not consider patches as a pavement defect. While this should be true for high quality patches as is done in a semipermanent patch, the throw and roll patch is just a cover. The underlying cause is still under the pothole. To repair a patch, a semi-permanent patch should be placed. Extensive potholes may lead to area repairs or reclamation. Reconstruction is only needed if base problems are the root source of the potholes.

E. Miscellaneous Distresses

1. Lane-to-Shoulder Drop-off
2. Water Bleeding and Pumping
3. Stripping or raveling

1. **Lane-to-Shoulder Drop-off.** Lane-shoulder drop-off is a difference in elevation between the pavement edge and the shoulder. This drop-off most often occurs when the materials in the traveled lane and shoulder are different (i.e., concrete lane and asphalt shoulder, or concrete/asphalt lane and aggregate shoulder). This distress is usually caused by shoulder erosion or shoulder settlement due to inadequate compaction during construction. Lane-shoulder drop-offs of two inches or even lower can cause vehicular loss of control and lead to accidents.

2. **Water Bleeding and Pumping.** Water bleeding occurs when water seeps out of joints or cracks or through an excessively porous HMA layer. Pumping occurs when water and fine material is ejected from underlying layers through cracks in the HMA layer under moving loads. In some cases it is detectable by deposits of fine material left on the pavement surface, which were eroded (pumped) from the support layers and have stained the surface. Water bleeding and pumping results in decreased skid resistance, an indication of high pavement porosity (water bleeding), decreased structural support (pumping).

   There are several possible causes of water bleeding and pumping, including:
   - Porous pavement due to inadequate compaction or poor mix design
   - High water table
   - Poor drainage

   Repairing this condition requires determination of its root cause. If the problem is a high water table or poor drainage, subgrade drainage should be improved. If the problem is a porous mix (in the case of water bleeding) a fog seal or slurry seal may be applied to limit water infiltration.

3. **Stripping or Raveling.** *Stripping* or *raveling* is another possible cause of crocodile cracking. Stripping occurs when poor adhesion between asphalt and aggregate allows the aggregate at the surface to dislodge. The loss of bond between aggregates and asphalt binder that typically begins at the bottom of the HMA layer and progresses upward. When stripping begins at the surface and progresses downward it is usually called raveling. If left uncorrected, this reduces the thickness of the pavement, reducing the affected portion's ability to carry its designed loading. This can cause crocodile

cracking to develop rapidly, as overloading will happen with loads of less magnitude or frequency. It can also cause rutting, shoving/corrugations. Bottom-up stripping is very difficult to recognize because it manifests itself on the pavement surface as other forms of distress including rutting, shoving/corrugations, raveling, or cracking. Typically, a core must be taken to positively identify stripping as a pavement distress.

The root causes of stripping or raveling may include:

- Poor aggregate surface chemistry
- Water in the HMA causing moisture damage
- Overlays over an existing open-graded surface course.

  A stripped pavement should be investigated to determine the root cause of failure (i.e., how did the moisture get in?). Generally, the stripped pavement needs to be removed and replaced after correction of any subsurface drainage issues.

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http://www.fhwa.dot.gov/pavement/pub_details.cfm?id=91

FAA Pavement Management System for Airports
FAA PAVEAIR is a public, web-based application designed to assist organizations in the evaluation, management, and maintenance of airport pavements.
https://faapaveair.faa.gov/Default.aspx

Pavement Distress Identification Manual for the NPS Road Inventory Program http://www.wistrans.org/mrutc/files/Distress-ID-Manual.pdf

Common Distresses on Flexible Pavements
Maintenance Technical Advisory Guide (MTAG) Caltrans

http://www.dot.ca.gov/hq/maint/MTAG-CommonFlexiblePavementDistresses.pdf

1. Which of the following is NOT one of the five primary causes of pavement deterioration?
   A Traffic Loading
   B Construction Quality and Materials
   C Moisture
   D Maintenance
   E Superelevation

2. Which of the following types of pavement deterioration is the result of insufficient adhesion between the asphalt cement and aggregate?
   A Bleeding
   B Reflective cracking
   C Raveling
   D Shoving

3. What is the name of the condition that is caused by an excessively high asphalt cement content in the mix, using an asphalt cement that is too flowable, too heavy a prime or tack coat, or an improperly applied seal coat
   A Bleeding
   B Reflective cracking
   C Raveling
   D Shoving

4. Why is pavement polishing undesirable?
   A Problems created by people stopping along the road to steal chunks of the pavement.
   B Polishing causes pavement slabs to crack.
   C Loss of surface friction is a safety concern.
   D Pavement slabs becomes too thin, crack, break-up, make a mess.

5. Which of the following pavement conditions is also known as, “washboarding”?
   A shoving
   B pushing
   C corrugation
   D rutting

6. What is often a prime cause of slippage cracking?
   - A Not enough tack coat,
   - B Too much asphalt in mix.
   - C Traffic wearing away the pavement surface.
   - D Drastic temperature change.

7. Which of the following is the most likely NOT the cause of channelization?
   - A Hydroplaning.
   - B Mechanical deformation.
   - C Plastic deformation of the asphalt mixtures near the pavement surface
   - D Consolidation.

8. Which of the following conditions could be caused by rounded or smooth textured coarse aggregate?
   - A swell
   - B block cracking
   - C corrugation
   - D crocodile cracking

9. What causes pavement depression?
   - A Too much traffic.
   - B hydroplaning
   - C Localized consolidation beneath the surface course.
   - D Braking from high speeds.

10. What is the name of the condition caused by the loss of bond between aggregates and asphalt binder that typically begins at the bottom of the HMA layer and progresses upward?
    - A stripping
    - B rutting
    - C shoving
    - D corrugations

11. Which of the following is a result of inadequate shoulder compaction during construction?
    - A hydroplaning
    - B lane to shoulder drop-off
    - C alligator cracking
    - D edge cracking

12. Which of the following is NOT a likely cause of delamination?
    - A Highly polished underlying pavement surface?
    - B Water seepage
    - C Insufficient tack coat
    - D Surface layer is too thick

13. Excess asphalt binder in the HMA is a possible cause for which of the following conditions?
    - A Delamination
    - B Swelling
    - C Flushing
    - D Bleeding

ADA Design Considerations Primer

Based on 2010 ADA Standards & AASHTO Green Book 2011 Edition

The Department of Justice published revised regulations for Titles II and III of the Americans with Disabilities Act of 1990 "ADA" on September 15, 2010. The 2010 ADA Standards are available on-line at:
http://www.ada.gov/regs2010/2010ADAStandards/2010ADAstandards.htm

1. The ADA Standards specify that the maximum ramp slope shall not be steeper than 1:12. However, the ADA standards make an exception for existing sites, buildings, and facilities.

   Suppose you are renovating a sixty year-old theater and need to install an accessible ramp that will rise 5 inches. You need to complete the ramp in one continuous run with no landing. What is the maximum slope you can use in this case?

   A 1:12
   B 1:11
   C 1:10
   D 1:9
   E 1:8

2. What is the preferred minimum width of a median and island "cut-through"?
   A 4'-0"
   B 5'-0"
   C 6'-0"
   D 6'-6"

3. What is the preferred minimum width of a median refuge area?
   A 4'-0"
   B 5'-0"
   C 6'-0"
   D 6'-6"

4. The cross slope of ramp runs shall not be steeper than _____.
   A 1:10
   B 1:12
   C 1:24
   D 1:48

5. What is the maximum rise of a ramp run?
   A 2'-0"
   B 2'-6"
   C 3'-0"
   D 3'-6"

6. What is the minimum length of a ramp landing?
   A 5'-0"
   B 5'-6"
   C 6'-0"
   D 5'-6"

7. Suppose you are building a new school. What is the minimum total length of a proposed ramp structure (including all ramp runs and ramp landings) required for a rise of 6 feet? Assume level landings are provided at top, bottom and as needed in between.
   A 80'-0"
   B 87'-0"
   C 92'-0"
   D 94'-6"

8. What is the clear width of a ramp run where handrails are provided?
   A 24"
   B 30"
   C 36"
   D 42"

9. What is the maximum cross slope (counter slope) on a roadway surface at a curb ramp?
   A 30:1
   B 25:1
   C 20:1
   D 15:1

10. What is the maximum cross slope (counter slope) on a roadway surface at a curb ramp?

A 10:1
B 15:1
C 20:1
D 25:1

See ADA Standards, Section **406.3 Sides of Curb Ramps.** Where provided, curb ramp flares shall not be steeper than 1:10. The correct answer is A.

11. What is the maximum longitudinal slope on the walking surface of an accessible route (not including ramps or curb ramps)?

A 10:1
B 15:1
C 20:1
D 25:1

12. What is the minimum width of an accessible van parking space, if an adjacent access aisle is provided?

A 88 in
B 96 in
C 124 in
D 132 in

13. What are the minimum length x width of the landing at the top of a curb ramp?

A 36" x 36"
B 36" x 48"
C 48" x 48"
D 54" x 54"

14. What is the minimum width of a curb ramp?

A 30”
B 36”
C 48”
D 54”

15. What is the maximum slope of a curb ramp?

A 4.33 percent
B 6.33 percent
C 8.33 percent
D 9.33 percent

16. What is the width of the detectable warning strip required at the bottom of curb ramps **a curb ramp?**

A 12”
B 18”
C 24”
D 30”

17. If a sidewalk is less than 1.5 m [5 ft], a passing section should be provided. In this situation, what is the maximum distance between passing sections?

A 50’
B 100’
C 150’
D 200’

18. If a planted strip is provided between sidewalk and traveled way curb, what is the minimum width planted strip that should be how wide to allow for maintenance activities?

A 0.3 m [1 ft]
B 0.6 m [2 ft]
C 0.9 m [3 ft]
D 1.2 m [4 ft]

19. Which of the following factors would NOT affect curb ramp design details?
    - A Sidewalk width
    - B Sidewalk location with respect to the curb
    - C Height and width of curb cross section
    - D Design turning radius and length of curve along the curb face
    - E Angle of street intersections
    - F Planned or existing location of sign and signal control devices
    - G Stormwater inlets and public service utilities
    - H Potential sight obstructions
    - I Thickness of pavement subbase course
    - J Street width
    - K Border width

Cross Sectional Elements Primer

Based on AASHTO Green Book 2011 Edition

The AASHTO Green Book devotes Chapter 4 to the discussion of more than 20 kinds of cross-section elements, including lanes, shoulders, curbs, clear zones, drainage channels and side slopes, medians, traffic barriers, and frontage roads. Chapter 4 contains 74 pages and 45 references to other publications. This primer includes 15 questions directly related to the material presented in Chapter 4. The purpose of this primer is to encourage candidates to become familiar with Chapter 4 so that they are well prepared to answer similar questions on the PE exam.

1. The selection of surface type is determined based on many factors. Which of the following is NOT a factor in determination of surface type?

   A Traffic volume and composition,
   B Soil characteristics,
   C Noise
   D Performance of pavements in the area,
   E Availability of materials,
   F Initial cost, overall annual maintenance cost and service-life cost.
   G All of the above are legitimate factors that affect surface type.

2. When designing a divided highway the designer must decide whether to drain the roadway surface away from the median or toward the median. Which of the following is NOT an advantage of draining away from the median?

   A May provide a savings in drainage structures.
   B Minimize drainage across the inner, higher-speed lanes.
   C Simplify treatment of intersecting streets.
   D The outer lanes, which are used by most traffic, are less free of surface water.

3. Skidding crashes are a major concern in highway safety. It is not sufficient to attribute skidding crashes merely to “driver error” or “driving too fast for existing conditions.” The roadway should provide a level of skid resistance that will accommodate the braking and steering maneuvers that can reasonably be expected for the particular site.

   Which of the following is NOT one of the main causes of poor skid resistance on wet pavements?

   A pavement rutting,
   B pavement polishing,
   C pavement bleeding,
   D pavement milling or grinding.

4. Auxiliary lanes at intersections and interchanges often help to facilitate traffic movements. Where continuous two-way left-turn lanes are provided, what is the width that provides the optimum design?

   A 3.0 m to 4.9 m [10 to 16 ft]
   B 3.4 m to 5.2 m [11 to 17 ft]
   C 3.7 m to 5.5 m [12 to 18 ft]
   D 4.0 m to 4.8 m [13 to 19 ft]

5. Desirably, a vehicle stopped on the shoulder should clear the edge of the traveled way by at least ____ m [___ ft]. (fill in the blanks)

   A 0.30 m [1.0 ft]
   B 0.45 m [1.5 ft]
   C 0.60 m [2.0 ft]
   D 0.75 m [2.5 ft]

6. If shoulders are to function effectively, they should be sufficiently stable to support occasional vehicle loads in all kinds of weather without rutting. Evidence of rutting, skidding, or vehicles being mired down, even for a brief seasonal period, may discourage and prevent the shoulder from being used as intended.

   Paved or stabilized shoulders offer numerous advantages, including:
   A provision of refuge for vehicles during emergency situations,
   B elimination of rutting and drop-off adjacent to the edge of the traveled way,
   C provision of adequate cross slope for drainage of roadway,
   D reduction of maintenance,
   E provision of lateral support for roadway base and surface course
   F provision of convenient parking areas for sleepy motorists.

7. Which of the following statements about clear zones is false?

   A The clear zone includes shoulders, bicycle lanes, and auxiliary lanes unless the auxiliary lane functions like a through lane.
   B A full-width clear zone needs to be established in all locations, regardless of whether urban or rural areas.
   C The term “clear zone” is used to designate the unobstructed, traversable area provided beyond the edge of the traveled way for the recovery of errant vehicles.
   D Basic clear zone width is determined by design speed, traffic volume, and roadside grading.

8. In an urban environment, a lateral offset to vertical obstructions (signs, utility poles, luminaire supports, fire hydrants, etc., including breakaway devices) is needed to accommodate motorists operating on the roadway and parked vehicles. This lateral offset to obstructions helps to:

   1. Avoid adverse impacts on vehicle lane position and encroachments into opposing or adjacent lanes;
   2. Improve driveway and horizontal sight distances;
   3. Reduce the travel lane encroachments from occasional parked and disabled vehicles;
   4. Improve travel lane capacity.

Which of the above statements is false?

- A None are false.
- B All are false.
- C Statements 1 and 2 are false.
- D Statements 3 and 4 are false.

9. The type and location of curbs affects driver behavior and, in turn, the safety and utility of a highway. A curb, by definition, incorporates some raised or vertical element. Curbs serve any or all of the following purposes:

- A drainage control,
- B roadway edge delineation,
- C impact attenuation,
- D delineation of pedestrian walkways,

Which of the above purposes is NOT correct?

10. Roadside ditches and channels are important drainage facilities.
    1. The use of foreslopes steeper than 1V:4H severely limits the range of backslopes.
    2. Flatter foreslopes permit greater flexibility in the selection of backslopes to permit safe traversal.
    3. Steeper foreslopes provides greater recovery distance for an errant vehicle.
    4. From a standpoint of hydraulic efficiency, the most desirable channel contains flatter sides.

Which of the above statements is false?

- A None are false.
- B All are false.
- C Statements 1 and 2 are false.
- D Statements 3 and 4 are false.

11. Development of streets or highways may include sections constructed in tunnels either to carry the streets or highways under or through a natural obstacle or to minimize the impact of the freeway on the community.

General conditions under which tunnel construction may be warranted include:

1. Narrow rights-of-way where all of the surface area is needed for street purposes;
2. Large intersection areas or a series of adjoining intersections on an irregular or diagonal street pattern;
3. Railroad yards, airport runways, or similar facilities;
4. Parks or similar land uses, existing or planned;

Which of the above statements is false?

A All are false.
B Statements 1 and 2 are false.
C Statements 3 and 4 are false.
D None are false.

12. You are designing a new tunnel for a two lane highway. The lanes are each 12-feet wide. The roadway is to have left and right shoulders, and sidewalks on each side for emergency egress. What is the desirable cross section width (face of wall to face of wall) for a two-lane tunnel?

A 9.0 m [30 ft]
B 10.0 m [33 ft]
C 10.6 m [35 ft]
D 13.4 m [44 ft]

13. A proposed park-and-ride will provide a special section for subcompact cars. The designer has designated a 400-ft long section of curb and sidewalk. The subcompact cars are to park perpendicular to the curb. What is the maximum number of subcompact cars this area will accommodate?

A 44
B 47
C 50
D 53

14. A new Park-n-Ride facility will include a principal passenger-loading area with a shelter to protect public transit patrons. The off-peak passenger volume expected to use the shelter at any one time is 320. How large should the proposed shelter be?
    A 58 to 96 m^2 [576 to 960 ft^2]
    B 77 to 128 m^2 [768 to 1280 ft^2]
    C
    D 110 to 184 m^2 [1104 to 1840 ft^2]

15. A new Park-n-Ride facility will include a bus-loading area. The bus loading area will be of the sawtooth design. Assume the bus loading area should have enough bays for five buses to load at one time. What is the minimum required length of the loading area?

    A 40 m [130 ft]
    B 60 m [195 ft]
    C 80 m [260 ft]
    D 100 m [325 ft]