5G-1 Crack Control and Load Transfer

A. General information

A good jointing plan will ease construction by providing clear guidance. The development of a jointing plan requires the designer to think about not only the specific project requirements but also the entire project jointing system. Jointing layouts in some parts of a project can have a substantial impact on other parts. In order to control concrete pavement cracking and subsequently maintain structural integrity, designers need to develop an understanding of how to complete jointing layouts of mainline pavements and intersections to obtain a comprehensive jointing system. This will allow a check on the pattern, type of joints, and the matching joints to their purpose.

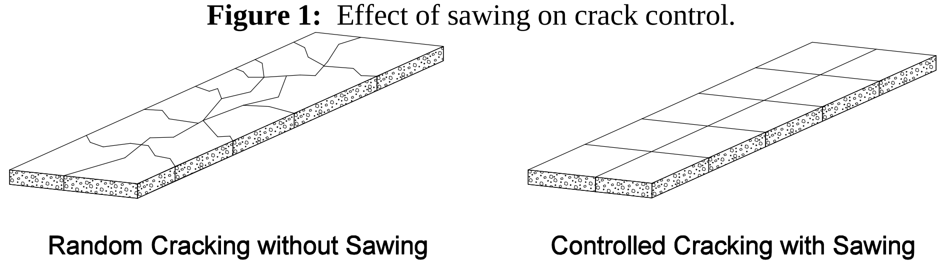
This section deals primarily with plain jointed pavements (tie bars or dowels only at specified joints). The primary function plain jointed pavements is to provide for load transfer across the joint, either through tie bars that hold the adjacent slabs together and allows for aggregate interlock to be maintained; or dowel bars that provide for mechanical load transfer even with slab movement.

Some cities in Iowa utilize jointed reinforced (JR) pavements, sometimes referred to as distributed steel reinforcing pavements. Section 5G-2, F discusses joint reinforced pavements. Joint reinforced pavements are used primarily to control cracking of a concrete pavement, to provide for load transfer, and to maintain the structural integrity of the slab between transverse joints. Joint reinforced pavements should not be confused with continuously reinforced pavement, which has very few or no joints.

The primary benefits of jointing are as follows:

1. **Crack control.** Cracking results from stress caused by concrete drying shrinkage, subgrade restraint, temperature/moisture differentials and applied traffic loads, and the combined effects of restraint curling and warping. It is highly desirable to control the location and geometry of transverse and longitudinal cracking in pavements. Without this control, cracking occurs in a random pattern similar to Figure 1, which results in increased distress of the joints.

Figure 1: Effect of sawing on crack control.



2. Accommodating slab movements.
3. Providing desirable load transfer.

Secondary benefits of jointing include:

1. Dividing the pavement into practical construction increments (i.e. traffic lanes).
2. Providing traffic guidance.

During construction it is likely that location changes will be necessary for some joints within an intersection. The primary reason is to ensure that joints pass through fixtures like manholes or drainage inlets that are embedded in the pavement. As a result, it will be desirable for the construction crew to adjust the location of some joints so that they coincide with the actual location of a nearby manhole. The designer should consider placing a note on the plan to give the field engineer and contractor the latitude to make appropriate adjustments.

It is common practice for some designers to leave intersection joint layout to the field engineer and contractor. These designers often justify this practice by citing the many field adjustments that occur during construction, which they contend negates the usefulness of a jointing plan. However, it is not desirable to eliminate the jointing plan except for very simple intersections. A jointing plan and appropriate field adjustments are both necessary for more complex intersections because islands, medians, and turning lanes complicate joint layout and require some forethought before construction. The plan will also enable contractors to more accurately bid the project.

B. Crack development

Cracking results from stress that exceeds the strength of the concrete. Cracking can be broken into two categories: initial and mature.

1. **Initial cracking**. Initial cracking occurs within a few hours to a few months after the pavement has been placed. It may be caused by the following conditions:

    a. **Concrete shrinkage (loss of volume).** Caused by shrinking (contraction) of concrete from:

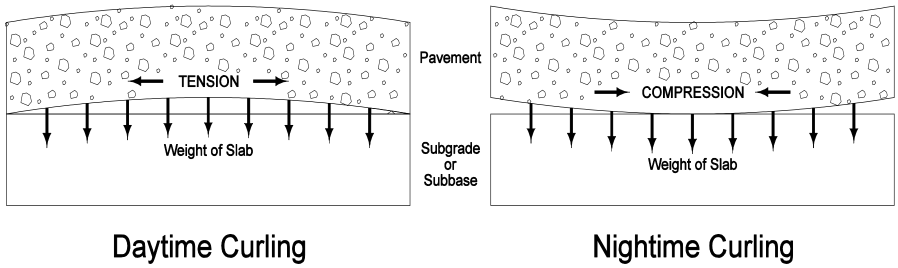
        1) **Temperature change during hydration.** The heat of hydration and temperature of pavement normally peak a short time after final set. After peaking, the temperature of concrete declines due to both reduced hydration activity and lower air temperature during the first night of pavement life. As the temperature of concrete drops, the concrete contracts or shrinks. If severe air temperature changes occur within the first few hours after construction, high tensile stresses may cause a transverse cracking to occur.

        2) **Loss of water during hydration (drying shrinkage).** This results from the reduction of volume through loss of mix water. Concrete mixes for roadway applications require more mix water than is required for hydration (water consumed through chemical reactions with cement). The extra water helps provide adequate workability for placing and finishing operations. During consolidation and hardening, most of the excess water bleeds to the surface and evaporates. With the loss of the water, the concrete occupies less volume.

    b. **Subgrade and subbase restraint.** Subgrade or subbase friction resists the contraction of the pavement from reduced volume and temperature. This resistance produces tensile stresses within the concrete.

    c. **Curling and warping.** Curling is the result of temperature changes through the depth of the pavement. Daytime curling occurs when the top portion of the slab is at a higher temperature than the bottom portion. As a result of the higher temperature, the top expands more than the bottom, causing the tendency to curl. Subgrade and subbase friction and the weight of the slab are factors that help to counteract the daytime curling. During the night the effects of curling are reversed, see Figure 2.

Figure 2: Daytime and nighttime curling.



Moisture warping results from a moisture differential from the top to the bottom of the slab. The top of the slab is normally drier than the bottom. The decrease in moisture content causes contraction at the top of the slab, which helps to counteract daytime curling. This contraction causes stresses in the concrete, which in turn leads to cracking.

2. **Mature cracking**. Mature cracking occurs several months or years after the pavement has been poured. As traffic loads are applied to the pavement, along with temperature and moisture changes, tensile strain/stress will develop in concrete as the result of:
   - Curling and warping in combination with repetitive traffic loads.
   - Poorly designed pavement joints that do not provide for proper load transfer across the slab.
   - Poor subgrade support due to unsuitable or non-uniform soils (different subgrade density).

C. Crack control

Cracking can be minimized by the following methods:

1. Proper timing and sawing of joints in concrete pavement in the correct location.

2. Properly designed joints which account for load transfer.

3. Proper curing of concrete, which prevents high initial shrinkage and thus cracking of hardening concrete.

4. Uniform soils, moisture, and density of the subgrade. If it is not possible to use natural soils to achieve uniformity, then subgrade replacement or subbase is used.

5. Uniform moisture in subgrades and the elimination of concentrated "wet areas" through proper design of subgrade and installation of a subdrain system.

D. Considerations for good pavement jointing

In order to design a suitable pavement jointing system, the following considerations have been included in the jointing layout steps covered in this section. The following elements need to be considered for adequate jointing:

1. **Joint purpose.** Transverse joints serve to control cracking resulting from contraction of the pavement. Both transverse and longitudinal joints are used to control cracking of the pavement by relieving internal curing and loading stresses.

2. **Environmental conditions.** Depending upon temperature and moisture changes that occur at the time of construction, expansion and contraction of the slab will occur, resulting in stress concentrations, warping, and curling.

3. **Slab thickness.** Pavement thickness affects curling stresses and deflections for load transfer. Thicker pavements are less prone to curling.

4. **Load transfer.** Load transfer is desirable across any concrete pavement joint. However, the amount of load transfer provided varies for each joint type, aggregate interlock, and the type of reinforcement.

5. **Joint spacings vs. thickness.** The manual includes standard joint spacing as a function of subgrade and subbase types and thickness.

6. **Traffic.** Traffic is an extremely important consideration in joint design. Traffic classification, channelization, and particularly the amount of truck traffic influence the load transfer requirements for long-term performance.

7. **Concrete material and construction characteristics.** Specific materials and their combinations can affect concrete strength and joint requirements. When special mixes outside of standard mixes are proposed to meet project conditions and requirements, the materials selected for the concrete can influence slab shrinkage. Substandard materials and construction practices can have a detrimental affect on joint performance. For example, poor coarse aggregate can lead to D-cracking that initially occurs along pavement joints, or overvibration can lead to low air, which can lead to early deterioration of pavement joints.

8. **Subbase type.** The support values and interface friction characteristics of different subbase types affect movement and support of the slabs.

9. **Shoulder design.** The shoulder type (tied concrete, asphalt, granular, or earth) affects edge support and ability of mainline joints to transfer load. Widened outer lanes are also effective for helping maintain load transfer.

10. **Past performance.** Performance records have been used to establish standard joint design (what has worked and what hasn't).

E. Load transfer

For jointed concrete pavement to perform adequately, traffic loadings must be transferred effectively from one side of the joint to the other. This is commonly referred to as load transfer, which is measured by joint effectiveness.

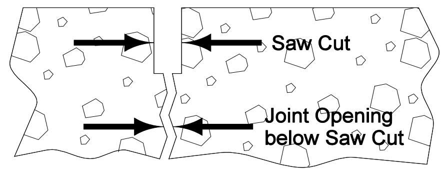
If a joint is 100% effective, it will transfer approximately one half of the applied load. Field evaluation of load transfer is calculated by measuring the deflection on each side of a joint from the applied load.

Load transfer is necessary for jointed concrete pavements to perform well. Adequate load transfer lowers deflections and reduces faulting, spalling, and corner breaks.

Table 1 shows that joint efficiency drops considerably when the joint opening below the sawcut line starts to exceed 1/8 inch.

Table 1: Joint opening below the sawcut vs. joint efficiency

Joint Opening Below Saw Cut	Joint Efficiency
1/16 in	>50%
1/8 in	<50%
1/4 in	0%



The following factors contribute to load transfer across joints:

- Aggregate interlock
- Mechanical load transfer devices
- Quality of subgrade, subbases, and bases
- Skewed joints

1. **Aggregate interlock.** Aggregate interlock is the interlocking action between aggregate particles at the face of the joint. It relies on the shared interaction between aggregate particles at the irregular crack face that forms below the sawcut. This form of load transfer has been found to be the most effective form of load transfer on streets with short joint spacings and low truck volumes. A 1985 study by the Minnesota DOT found that aggregate interlock load transfer provides acceptable pavement performance when semi-trailer volumes are fewer than 80 to 100 trucks per day per lane. The following are considered to increase aggregate interlock load transfer and minimize faulting:

   a. **Longitudinal tiebars and/or keyways**.
      - Typically used in longitudinal contraction and construction joints that tie traffic lanes and/or lanes with curb and gutter units or paved shoulders.
      - Tiebars provide little load transfer themselves, but they do hold the slabs relatively tight together to allow the slabs to provide aggregate interlock.

   b. **Shorter joint spacings (e.g. 15 feet or less).**
   c. **Stiff subgrades (high effective k value).**
   d. **Coarse grain subgrade soils (drainage).**
   e. **Improved subgrade drainage (pipe collection system, permeable subbase).**
   f. **Larger aggregate size (critical to load transfer).**
      - Small (½ inch) aggregate provides only a marginal interlock.
      - Larger (greater than 1 inch) durable aggregates are helpful in maintaining load transfer, especially for larger joint openings.

   g. **Crushed stone.** Generally, crushed stone aggregates perform better for aggregate interlock than rounded aggregates because the angular aggregates create a rougher joint face.

2. **Mechanical load transfers.** Aggregate interlock alone may not always provide sufficient load transfer in transverse joints for highway pavements and streets subject to heavy truck traffic. Under these circumstances, dowel bars and/or keyways are used.

   a. **Dowel bar benefits.** Dowel bars are smooth round bars placed across joints to transfer loads without restricting horizontal joint movement. The benefits of dowel bars are as follows:
      - They keep slabs in horizontal and vertical alignment.
      - Since dowel bars span the joint, daily and seasonal joint openings do not affect load transfer across doweled joints as much as they do undoweled joints.
      - Dowel bars lower deflection and stress in concrete slabs, and reduce the potential for faulting, pumping, and corner breaks.
      - Dowel bars also increase pavement life by effectively transferring the load across the joint.

b. **Dowel bar use.** Historically, dowel bars have been used to provide additional mechanical load transfer where truck traffic exceeds 120 vehicles per day, or accumulated design traffic exceeds 4 to 5 million AASHTO ESALs. Typically, this truck traffic level will require at least an 8-inch thick slab. For 8-inch slabs, transverse joints are recommended at 15-foot intervals for most street and highway applications. For 9-inch slabs or greater, the typical transverse joint spacing in Iowa for concrete pavement is 20 feet when dowel bars are used.

3. **Quality subgrades, subbases, and bases.** A proper foundation for pavements reduces joint deflection, assists in aggregate interlock, and improves and maintains joint effectiveness under repetitive loads. Subgrades, subbases, and bases not only provide this support but also provide an all-weather working platform and stable smooth trackline for paving equipment.

   It should be noted that the base type and the subgrade support value k have an effect on stresses in pavement slabs. The stiffer the foundation, the greater the slab's curl and warping stresses will be. Therefore, a shorter transverse joint spacing may be required when a stabilized base is used.

   a. **Subgrades.** Pavements can and have been placed on natural subgrades successfully for many years. When a significant number of trucks are anticipated, the use of a treated or stabilized subgrade will reduce pavement cracking by providing additional support. The typical subgrades are as follows:

   - *Natural subgrade*- Many Iowa soils are capable of supporting concrete pavements when uniform material and moisture exists. Uniform soil material and moisture (uniform density) result in uniform subgrade movement, which leads to reduced pavement cracking. If any of the following conditions exist, further treatment of the subgrade is necessary:
     - Lack of uniform material and moisture
     - Soil is susceptible to frost heave or pumping
     - Soil is expansive

     The treatment can either be the replacement of the non-uniform or poor quality soils, the stabilization of the soils, and/or the placement of a subbase. The choice of the treatment needed depends on the given situation, but in general, if select soil is economically available, it is usually more practical to remove and replace the poor soils. In the case where potential for pumping of the subgrade exists, typically subdrains and a subbase is required. However, it should be noted that the use of thick subbase layers (12 inches or greater) for substantial control of expansive soils and frost heaves may not be as cost effective as subgrade treatment.

   - *Select soil*- A good quality soil material that replaces the in-place natural soil for better uniformity and support under the entire pavement.

   - *Fly ash stabilization*- Fly Ash (Class C) mixed with one to two feet of existing soils helps dry out soils and provides uniformity. It is usually placed at a 10% mixture rate for drying and 14% for drying and strength gain.

   - *Soil aggregate subgrades*- A uniform mixture of Class C aggregate and in-place natural soil. The aggregate helps provide stability and uniformity to the existing natural soil. A typical soil aggregate treatment is one foot thick.

b. **Subbases.** A subbase is often placed on the subgrade to provide pavement support and/or a drainage layer. Iowa subbases typically consist of a granular material with various gradation requirements. Selection of subbase is dependent in part, on the type of construction used.

- *Granular subbase*- Strictly used as a drainable subbase, the Granular Subbase typically consists of 6-inch granular material but can range up to 12 inches under heavy loads. It should not be used as a working platform because of low stability. When heavy construction trucks are placed on the granular base, the weight of the truck causes higher density in the wheel line as compared to the rest of the subbase, which can contribute to the cracking of the pavement.

- *Modified subbase*- Is used as a drainable subbase with moderate stability. It is similar to Special Backfill but has a greater percentage of larger crushed particles than Special Backfill and therefore is more permeable but still provides a working platform.

- *Special backfill subbase*- Consists of a uniform mixture of coarse and fine crushed concrete or limestone typically at 6 inches to 8 inches thick provides a moderately drainable base and all-weather working platform with medium to high stability.

- *Polymer grid*- Used to provide extra pavement support in particularly wet conditions or high traffic construction areas, a polymer grid is sometimes used with granular subbases.

c. **Bases.** Common usage of the term bases refers to a stabilized material, either treated with a cementitious or an asphaltic material, which is located immediately below the pavement. Because this is a relatively strong, stabilized material cement-treated subbases, can have an effect on curling stresses. The designer should consider utilizing a shorter joint spacing if stabilized bases are used.

4. **Skewed joints.** Upon approval of the Jurisdictional Engineer, transverse contraction joints for undoweled pavements may be skewed counterclockwise (right ahead) 4 to 5 feet. Skewed joints are effective in decreasing the dynamic loading in the joint area by distributing the transfer of load. Each wheel on an axle crosses a skewed joint at a separate time. This reduces stresses and deflections in the concrete slab and helps reduce pumping and faulting. Also the joints are 4 or 5 inches longer which increases the slab support area. The use of skewed joints is more appropriate for rural low volume roads and is not as practical for urban conditions due to the need to have right angle jointing patterns at intersections. A word of caution: If random cracks occur, they normally are at somewhat right angles and can create a pie shaped piece of pavement when they cross a skewed joint.