Installation of Concrete Pavers on *Steeply Sloped Residential Driveways and Streets*

Designers, contractors and homeowners often ask what's the maximum driveway slope for concrete pavers? The best example of a steeply sloped project is a street with an 18% grade in Colma, California. While there might be driveways and streets with steeper slopes, the Colma project provides the current upper limit in North America at 18%. Figure 1 shows this street which was reported in the November 2001 issue of *Interlocking Concrete Pavement Magazine*.

Higher slopes have been achieved in a Central American road project. Figure 2 shows a Costa Rican road on the Papagayo Peninsula in service for four years that leads to a mountain hotel. The random pattern pavers suggest a herringbone pattern which slopes up to 25%. Moving into South America, Figure 3 shows a pedestrian walk and street in Medellín, Colombia, just completing construction with a 14% slope. Photos are courtesy of Germán Madrid who assisted with these projects.

For embankment applications without vehicles, the limiting factors are the angle of repose of the bedding sand, base and soil subgrade and more importantly, the resistance to soil and base sliding under compaction equipment. The angle of repose can be as much as 35 degrees or about 70% however, the tendency of soil and base to slide during compaction will reduce this limit.

Adequate performance of interlocking concrete pavements on slopes greater than 7% depends on careful consideration of many factors in design and proper execution of construction details. Experience with steep sloping streets and embankments next to bridges have demonstrated that stationary edge restraints, consistent and tight paver joints and herringbone patterns will help create interlock among the units. Another principle influencing design and construction is the need to remove water from the base, bedding sand and surface. Before moving into these subjects, soils and base require some discussion.

Figure 1. The highest sloping street on record in North America is this one in Colma, California near San Francisco.

Soil subgrade – If there is cut and fill of the soil, it should be compacted to a minimum of 98% standard Proctor density for pedestrian and residential driveway applications and a minimum of 98% modified proctor for roads. Compaction should be done in lifts and density checked by a technician with a nuclear density gauge to the depth of each lift. Lift

Figure 2. This Costa Rican road reaches up a mountain at maximum 25% slope. The paving pattern imitates a herringbone which is recommended for sloped applications. This photo shows a four year-old pavement.

thickness will depend on the size of the compaction equipment. Establishing 100% Proctor (or modified) and optimum moisture content in a soil testing laboratory and comparing it to the compacted and measured field density of the soil and moisture provides the highest degree of assurance against settlement and call backs.

Geotextile – Geotextile is recommended over clay or silty soils. Overlap at least 12 in. (30 cm) and remove all wrinkles prior to placing base material. Be sure that the fabric covers the sides of the excavated area. Staples are helpful in holding the smoothed fabric in place. Be sure to place base over the geotextile so it doesn't wrinkle under moving tires from construction vehicles. Geotextile manufacturers can provide guidance on selecting a fabric for separating the base from the soil subgrade.

Drainage Mat – A key design consideration is draining excess water from the base and bedding sand at the concrete header which is typically the lowest elevation of the interlocking concrete pavement. While not essential, J-Drain or equal drainage mat can facilitate water removal. The mat is placed vertically against the concrete header beam located at the base of the pavement. Do not use drainage mats with plastic waffles as they risk crushing. Note the placement with respect to the pavers and bedding sand on Figure 4 cross section. Note that the top of the mat is covered with a small strip of geotextile to keep sand out. A drainage mat placed horizontally under the bedding sand should never be used in vehicular applications including residential driveways.

Aggregate base – Use material that conforms to state or provincial DOT specifications for base under asphalt pavement. (A few examples include California = Class 2; Virginia = 21A, Ontario = Granular A, etc.) Place and compact in 3 to 4 in. (75 to 100 mm) lifts. Compact the base to at least 98% of standard Proctor density at optimum moisture content. Density and moisture information can often be obtained from the quarry supplier, e.g. standard Proctor density = 145 lbs/cf (2,323 kg/m^3) at 6% optimum moisture content.

The compacted base thickness should be at least 8 in. (200 mm). Thicker bases should be built in cold, northern climates. The compacted surface should have a surface tolerance of ±3/8 in. over a 10 ft (±10 mm over a 3 mm) straightedge. Stabilizing 3 ft (1 m) of base with cement next to the header beam can help prevent base rutting and the header-paver junction. Another approach is to thicken the aggregate base about 40% over normal thickness to provide extra mass for taking wheel loads. These modifications are especially important when transitioning from a rigid concrete pavement to an interlocking concrete pavement with a flexible, compacted aggregate base.

Concrete Header Beam – This is poured at the same time or after pouring the curbs on the sides and top of the pavement. Precast concrete or stone units are not recommended. Located at the down slope end of the interlocking concrete pavement, this beam should be a minimum of 6 in. wide by 12 in. (150 mm x 300 mm) deep with one #4 bar centered in the bottom third of the beam with 2 in. (50 mm) clearance from the bottom. The designer may wish to include a second reinforcing

Figure 3. Redevelopment of popular neighborhood in Medellín, Columbia included a 14% slope for the sidewalk and adjacent street.

bar along the top in street applications. Reinforcing bar should be continuous. Use minimum 4,000 psi (30 MPa) concrete. Prior to forming the header, place and compact about 4 in. (100 mm) of base to serve as a platform for the forming the bottom of the concrete header. A larger header beam may be required in more severe climates or when truck traffic is expected.

Locate the forms such that there is ½ in. (13 mm) gap between the end of the curbs and the header beam. This provides space for the drainage mat to continue the full length of the header beam so water can drain to each side of the driveway or road. The gaps can be covered with geotextile to contain base and bedding sand while allowing water to drain.

The header beam should be formed, poured and forms removed prior to placing aggregate base against it. Construction joints should be placed a minimum of every 5 ft (1.5 m). These are daylight joints to reduce cracking risks and not joints made by tooling the beam surface. Besides controlling cracking, the joints will allow water to drain after rain during construction. After the concrete beam has cured a few days and forms are removed, (if necessary excavate and) compact the soil and place the drainage mat against the upslope side of the beam.

Since running dump trucks and compaction equipment will damage the curbs, the following sequence should be considered: pour the curbs on the sides of the pavement, compact the soil and base up to the header beam location. Pour the header beam, then compact the soil, place and compact base after removal of forms around the cured header. The soil and base along the header beam will require compaction with a hand tamper or small equipment since it is unlikely that equipment will be able to reach corners. This is where density should be tested.

More importantly, the drainage mat cannot be damaged, soiled or be allowed to fill with base along the edges during compaction. Cover the upslope side and top of the drainage mat to prevent base material from entering. Remove the cover after the base is completely compacted, meets density and elevation requirements. Immediately cover the top with geotextile to prevent ingress of base or bedding sand. This is indicated in Figure 4 with a small strip over the top of the drainage mat and anchored by the pavers.

The drainage mat will extend the end of the header and direct water to one or both sides. The area outside the header and curb joints can be filled with No. 57 crushed stone or equivalent to facilitate drainage of water out of the drainage mat and down slope.

In a few cases, the interlocking concrete pavement may abut an existing concrete slab. This could be a driveway apron or an abutting street. Careful consideration should be given on whether to construct a header beam to help direct water away from the side of slab. Care should be taken to not undermine the base and soil under the existing slab during excavation and later from water working its way through the bedding sand and base. The existing concrete slab should be free of cracks and spalls, especially along the edge that meets the header beam and/or concrete pavers. If pavers are abutted against a concrete slab, their final surface elevation after compaction should be 5 to 6 mm higher than the concrete slab surface.

Bedding Sand – The gradation of the bedding sand should conform to ASTM C 33 or CSA A23.1 (concrete sand) with a limit of 1% passing the No. 200 (0.075 mm sieve). It is important that the No. 200 or fines be controlled as an excess amount can slow the drainage of the bedding sand. Note in the detail how the bedding sand is contained by geotextile and is kept from entering the top of the drainage mat. It should be noted that coarser sand should be used on the highest slopes for drainage and resistance to movement.

Joint Sand – Joint sand gradation should conform to ASTM C 144 or CSA A179. This material is finer than the bedding sand and it should be completely dry to facilitate entering and filling paver joints. Concrete sand can be used for joint sand. In either case, the sand should be crushed (and not rounded river sand) to facilitate interlock.

Concrete Pavers – The pavers should be at least 2 3/8 in. (60 mm) thick for residential driveways. They should conform to requirements of the ASTM C 936 in the U.S. or CSA A231.2 in Canada. Square units are not recommended on steep slopes.

Paving Pattern and Shapes – Herringbone patterns are recommended on steep slopes as they resist horizontal forces from braking and turning tires better than other patterns. Dentated pavers may provide additional stability in steep slopes. Other patterns such as running bond or random patterns should be avoided.

Paver Installation – Paver laying should begin at the header beam and work up the slope. Place pavers in a herringbone pattern. A 45° pattern encourages the surface water flow to the pavement sides of the pavement but will likely require more edge cutting to install. Additional upslope header beams should not be necessary if the pavers are installed from the lowest to highest slope and within stationary curbs. Pavers with spacer bars are recommended so that sand can enter the joints. Paver joint widths should be tight (2–3 mm) and checked for consistency and alignment for every 6 ft (2 m) of pavers placed. Adjustments in joint widths or alignment should be made before compacting the pavers.

The pavement surface should have a minimum 2% crown or crossfall to direct water to its sides. A crown can increase interlock as the pavers settle slightly from traffic. The cross slope should allow for sheet drainage of runoff to the sides of the pavement. Flush curbs will allow the water to move off the pavement. Once the water is off the curb, consider how water at the sides of the pavement will be transferred down slope. It may be sent down a grass swale, a rip-rap lined ditch or a concrete gutter. Regardless of the method, the design objective is to maintain sheet flow and prevent channel flow of water over the concrete pavers. The finish elevation of the pavers (after second compaction of the pavers on bedding sand) should ¼ in. (5–6 mm) higher than the header beam. This will help prevent water from being trapped against the curbs even if there is minor pavement settlement.

Joint Sand Stabilization – A joint sand stabilization material should be placed in all the joints. *ICPI Tech Spec 5 – Cleaning, Sealing and Joint Sand Stabilization of Interlocking Concrete Pavement* provides guidance on joint sand stabilizers. There are two types, liquid applied after the pavers are compacted with joint sand and those mixed with joint sand and compacted into the joints, then activated with a water spray. Liquid applied are typically applied with a low-pressure spray, allowed to soak into the joints and excess material squeegeed to an unstabilized area. Liquid applied stabilizers are applied to completely dry joints and must dry at least 24 hours prior to vehicular traffic. Manufacturer's directions should be followed for handling and application of both types of stabilizers.

Stabilizers can reduce the amount of water infiltrating the joints and bedding sand, but they do not render the pavement completely impervious. That is why the design facilitates drainage of the bedding sand should it become saturated. Stabilizers will have the additional benefit of maintaining sand in the joints should they be exposed to concentrated discharges such as downspout water, gutter-less eaves dripping water, air conditioning condensate and exterior hose faucets.

Edge Maintenance – The repeated force of tires in the same locations may cause minor settlement over time as well as minor horizontal creep of

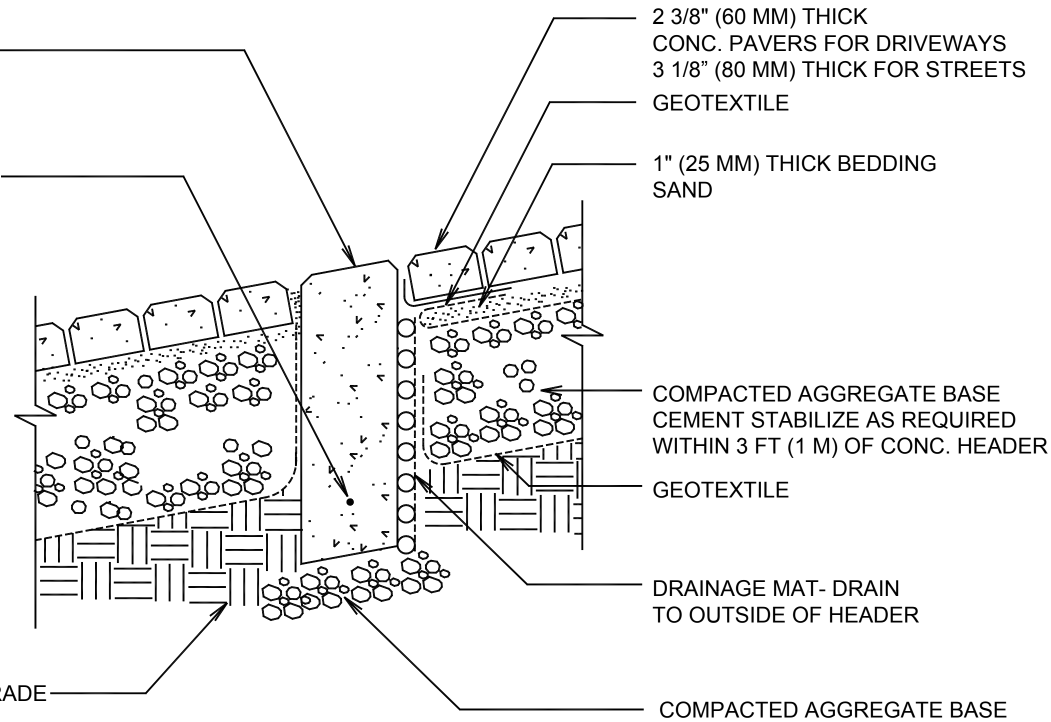

Figure 4. One way to remove water at the base of the installation is by placing drainage mat vertically against the concrete header curb. Note the location of geotextile to prevent loss of bedding sand.

the units. This may be especially evident at the top of the pavement or at protrusions such as the down slope side of utility covers. If left unchecked, water can enter the opening and undermine the bedding sand. The pavement should be monitored for 3 to 6 months for this condition. If joints at the top or at protrusions open a few millimeters, they can be filled with joint sand and stabilized. If wider gaps occur, it may be necessary to relay the pavers to fill the gaps.

These guidelines will require judgment in their application to a specific project and diligent inspection on the job site. Every project will have unique conditions not addressed in this article and the advice of a design professional and contractor experienced in high slope installations should be sought for specific project recommendations. ❖