	TMC – Tinni Management Consulting	Issue No.
	PAVEMENT INFORMATION NOTE	**21**
Edited by Arvo Tinni. Email arvo@tinni.com.au		18 11 2008

DESIGN and CONSTRUCTION FACTORS that AFFECT INITIAL SMOOTHNESS

The following is a summary from a portion of FHWA-HRT-05-068 Research Report: "Achieving a High Level of Smoothness in Concrete Pavements Without Sacrificing Long-Term Performance". (Note that they describe the condition as "smoothness" rather than "roughness").

The factors that influence pavement smoothness fall in the following categories:
- Pavement design factors;
- Concrete mix design and
- Construction operations.

1 Pavement Design Factors

1.1 Base/Subbase
1. It is most important to have a stable and smooth track line. Irregularities will cause the profile pan to continuously adjust its position relative to the machine frame. This can cause bumps or dips in the pavement surface.
2. It has been suggested that the Subbase should be 1 m wider than the base.

1.2 Horizontal Alignment
1. It is more difficult to construct along horizontal curves than on tangents. This is because of the continuous adjustment over the transition lengths.
2. Apparently this is also more prevalent on the superelevated portions of the curves.
3. For radii less than 300 m, the stringline staking interval should be reduced.

1.3 Embedded Items.
1. Our PCPs do not have dowels, but will have tiebars for the longitudinal joints and CRCP has the embedded reinforcement. There are four conditions that can cause roughness:
   - Lack of compaction. The concrete is prone to settle over the reo bars, creating a rough surface;
   - Reinforcement ripple occurs when the concrete is restrained by the reo bars. This results in a ripple on the surface, with the surface slightly lower near each bar than between bars. The degree depends on finishing technique and cover over the reo;
   - Springback occurs when the tiebar basket or suspended reo deflects and rebounds after the profile pan has passed over the area. This results in a slight hump just ahead of the basket, and

- Damming typically occurs when paving down steep grades or where there is a low friction paving surface. Any basket or transverse steel can act as a dam and cause bumps to form.

2 Concrete Mix Designs

2.1 General

1 Mix design influences the workability and slump, which have a direct impact on the ease of placement and finishing;
2 Harsh mixes require more finishing, resulting in rougher surface;
3 Mixes with slump between 50 and 65 mm give the smoothest surfaces;
4 Concrete designed with well graded combined aggregates perform better than gap graded or poorly graded aggregates. Because of this, a number of Authorities now specify the Shiltstone-type mix design as mandatory.

2.2 Aggregate

1 Aggregates play a major role in affecting workability and thus affect the pavement smoothness. This includes grading, particle shape, stockpiling and handling and moisture content;
2 Variability in grading will cause changes in water demand, resulting in inconsistent workability of mix from batch-to-batch;
3 Rounded aggregates produce more workable mixes, while angular manufactured aggregates are prone to produce harsh mixes and as a result rougher surfaces;
4 Improper stockpiling and handling of aggregate can cause segregation in the mix, which makes it impossible to produce uniform concrete. In addition, slump, yield and air content can also be affected;
5 Variable moisture content in aggregate can produce mixes with variable slump.

2.3 Admixtures

1. Different types of fly-ash and the use of water reducing and air-entraining agents affect the workability of concrete and hence smoothness of the pavement;
2. An air-entraining agent improves the durability and has a positive effect on smoothness because it increases the slump (workability) of the concrete. Mixes with low air content tend to bleed, whereas mixes with high air content will make the mixes sticky and unworkable. A range of 5 – 7% is recommended;
2. Water reducers have a positive impact on smoothness;
3. Retarders are also beneficial by keeping the mix workable for longer periods.

3 The Shiltstone Mix Design

This design methodology has the following advantages over the traditional concrete mix designs we currently use:

- It produces more stable concrete mixes;
- The concrete will have less shrinkage and hence may reduce moisture warping of the slabs at early stages. Less shrinkage can reduce built-in pavement roughness that occurs due to warping and curling;
- Compared to conventional mix designs, this concrete mix responds better to vibration and requires less energy for consolidation.;

- Mixes with more uniform aggregate gradings will hold up better after vibration;
- Well graded mixes are most effective because they minimise the paste (the most expensive part of the mix) and maximise the aggregate (the least expensive part);
- Well graded mixes will be stronger and have better long term durability.

4 Construction Operations

4.1 Stringline Setup and Maintenance

1. Spacing of stringline stakes at 7 – 8 m is recommended on straights. On Curves and transitions this should be closer;
2. Air temperature and humidity during the day can cause sagging of stringline between stakes;
3. Hand winches should be placed at no more than 300 m intervals;
4. The stringline should be inspected regularly throughout the day.

4.2 Grade Preparation

1. The finish of the Subbase must be as true as possible. Extra or less concrete may affect the paving speed and hence cause unevenness.

4.3 Vertical Grades and Curves

1 There are no proven differences between paving uphill or downhill.

2 According to ACPA, the following adjustments may be necessary when paving on steep grades:
  - The slump should be reduced if it exceeds 12-25 mm and if it is difficult to maintain an uniform head of concrete in front of the paver;
  - The angle of attack of the paver may need to be adjusted. On flat grades the profile pan is usually parallel to the stringline. On a steep upgrade, the pan may be adjusted to about 50 mm below the surface grade and on down grades, 50 mm above the surface grade;
  - On straights the staking interval should not be more than 7.5 m and on curves a lot closer.

4.4 Concrete Consistency

1 Batch-to-batch consistency is essential. Variations in wet and "dry' batches results in constant equipment adjustments;

2 Moisture content in the sand has more impact on the mix than that of the aggregate;

3 The ACPA recommends the following to help control batch-to-batch variations in concrete consistency:
  - Remove free water from stockpile areas after washing or rainfall;
  - Maintain a consistent, clean operation of the FELs and other heavy equipment moving aggregate at the batch plant. Remove aggregate evenly from the stockpiles to maintain consistent aggregate moisture;
  - Water coarse aggregate stockpiles as necessary. Some aggregates are highly absorptive, requiring a significant quantity of water to create the saturated surface dry condition assumed in the mix design;

- Measure moisture content continually. Moisture sensors in the aggregate bins detect the moisture content for the plant's computer to make corrections for the water added.

4.5 Concrete Delivery

1 Ensure uniform rate of delivery to the paver. This can have a direct impact on the smoothness of the finished surface;
2 Slowdowns or stoppages in the paving process will result in humps and dips;
3 A study in Argentina demonstrated that for best results, besides the type of paver and the rate of concrete placement, the concrete delivery and the batch mixer type had also an affect on the finished smoothness. Pavement sections with shorter concrete delivery distances showed a lower IRI.

4.6 Construction Equipment

1 The proper operation of the batching and paving equipment is essential.
2 Paver must always be clean and well maintained;
3 There is a high correlation between equipment condition and pavement smoothness;
4 A heavier paver generally produces smoother pavement.

4.7 Slipform Paver Operation

Many factors will influence the paver operation and hence the final smoothness. The essentials could be summarised as:

- Proper **paver setup**;
- Adequate paver travel **speed.** It is essential that it is constant. No stops and starts;
- **Vibration**. Speed influences the amount of vibration. Too much vibration causes pumping and fluffing at the rear of the pan and brings excess grout to the surface. Insufficient vibration creates drag-out and surface voids. When operating at a very high frequency, vibrators may cause other undesirable results such as loss of air entrainment or vibrator trails;
- **Concrete head**. Maintaining a consistent and adequate head of concrete in front of the paver can improve the smoothness of the pavement. This will also ensure consistency in speed, vibration and consolidation. A consistent head also evens the pressure on the paver so that when required, the automatic adjustments can be made more accurately.

  If the head gets too high, it can create a pressure surge under the paver which can cause the concrete behind the profile pan to rise and create a bump. If not enough concrete is placed in front of the paver, the concrete head may run out or the grout box may run empty, creating low spots or voids on the pavement surface;

- **Tiebar Baskets and Reinforcement**. Both should be firmly fixed to the Subbase to minimise tiebar or reinforcement related pavement roughness. Thorough vibration and compaction is the key;

- **Communication**. There must be effective and constant communication between the plant and the slipform operator for the latter to match the paver speed to accommodate the concrete deliveries.

5 Finishing, Texturing, Curing and Headers

5.1 Finishing

1. If the paver is operated properly, minimal hand finishing will be required;
2. Any hand work will/can cause roughness;
3. Checking of the surface finish should be carried out extremely carefully so as not to leave any rills or marks. Texturing will tend to remove these.

5.2 Texturing

1. Texturing will not usually affect surface smoothness;
2. However, transverse tining may cause surface roughness if the rakes do not run over the surface evenly.

5.3 Curing

1. A Kansas study has shown that the application of the curing compound was a significant factor affecting the IRI value, with a lower IRI being obtained from the double application of the curing compound.

5.4 Headers or Stop Ends

1. Transverse construction joints are the most significant contributors to concrete pavement roughness;
2. Most pavers leave s dip in the slab when they lose the head of the concrete.
3. Stop ends typically require hand finishing, which makes the controlling of tolerances and finish even harder;
4. Some recommend running the concrete out and next morning saw cutting the pavement 2 m back from the end and removing the end material. Drilling and insertion of epoxied tiebars will be required.

5.7 Skilled and Motivated Crew

1. Regardless of the equipment, an experienced and motivated crew is essential;
2. Crew training is vital, especially in topics that directly affect smoothness;
3. Stringline personnel need skills and a good eye;
4. Operators must know how the equipment activities affect smoothness;
5. In the Argentinian study they found that IRI values decreased chronologically for paving projects i.e. increased experience and knowledge.

Arvo Tinni
November 2008