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PAVEMENT STRUCTURES AT THE INTERSECTION AREA

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Abstract:

From the very beginning of the application of modern pavements, it was known that with increasing load on the pavement structure, more attention should be paid to the details during design and construction in order for the pavement structure to reach the planned lifetime. Heavy, slow vehicles that stop, stand, rotate and accelerate transmit the largest possible load on any pavement structure. These phenomena are most frequent at intersections, but also occur at traffic lanes on increased longitudinal slopes, weighing stations, bus stations and stops, parking lots and rest areas, and the like. Due to the need to equalize the characteristics and behavior of all elements of the road, the areas exposed to increased and non-characteristic loads must receive particular attention during design.

Keywords: pavement structures, load, intersections.

KOLOVOZNE KONSTRUKCIJE U PODRUČJU RASKRSNICA

Rezime:

Od samog početka primjene modernih kolovoznih konstrukcija je bilo poznato da se s povećanjem opterećenja na kolovoz mora obratiti više pažnje na detalje tokom projektovanja i izgradnje kako bi kolovozna konstrukcija dostigla planirani životni vijek. Teška, usporena vozila koja se zaustavljaju, stoje, okreću i ubrzavaju prenose najveća moguća opterećenja na bilo koju kolovoznu konstrukciju. Ove pojave su najčešće kod raskrsnica, ali se javljaju i kod traka na povećanim podužnim nagibima, stanicama za vaganje, autobuskim stanicama i stajalištima, parkinzima i odmorištima i sl. Zbog potrebe ujednačavanja karakteristika, odnosno ponašanja svih elemenata puta, površinama izloženim povećanim i nekarakterističnim opterećenjima se mora obratiti posebna pažnja prilikom projektovanja.

Ključne riječi: kolovozne konstrukcije, opterećenje, raskrsnice.

1. INTRODUCTION

Heavy, slow-moving vehicles that are stopping, turning, or accelerating expose intersections to some of the highest stress levels found on pavements. High-stress locations also include climbing lanes, truck weigh stations, rest areas, and other low- or zero-speed areas. That is why some intersections need special attention to ensure that these areas deliver the same outstanding performance as other asphalt pavements.

While asphalt has continually proven to have superior life-cycle cost-benefits, special attention should be focused on intersections to ensure the same outstanding performance. Braking, accelerating and turning movements that occur put additional stress on the pavement surface. Engine fluid drippings and heat exhaust increase with slower traffic and has a softening effect on asphalt. In addition, load repetitions at intersections are sometimes double that of mainline pavement due to the dross flow of traffic. Together, those are the reasons that intersection pavement need to be treated differently [1].

2. EFFECT OF TRAFFIC LOAD ON PAVEMENT

Static and dynamic effect of traffic load, i.e. of the real vehicle, is transmitted to a pavement structure through a vehicle's tires. Tires represent a complex structure, mainly made of natural or synthetic rubber, and as such, they have characteristics of rubber as a material.

The static force from the vehicle shaft is transferred to a smaller or larger pavement-tire contact surface (Figure 1) depending on the: size of the axle load of the vehicle, tire pressure, type and characteristics of the tire and speed of the vehicle.

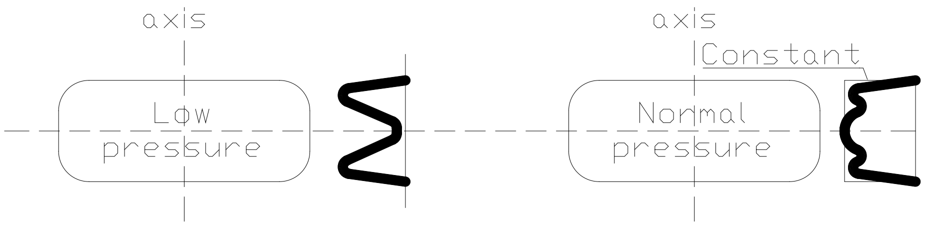

Figure 1. The contact surface of the tire-pavement depending on the air pressure in the tire [2]

The tire pressure on the pavement surface is not constant, i.e. evenly distributed on the contact surface, and as such equal to the internal pressure in the tire, however, for the needs of the calculation in designing of the pavement structure, a big mistake isn't made if it is adopted for a constant, i.e. that the tire pressure is approximately the same as the pressure on the contact surface.

Normal pressures at the contact between the tire and the pavement surface are not the only forces that are transmitted through the tire to the pavement structure. In the case of the vehicle braking and accelerating, which is particularly pronounced in the area of the intersection, horizontal forces also act on the pavement.

It should be emphasized that even when there is no sudden change in the speed of the vehicle's movement or when the vehicle is stationary, there are forces that act on the pavement surface. It is very difficult to calculate the values of these shear forces (tangential shear on the pavement), however it must be noted that their role is of great importance. The consequences of these forces can often be seen in poorly designed, poorly constructed or inadequately maintained roads in the form of rutting, shoving etc. These forces occur as a result of tire deformations caused by load on an imaginary undeformed and deformed, but unstretchable rubber element of a circular shape (Figure 2).

Figure 2. Display of the shear under the tire
(left: longitudinal shear under the tire (meridian plane);
right: longitudinal shear under the tire (equatorial plane)) [2]

Because the tire can be deformed, the tire causes shear, not skidding, i.e. horizontal force which depends on the vertical force and the friction coefficient μ ($Fx, y = \mu \cdot Fz$). The layout of the longitudinal shear on the contact surface in the case of vehicle movement is shown in Figure 3.

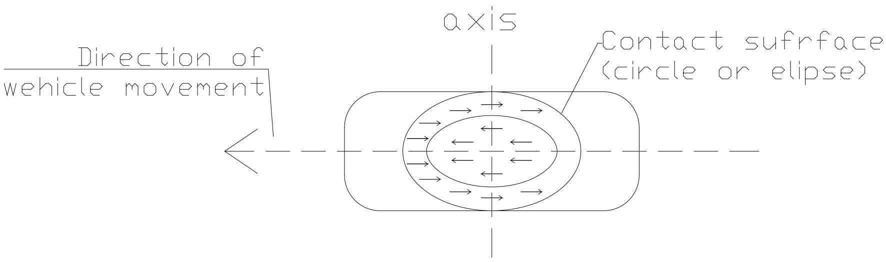

Figure 3. Distribution of longitudinal shear [2]

For designing of the pavement structure, when calculating the static traffic load (all the aforementioned phenomena of shear force are significant), the axial load of the vehicle is of particular importance, especially when the dimensioning is carried out using the analytical method. The static load can be relevant for designing of the pavement structure in all cases of stationary traffic (traffic on urban roads, often disrupted free flow outside urban areas, etc.).

Dynamic impacts on vehicles moving along the road can be viewed from two aspects: comfort when driving, and secondly, the impact on the dynamic components of the vehicle force in the pavement structure, which may be significant, and as such should be included in the design analysis of the pavement structure.

Comfort or driving cosiness is a serious preoccupation in the construction of the vehicle and is conditioned by many factors that define mechanical, i.e. dynamic performance of the vehicle. One of the most important factors affecting the comfort is the level of the roughness of pavement surface. This factor is very often researched and analyzed, and based on it, normatives that define comfort conditioned by roughness of the road are defined very often.

2.1. MUTUAL INFLUENCE VEHICLE-ROAD

Features, characteristics, models, etc. of driving with a motor vehicle, except driver factors, are mainly conditioned by the interaction of vehicles and road. Influences from the vehicle on the road are transmitted directly through the pavement structure (superstructure), indirectly to the substructure of road. However, the characteristics of the road and structures on the road, to a considerable extent, determine the driving, and above all, the surface characteristics of the pavement structure.

The forces that occur during the movement of a vehicle and transmitted to the pavement structure include: vertical forces (Q, P), tangential (longitudinal) forces (Z, Pk, T), transverse forces (C, W), suction forces, and impacts due to repetitive traffic loads (Figure 4).

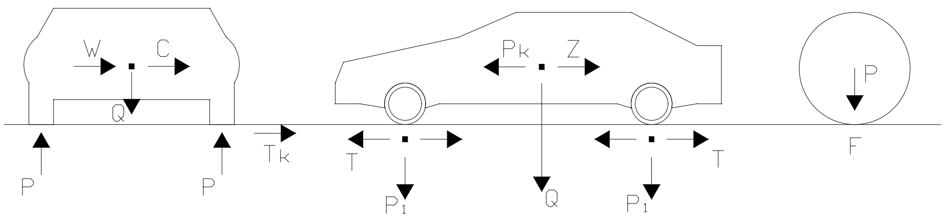

Figure 4. Impacts that occur when driving a motor vehicle on the road [2]

Of all these influences, the tangential and transversal forces are characteristic and significant for movement in the roundabouts, as a result of the movement in the curvature and frequent braking and acceleration of the vehicle.

2.1.1. Tangential (longitudinal) forces

In the longitudinal direction (horizontal path without the influence of the wind), there is an active and reactive force: the driving force Z, the braking force Pk and the adhesion force T (Figure 5).

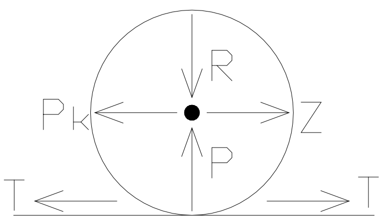

Figure 5. Tangential (longitudinal) forces acting on the pavement structure [2]

From these forces tangential stresses between the substructure and superstructure occurs, between the layers of any structure or, within one layer, and as a result, there is a tendency for shearing the pavement structure or its part.

The largest force that can be transferred from the drive wheels to the pavement is:

$$\max Z = \max P \times f_a \quad (1)$$

The specific stress (tangential τ) due to the tangential force is:

$$\tau = \frac{T}{F} = \frac{\max Z}{F} = \frac{3,6N}{V \times F}; \left(Z = \frac{3,6N}{V} \right) \tag{2}$$

where:

V is a vehicle speed,

Z is a tractive force,

F is vertical force,

N is engine power.

2.1.2. Transversal forces

Transverse force is a horizontal force that occurs as a result of a centrifugal force when vehicle moves in the curvature. These forces also are added the side wind force. Leaving out the influence of wind W, the greater part of the transversal force is:

$$C = \frac{m \times V^2}{R}; m = \frac{Q_p}{g}; Q_p = Q \times i_p \tag{3}$$

where:

C is a transversal force,

R is a radius of curvature,

m is a mass of the vehicle,

V is a vehicle speed,

Q is a weight of the car,

i_p is a cross slope of a road.

2.2. INFLUENCE OF TANGENTIAL AND TRANSVERSAL FORCES ON A PAVEMENT STRUCTURE

The forces transmitted from the vehicle's tires to the tire-pavement contact surface have a significant impact on the pavement structure. These forces also include transversal and tangential forces [2]. They also make a real traffic load (the equivalent axle traffic load is just an approximation). The special significance of these forces is in the case of flexible pavement constructions, i.e. pavement with a surface course constructed of bitumen-bound materials. Together with these forces, hydro-meteorological effects also affect the asphaltic concrete surface course.

In cyclic repetition of loads, the shear tensile stresses occur in the surface course made of bitumen-bonded materials (asphaltic concrete). In cases where these tensions exceed the permissible tension for a particular material that is embedded in the surface course, cracks occur. With this in mind, it is seen that the tensile shear strength is a very important parameter in design. It is very important to determine experimentally (laboratory) the tensile shearing strength of the material from which the bitumen bonded layers (wearing layer, bond layer, etc.) will be constructed. That has to be performed for test specimens in a certain shape and at the predefined loading rate.

Tangential and transverse forces can be the cause of the occurrence of undesired phenomena, and in cases where the shear strength is not relevant, i.e. in the case where the wearing layer is laid over rigid Portland Cement Concrete Pavement (PCCP) or reinforced concrete and similar pavement structures. In this case, a pure tension strength and adhesion between the wearing course and base course may be relevant. This phenomenon should be specifically investigated in the case of tangential forces caused by vehicle movement (braking, acceleration). In this case, and not only in this case, but also in the previous one, the appearance of cracks in the wearing layer, reflecting cracks, rutting, etc. can be prevented or improved by applying special types of asphaltic concrete wearing courses or using synthetic polymer mesh for reinforcement of asphaltic concrete.

Transverse forces cause transverse stresses in the pavement structure and cause transversal shear between the layers of the pavement structure, resulting in damage to the pavement. They also influence the intensification of the wear of the surface layer of the pavement structure, which requires a more frequent reconstruction of the pavement construction.

3. DISTRESS OF PAVEMENTS AT THE INTERSECTION AREA

Asphaltic concrete and Portland cement pavements at intersections and their approaches, where traffic is required to stop and start, exhibit several types of distress. Research in this area has shown that leading causes of pavement failures at these locations are primarily materials related [3]. Meaningful amounts of funds allocated for maintenance operations are exhausted each year to rehabilitate intersection pavements that have become safety hazards as a result of simple traffic action. Significant savings may be realized if intersections and their approaches are designed and constructed to accommodate the shear stresses as well as fatigue to which they are subjected.

Figure 6. Distresses of pavement at the intersection area
(left: rutting, middle: shoving, right: slippage cracking)

In regard to the wide range of distresses that can occur as a result of the impact of traffic loads and the environment, as well as other factors that can affect the pavement construction, the following specific types of distresses occur at intersections (Figure 6) [4]:

- Rutting - surface depression in the wheel path, caused by improper mix design or manufacture, inadequate pavement structure or insufficient compaction of layers during construction.
- Pushing, shoving and severe wash boarding - a form of plastic movement typified abrupt wave across the pavement surface perpendicular to the traffic direction, most often due to insufficient stability of the mixture and poor bonding between the layers;
- Slippage cracking - crescent or half-moon shaped cracks generally having two ends pointed into the direction of traffic, occur on surfaces exposed to sudden

changes in the turning point (braking, starting or turning), caused by a low-strength surface mix or poor bonding between the surface layer and the next underlying layer in the pavement structure.

Average daily traffic and the percentage of trucks do not necessarily indicate whether an intersection will or will not have an Asphaltic Concrete Pavement (ACP) rutting problem. Factors that can affect rutting include the starting and stopping of trucks, roadway grade, climate and mix properties combined with the average daily traffic, truck percentage, and Equivalent Single Axle Loads (ESALs) [5].

By repairing damaged surfaces and depressions, the required slope and required roughness are established. Damaged surfaces can be fixed with flattening, which can be done on small, medium and very damaged surfaces. A little damage to the surface does not have to be repaired, but must be monitored to prevent serious destruction. It is also possible to fill slippage cracking to prevent water penetration and further destruction of the carriageway surface. Delays in taking these measures can lead to much more serious damage and even higher costs of repairs.

It is possible to use the reinforcement procedure - "overlaying" of the pavement, which increases the strength of the structure in which certain displacements (rutting, etc.) have occurred. Care must be taken not to mix materials, that is, never reinforce PCCP structures with bituminous bonded materials [6].

At some roundabouts, the problem can be cracks, especially around the outer edge of the circular flow, near the outer curves and dividing islands, so special attention should be paid to provide the necessary relief [7].

4. GENERAL COMPARISSON OF PAVEMENT STRUCTURE TYPES FOR USE AT INTERSECTIONS

Pavement structure in areas of turning, such as the intersection area, curves on road and roundabouts, is exposed to very severe shearing forces from the vehicle's tires, especially the trucks.

Horizontal loads that are transferred from tire to the pavement during a narrow maneuvering angle are as large as 80% of the static load. These loads cause the wear of the surface layer and the shear between the layers of the pavement structure. As a result, the traditional ACP structure in the area of the intersection or the roundabouts eventually wears out and requires regular reconstruction, sometimes every five years, and even more often. The cost of maintaining these pavements is therefore very high.

In order to function well, flexible (asphaltic concrete) pavement structures at intersections must first of all have adequate thickness and density in order to meet the traffic needs. It is necessary to carefully select the bitumen binder to provide the desired functionality in the long run. At intersections binders that are more resistant to wear and tear should be used. As is it important to select the appropriate binder, it is also important what kind of aggregate will be used in the mixture for pavement structure. The structure of the aggregate must be able to withstand the load and develop a high degree of blocking between the stones that will withstand shear. Both the coarse and fine particles of the aggregate must be of an angular shape in order to provide the blocking required for shear resistance. It is important to limit the use of rounded particles and non-crushed sand. The purpose of the design of the pavement mix is to select the appropriate materials and in an appropriate proportion in order to withstand the shear.

Experience shows that the amount of voids of the mineral aggregate is very significant. Low void mixtures may be susceptible to relatively small changes in the total content of the fluid (asphaltic binder, moisture and small fill). Small fluid's increase can cause rutting and shearing of these mixtures under load. On the other hand, mixtures with high void content produce a thick asphalt protective layer around aggregate particles, which can serve as a lubricant allowing particles to reorient under traffic. Quality control of the asphalt mix is crucial and preliminary tests are necessary in order to identify all the necessary volumetric settings.

PCCP (rigid) at intersections and roundabouts will prevent shear between layers of pavement structure, to which particular attention should be paid at ACP structures. In areas with high traffic loads, where safety is a priority, PCCP will withstand heavy traffic. PCCP do not require periodic rehabilitation, as required by ACPs. An advantage with PCCP is that 40-year design life, with minimal or no rehabilitation required. In addition, the drainage characteristics are preserved over time, because the concrete will not leak and there will be no holes.

Advantages of PCCP for heavily loaded intersections (intersections with crossing of traffic streams or roundabouts) are:

- They do not compact and do not collapse during turning maneuver of large vehicles, i.e. they are resistant to the appearance of depressions and rutting (as opposed to ACPs), and therefore are much more durable;
- They are the cheapest option at intersections where the traditional flexible ACP structure works poorly;
- The traffic congestion due to the maintenance of the PCCP is minimal because the repairs are less frequent and to a lesser extent;
- They are generally thinner than ACPs, and it is therefore necessary to dig out less material during reconstruction. This has a particular advantage in urban areas, where it is necessary to move the buried technical infrastructure, or when the depth of excavation is limited in order to avoid this infrastructure;
- PCCP are suitable for part-to-part construction in limited urban areas where large rollers required for ACPs cannot be effectively maneuvered due to spatial constraints;
- Good skid resistance, more reflective materials of a lighter color for paving;
- PCCP are ecologically more acceptable because concrete can be recycled and the materials used for its production are natural and can be recycled (stone, water, cement), as opposed to asphalt which uses some expensive non-renewable materials (oils);
- Portland cement concrete mixes can be easily painted and textured to differentiate and to be visible areas of intersection.

Because the intersection carries traffic from two or more roads, it may be necessary that the thickness and density of the concrete slab be greater than the thickness and density of the access roads. For pavement structures at intersections, the usual thickness of concrete is 12,5 to 25 cm. The exact required thickness will depend on the expected traffic, local conditions, etc.

Based on the excellent performance of the concrete sections observed during some studies, the use of Portland cement concrete is strongly recommended whenever maintenance expenditures at intersections are excessive. Further, PCCP should be considered for use at newly constructed intersections and their approaches.

The adoption of geosynthetic for pavement aims to improve long-term bearing capacity and performance of the road [8]. The use of high-strength, polypropylene grids can be regarded as one way to reinforce an ACP to diminish the distressing effects of traffic such as rutting and shoving. Observations indicate that high-density plastic geogrids placed in the asphalt layers provide some resistance to long-term permanent deformation. However, the key to using these high-strength materials efficiently for ACP reinforcement lies in the ability to suitably install the grid in a manner that it can provide the added tensile strength as designed. It is recommended that high-density plastic reinforcing grids be considered as a rehabilitation option if it can be determined that the geogrids can be suitably installed with minimal difficulties [3].

The major disadvantage with PCCP intersections is the initial construction cost. However, a life cycle cost analysis of PCCP intersections versus ACP reconstruction and future inlays shows that PCCP intersection construction competes with and can be less expensive than rebuilding with ACP [5].

Because budget constraints have often dictated the choice of construction, ACP was the dominant choice, largely due to its lower initial cost. Life cycle cost analyses between ACP and PCCP reconstruction typically are not done. An additional reason for not considering PCCP reconstruction was related to constructability and concerns about accommodating high traffic flows through urban intersections. Rehabilitating urban intersections with ACP requires rotomilling and inlaying with ACP to remove wheel rutting. This work can typically be done at night, in a short period, and with minor inconvenience to the public. Rehabilitating intersections with PCCP, on the other hand, involves the complete disruption of the intersection, as construction for specific areas sometimes must be staged over several days [5].

With rising prices and intense labor costs for concrete pavement construction, the cost of an asphalt intersection is often half the cost of a concrete intersection, sometimes as low as 30% [8]. The reason is simple - asphalt is less costly to build and maintain than concrete pavement, and asphalt is environmentally acceptable since it is recyclable, so it is the life cycle cost solution.

A great advantage of using hot mix asphalt is that it takes significantly less time to construct than concrete. Intersections can be open to traffic within minutes after construction. This results in much less delay and impact on motorists and businesses. In addition, asphalt paving can be completed at night, further lessening the impact of construction on the motoring public and businesses.

Through the use of improved materials and mixture designs developed by the Superpave system, mixes can now be designed for very high traffic level intersections. These new designs and premium mixes can withstand the loadings and conditions that have resulted in rutting, shoving and cracking in the past.

Asphalt street cuts for underground utilities are easier, quicker, and less costly to make - resulting in quicker repairs and less traffic delays than are necessary for concrete intersections. Street cuts often damage electronic traffic detection loops - which are more quickly re-installed in asphalt, lessening traffic flow disruptions [8].

Asphalt provides superior driver visibility for pavement markings, especially at night and during wet pavement conditions. This enhances safety for drivers, bicyclists, and pedestrians. White and yellow stripes show up best against smooth black surfaces - helping drivers to be more aware of crosswalks, stop bars, turn lanes, and off-set line stripes at intersections. In addition, asphalt provides superior skid resistance without special grooving. There are no joints, saw cuts, or grooving required in asphalt pavements, so asphalt intersections can be built smoother than concrete and much quieter. Asphalt is a flexible pavement that can be made to easily conform to the grade changes which occur at intersections.

5. HIGH-PERFORMANCE INTERSECTIONS WITH FLEXIBLE PAVEMENT STRUCTURES

Pavement engineers have adopted a four-point strategy to ensure good performance for intersections and other high-stress applications. A basic intersection strategy consists of four steps [1, 8, 9, 10]:

1. Assess the situation

Two types of pavement evaluations are normally conducted: a functional evaluation and a structural evaluation. A functional evaluation considers the surface characteristics of a road, including certain types of cracking, surface smoothness, noise, and surface friction characteristics. A structural evaluation is used to determine the ability of the pavement structure to carry current and future traffic. A structural evaluation typically requires detailed information about pavement layer thicknesses, paving layer material properties, subgrade support conditions, traffic, and the response of the existing pavement to loading.

2. Ensure structural adequacy

To perform well, an intersection must first have adequate thickness to provide the structural strength to meet traffic needs. Whether new or existing, the thickness of each component of the section must provide structural integrity and be sufficient so that, as a combined unit or pavement section, it will carry the anticipated loads and higher stresses resulting from slower moving traffic. Key factors to consider when ensuring structural adequacy: subgrade strength, frost depth, subbase and base thickness, asphalt thickness, traffic type and loading, drainage [8]. For existing pavements, it is critical that the structural adequacy of the in-place material be evaluated. The key elements of a properly designed intersection include various combinations of quality materials (modified subgrade, geo-synthetic fabrics and mats, aggregate subbase, aggregate base, drainage systems, recycled construction materials, hot mix asphalt). Any failed or weak pavement layers identified during the evaluation process must be removed. Simply paving over existing failed material will likely result in recurring failure.

3. Select high-performance materials and confirm the mixture design

Current technology, known as the Superpave process, provides engineers the necessary tools for improving the performance of asphalt intersections and other high-stress locations. The performance-graded binder system is used to select the proper type of liquid asphalt to bind the aggregate particles together in the finished pavement. This selection is based on each project's expected climatic and loading conditions. One of the provisions for selecting the appropriate performance-graded binder recognizes the need for a stiffer binder for slowed or stopped traffic associated with intersections. This provision, commonly called "grade bumping," rounds up one grade higher for slow-moving traffic or two grades higher for standing or stopping traffic.

While the asphalt binds the pavement together, waterproofs and gives additional stiffness, it is the aggregate structure that actually carries the load. This makes aggregate selection and blending a critical step. The Superpave aggregate requirements (coarse aggregate angularity, fine aggregate angularity, flat and elongated particles and clay content) are used to characterize the aggregates being considered. As the expected traffic loading on the pavement increases, the individual aggregates and aggregate blends must meet higher standards. A successful blend of aggregate must have high internal friction to develop the degree of interlock needed to resist shearing or rutting. Crushed, angular aggregates are a necessity, while rounded aggregate must be avoided in both the coarse and fine portions of the mix.

The purpose of the mix design process is to develop an economical and constructible blend of component materials that will satisfy the engineering requirements of the application. For intersection mixtures, it is particularly important to use a mix design that produces stone-on-stone contact or aggregate interlock. Strong, durable aggregates are a necessity to avoid fracturing the individual aggregate particles.

4. Use proper construction techniques

Use of proper construction techniques is of course important for all pavements and it is critical for high-performance intersections. Three aspects are worth special mention here: proper compaction, avoidance of segregation and proper joint construction.

Proper compaction is vital for long-term durability. The mixture must be properly compacted to resist additional compaction under heavy traffic. Proper compaction also reduces air and water intrusion that could cause accelerated aging which reduces the long-term durability of a pavement.

Segregation occurs when different-size aggregate particles separate in the loose mixture during handling and placement, creating a weaker, more open-textured pavement that is less durable. Best management practices to prevent segregation must be followed closely in intersection work; otherwise, problems may occur.

Proper joint construction techniques, both transverse as well as longitudinal joints, must be executed to prevent the intrusion of air and water at the construction joints.

The quality of a completed project is not only dependent on proper design and good quality materials, but also on using quality workmanship. Issues to be address to ensure quality workmanship are [7, 8, 11]:

- Process control plan - All details of construction, including control of materials and their transportation and placement, need to be covered. A complete schedule of construction activities should be included;
- Compliance with project specifications - Materials delivered to the intersection construction project should be sampled and tested before placement to make sure they are of high quality and in compliance with project specifications. Additional sampling and testing should be performed again during placement and upon a completion of each phase to ensure that they are still in compliance and have been placed or installed properly;
- Utilities - A utility study should be performed to determine if utilities being proposed, or that are already installed, are adequate in size to handle the projected growth within their service area;
- Production and placement - At the start of paving, the volumetric properties of the plant produced material should be re-evaluated. Adjustments should be made to the plant produced material as necessary, so that all of the volumetric criteria remain within the specification limits required for the job mix formula (mix design). During hot mix asphalt paving, it is vital that the contractor

practice proper construction techniques and pay attention to details (achieve target density; avoid the use of diesel fuel in truck beds; do not overheat the mixture; thoroughly clean milled areas; avoid segregation during production, transportation and placement; proper joint construction is important to prevent the entrance of water).

6. RECOMMENDATIONS FOR RIGID PAVEMENT STRUCTURES

Some experiences with constructing PCCP intersections convinced engineers that design and construction details were important [5]. Resulting random cracking and construction difficulties provided valuable learning experiences. Recommendations and conclusions for the use of PCCP at urban intersections are:

1. Construction costs

Full-depth PCCP reconstruction at urban intersections costs approximately 25-30% more than full-depth ACP construction. Construction costs have been lower when urban intersection construction has been included as part of larger ACP resurfacing projects. Traffic control costs typically run 4-5% of the project subtotal when intersection construction is included as part of a larger ACP resurfacing project, and 12-17% of the project subtotal when intersections are constructed as a separate contract.

2. Life cycle cost analysis

The 40-year annualized costs for intersections with and without user delay costs show that full-depth PCCP intersection reconstruction typically costs less than full-depth ACP reconstruction with future ACP inlays when intersection reconstruction is necessary. When user delay costs are used, studies showed that PCCP reconstruction cost is 5,5-14% less than ACP reconstruction. A comparison of the 40-year annualized costs for reconstructed PCCP intersections with and without user delay costs to ACP inlays at four-, six-, and eight-year cycles showed that ACP inlays will always cost less than reconstructing with PCCP at an urban intersection. However, with ACP inlays, the state or local agency must decide whether inlays meet the expectations of the public. The public's view of rehabilitation of the same section of roadway at four-, six- or eight-year-cycles does not reflect well on the agency, even if the section needs rehabilitation because of the distress present. In addition, the public does not appreciate delays during roadway rehabilitation.

3. Traffic management

Reconstruction of PCCP intersections is faster when some type of closure has been used. Intersection projects with minimal or no detours have required 30 to 42 days for the PCCP reconstruction. Allowing at least some type of closure (such as closing minor legs) can shorten the number of construction days to 15 to 20. Full closure of the intersection facilitates the fastest construction period. It is also possible to reconstruct intersections during weekend closures.

4. Design considerations

A key element of constructing PCCP intersections is the planning of transverse and longitudinal joints. Often, state and local agencies are not prepared to make on-the-fly jointing decisions once intersection construction is under way. Therefore, joint planning is necessary to prevent distresses such as sympathy cracks, random cracks, and misalignment of joints with manholes and valves. It is strongly recommended the preparation of jointing plans to be included in contract documents.

5. Construction considerations

PCCP intersection construction requires the same care and consideration as any other PCCP project. However, PCCP intersections require special jointing considerations, especially around curb radii and utility fixtures. Field adjustments are often needed to avoid random cracking. As mentioned under "4. Design considerations", the best way to avoid random cracking is to provide PCCP jointing plans in the contract documents. Even with the best of jointing plans, field adjustments will still be needed, and project personnel need to be aware of the options.

7. CONCLUSION

Most intersections, roundabouts and intersections with crossing of traffic streams, are built using ACP. PCCPs generally have a longer lifetime and are better maintained under heavy traffic (trucks, etc.). However, experience shows that the occurrence of rutting is not a problem with well-constructed ACPs, which is often emphasized as one of the advantages of applying rigid pavement structures (PCCP).

ACPs can be economically maintained to preserve superior ride quality over long periods of time - and smooth roads keep the traveling public happy. Proper design, combined with quality materials and construction workmanship can make hot mix asphalt a long term construction solution for even the most heavily trafficked intersections [8]. When choosing a pavement type, constructability should also be considered. Although PCCP structures are recommended for heavy load areas, with particularly tangential and shear forces, ACPs can be effectively applied if an intersection must be built under traffic, as it can quickly be put into circulation. The decision to use an ACP or PCCP will depend on the local advantages and the type of pavement construction of the access roads.

LITERATURE

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