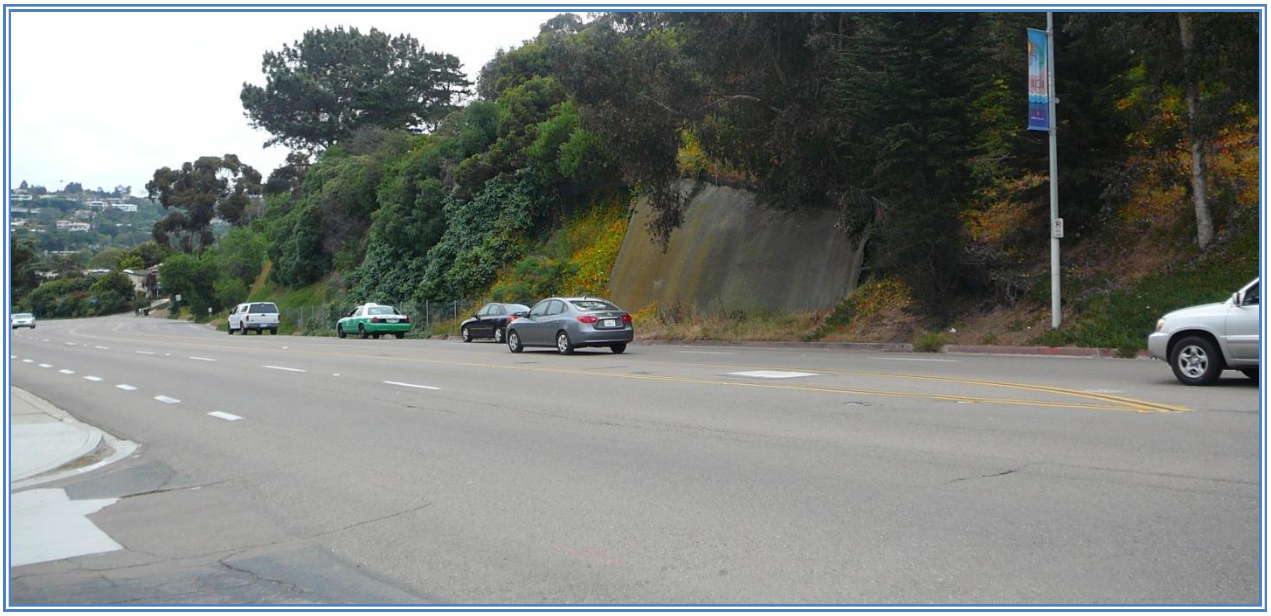
# TORREY PINES ROAD PRELIMINARY ENGINEERING STUDY

## TECHNICAL MEMORANDUM FOR

# MEDIAN OPTIONS



By


***TRAN CONSULTING ENGINEERS***


January 2011

# I. TOPIC DESCRIPTION

Technical items in Torrey Pines Road are being evaluated for a proposed improvement project between Prospect Place and La Jolla Shores Drive. Within the project area medians are intended to be designed and constructed to provide for safe left turns for residents and as a lane for emergency vehicles. This technical memo will look at methods for a safe median.

Median areas are located in the center of Torrey Pines Road throughout the project area.

# I. DISCUSSIONS OF FINDINGS

The proposed improvements will maintain or create a 10-foot corridor between west-bound and east-bound traffic. The median corridor will be available for emergency vehicles and left-turns into adjacent streets and driveways.

## II.1. Median Alternatives

Various commonly used types of medians in California considered are:

- Striping – double yellow lines or single yellow line with a broken stripe
- Striping with speed grooves
- Stamped concrete - Cobble stone appearance
- Grasscrete (with and without a rolled curb)
- Raised medians
- Depressed medians

At the present time the median area is paved with asphaltic concrete and is striped with yellow lines from Prospect Place (Station 10+00) to Roseland Drive (Station 45+00). Beginning at Roseland Drive, there are raised medians as shown in the photo below that continue east to the end of the project. the raised medians should be left or replaced to assure that vehicles from La Jolla Shores Drive don't try to cross traffic to make an illegal left turn. The beginning of the raised median to the west is shown in Picture 2721 below.

Picture 2721 - Raised Median at Roseland Drive

The recommended median type(s) must provide a suitable level of safety for its intended use. Maintenance is also an important consideration. Raised medians are not safe when the intended use is emergency vehicles, which would have a difficult time crossing over them. Depressed medians may create a safety issue if drivers inadvertently wander into the depressed medianand lose control causing an accident. Grasscrete requires some maintenance and watering, which would be difficult and costly in the project area. Therefore these three alternatives are not considered further.

The three remaining alternatives are: double yellow striping, double yellow striping with grooved pavement (or similar effect), and stamped concrete in a cobblestone appearance.

## II.2. Yellow Striping

Currently the pavement median is marked with yellow striping as shown in the Pictures 2361, 3965 and 3966 below. Yellow striping is required to alert motorists of the alignment of the traveled lanes.

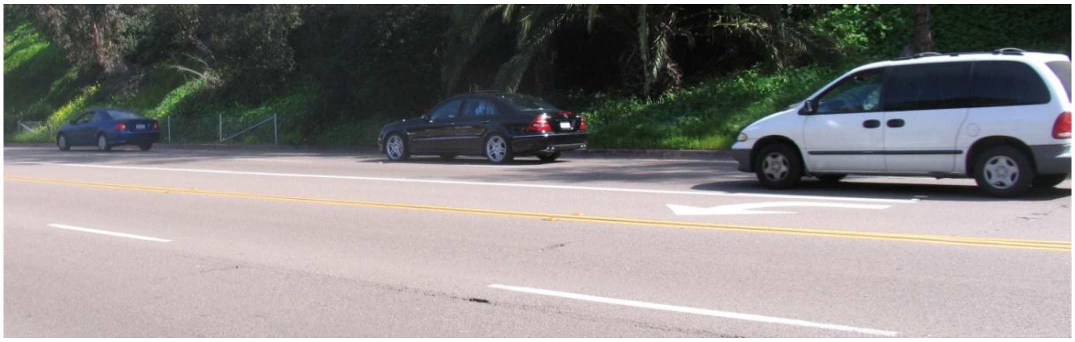
Picture 2361- Two Double Yellow Lines Define the Median

There are solid double yellow lines where there are no houses and no turns are permitted. There is single yellow line and a broken yellow line that defines the median area where turns are permitted for access to driveways. Each of these striping patterns are shown below in the project area.

Picture 3965 - Solid Yellow and Broken Yellow Stripes on Each Side of Median

Picture 3966 - Double Solid Yellow Strips on Each Side of Median

Left turn pockets are marked out in several locations for left hand turns onto side streets as shown in picture 2356 below.



Picture 2356 - Left-Turn Pocket in the Median

Defining the median with striping could be used in the proposed improvement project. It is one of the most common methods and motorists are accustomed to it. It is also the least expensive.

## II.3. Grooved (Rumble Strips) Pavement

In order to provide a possible traffic calming effect, provide a more distinct and safer median; grooves could be placed in the pavement as done along edges of highways to warn drivers when they are out of the travelled way. There are many types of groove patterns, including longitudinal, and transverse, and diamond. This is an added precautionary measure since grooves do not eliminate striping of the highway. Regulations require yellow stripes on each side of the median area. Studies performed have shown throughout the U.S. that grooved pavement has reduced accidents and injuries on rural highways by as much as 20%.

If installed correctly many highway departments find low maintenance cost with grooved pavement. Grooves are relatively easy and cost effective to create. The cost to groove pavement is approximately $3 per square yard.

*Diamond Grooved Pavement*

*Grooved Pavement on freeway (also note decorative strip at edge of shoulder)*

*A Special Effect Material*

## II.4. Stamped Concrete

Caltrans states that "Patterned (or stamped) concrete is standard concrete pavement that is colored and/or stained and imprinted with a pattern prior to curing. Best uses for patterned concrete pavement are in urban and suburban areas at high visibility locations including road edges, median strips and slope paving. Concrete is a good choice when longevity, visual quality and context adaptability outweigh initial cost considerations."

Stamped concrete could be used, which would provide a very distinctive median. Emergency vehicles could easily go over such a surface if designed correctly. It may also provide a traffic calming effect. There is a wide variety of colors and patterns available for use. Left-turn pockets would not have the stamped concrete, just normal pavement with appropriate arrows and other markings. Regulations would require double yellow stripes on each side of the median area.

Maintenance is required. Stamped concrete should be cleaned and resealed every few years, so maintenance costs would be higher than with other alternatives. Repairs can be difficult to match to original color and pattern.

The stamped concrete shown in picture 7 above also acts as a second rumble strip. This may be a more cost effective alternative to stamping the entire median however it does not compare to the lower cost of grooved pavement.

The cost of stamped concrete is estimated to be from $50 to $100 per square foot.

## III. Evaluation and Recommendations

Improvements in Torrey Pines Road involve selecting a safe and effective median for residents and emergency vehicles. Following is a summary of the median

| Median Type | Additional Cost to Striping | Advantages | Disadvantages |
|---|---|---|---|
| Yellow Striping | No additional Cost | Easily visible in good weather familiar to motorists | Sometimes difficult to see in poor weather (rain, fog, etc.) |
| Grooved (rumble strip) Pavement | $1 per foot | Provides alert to drivers who are not alert to their passing into the median.<br>Can be placed on the edge of the median so emergency vehicles do not continuously travel over it. | Must be installed properly |
| Stamped concrete | $50-$100 /square foot<br>Stamped strip cost = $50-$100/ linear foot | Can be highly attractive when decoration is selected properly. | Costly.<br>Higher maintenance<br>Difficult to repair to match pattern or color |

Yellow stripes along both edges of the median are a basic requirement. The addition of grooves is a relatively beneficial and inexpensive addition. Stamped concrete is much more expensive, but provides a special look and may have a traffic calming effect.

It is recommended to include stamped concrete in the median area if monies are available. Otherwise it is recommended to groove the median area on the edges, and stamped concrete can be kept as an option for the future.

## IV. Appendices

1. Caltrans Main Streets: Flexibility in Design & Operations, January 2005
2. A Comparison of Transverse Tined and Longitudinal Diamond Ground Pavement Texturing for Newly Constructed Concrete Pavement by Pennsylvania Transportation Institute Penn State University
3. Design Of Medians For Principal Arterials by Center For Transportation Research the University of Texas at Austin

# APPENDICES

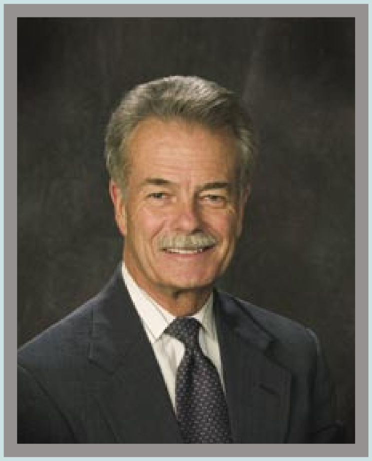
# Main Streets:
## Flexibility in Design & Operations

January 2005

Caltrans

Making main streets more livable

**January 2005**



This booklet emphasizes the California Department of Transportation's (Caltrans) commitment to make state highways that also happen to be local main streets more livable. It is a manifestation of a process that is sweeping rapidly across America – and across California: Context Sensitive Solutions (CSS).

Caltrans recognizes the potential benefits of measures such as reducing the number of lanes through a downtown, reducing lane widths, installing traffic calming devices, lowering speed limits, providing angled parking, wider sidewalks, roundabouts, raised medians and providing other street side amenities that provide a feeling that a town's main street is where you want to be.

None of these measures represent a reduction of Caltrans commitment to safety or mobility; all are within the parameters of the Caltrans Highway Design and Project Development Procedures manuals. Caltrans will continue to require appropriate justification for exceptions to design standards.

Caltrans remains committed to the notion that people live, work and play in the communities through which our facilities pass. It is our duty, by recognizing the needs of both non-motorized and motorized modes of transportation, to assure that living space is a good space in which to live. We are committed to full cooperation with the citizens and elected officials of those communities to find transportation solutions that meet both our duty to protect the safety and mobility of travelers, as well as making main streets an integral part of the community.

Will Kempton

# Main Streets:
## Flexibility in Design & Operations

## APPLICATION OF FLEXIBILITY 4



## TRAFFIC CALMING MEASURES 7

Main streets through a community that also happen to be state highways provide access to businesses, residential roads and other nearby properties. Main streets serve pedestrians, bicyclists, businesses and public transit, with motorized traffic typically traveling at speeds of 20 to 40 miles per hour. Main streets give communities their identity and character, they promote multi-modal transportation, support economic growth, and may have scenic or historic value.

The California Department of Transportation (Caltrans) recognizes the value of a main street to a community and understands that planners and designers need to address community values when developing highway improvements where state highways also serve as main streets. Caltrans is committed to early and continuous public participation to accommodate a community's values into the planning and design of projects.

This booklet identifies Context Sensitive Solutions and Livable Community concepts that can assist communities and Caltrans in balancing community values with transportation concerns for safe and efficient operations for travelers, pedestrians, bicyclists, transit users, and highway workers.

# Application of Flexibility

Caltrans advocates enhancements to state facilities that promote a community's vision and needs. Recognizing that meeting these needs may require flexibility, a process for approving alternative designs exists. This process evaluates each requested deviation for its potential effects on highway safety, regional needs, and the surrounding environment. Deviations from Caltrans policy or standards to meet community requests may require approval of an exception to a policy or nonstandard feature[1]. As previously mentioned, early communication between the community and District staff will help to identify opportunities to meet community needs. These early consultations will also open discussion about options that may not conform to department policy or standards. Since the approval process for a design-related exception is different from operational related policy, District staff will provide guidance on which approvals may be necessary.

This booklet is not intended to supersede existing Caltrans manuals, procedures or practices, but is a compilation of suggested options that may be used to enhance established traffic engineering and design practices, policies and standards.

## Philosophy[2]

The Project Development process seeks to provide a degree of mobility to users of the transportation system that is in balance with other values. In the development of transportation projects, social, economic, and environmental effects must be considered fully along with technical issues, so that final decisions are made in the best overall public interest.

Attention should be given to such considerations as:

- **Need for safe and efficient transportation**
- **Attainment of community goals and objectives**
- **Needs of low mobility and disadvantaged groups**
- **Costs of eliminating or minimizing adverse effects on natural resources, environmental values, public services, aesthetic values, and community and individual integrity**
- **Planning based on realistic financial estimates**
- **Safety, construction and ease of maintaining whatever is built**

Proper consideration of these items requires that a facility be viewed from the perspectives of the user, the nearby community, and larger statewide interests.

## Community Involvement

It's appropriate that Caltrans consider community values in the planning and design of state highways that are also main streets. The Transportation Equity Act for the 21st Century (TEA-21) of 1998 is emphatic on the role of public participation in transportation decision-making. In addition, the federal Interim Policy on Public Involvement requires Caltrans to promote an active role for the public in the development of transportation plans, programs, and projects from early stages of planning through detailed project development, construction, and maintenance. The interim policy also encourages Caltrans public participation programs to aggressively seek out and involve those traditionally underserved.

Extensive community involvement should guide the early planning and design of projects to ensure that projects address local issues and enhance the livability of communities. Identifying stakeholders and forming early partnerships are key to the success of these planning and design efforts.

## Partnerships - Funding and Responsibilities

Successful implementation of Livable Community concepts and Context Sensitive Solutions (CSS) depends on a commitment to the principles of partnership. Although each partner has different roles and responsibilities, the community and Caltrans must commit to working together to develop the best solutions and share responsibility for decisions.

Partnerships are expressed through collaborative transportation problem definition, shared decision-making and a mutual commitment to implementation. Traditional and non-traditional stakeholders must invest in the partnership with an expectation of receiving a return on their investment.

Caltrans recognizes that the construction and operating costs that may occur with the implementation of some livable community and CSS principles are a shared responsibility. The degree of financial contribution is a negotiated process based on roles and responsibilities of each stakeholder.

Early in the planning process, stakeholders should determine their financial commitment for the various elements proposed as part of the highway improvement. Additionally, stakeholders should agree to their role in the maintenance of the main street.

For further information and funding options, please contact the local Caltrans District Office[3] or the Regional Transportation Planning Agency (RTPA).

## Performance Measures


Community support for a highway project is always important, particularly when implementing design concepts such as those discussed here. Caltrans considers public participation a vital part of early project planning and desires full engagement with community members who express interest in implementing a community vision. The level of community support for a project is usually apparent in the planning and project development process. Local funding for elements of construction and maintenance or a commitment to implementing measures such as improvements to adjacent city streets or access management along the main street is a clear indication of community support.

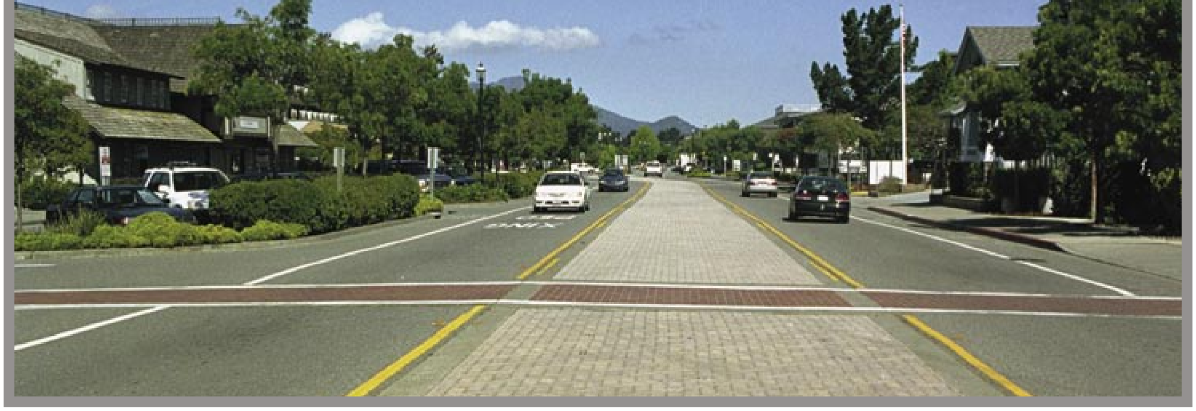
For state highway main street projects, indicators that help determine and confirm compatibility with community values include:

- **Lower motorized operating speeds and improved Level of Service (LOS)[4]**
- **Reduced congestion levels and reduction of motorist delay**
- **Improved pedestrian access and mobility**
- **Improved access to schools and businesses**
- **Improved safety**
- **Improved bicycle accessibility and mobility**
- **Protecting and preserving scenic and historic qualities and attributes**

# Traffic Calming Measures

"Traffic Calming is the combination of mainly physical measures that reduce the negative impacts of motor vehicle use, alter driver behavior, and improve conditions for non-motorized street users."[5]

An important tenet of public participation is that communities understand what traffic calming tools are available, and have input in determining which traffic calming features are considered. Traffic calming measures discussed throughout this booklet can be used to enhance livability of community main streets on state highways.



## Reducing the Number of Lanes

Reducing the number of lanes can provide space for features such as wider shoulders, bicycle lanes, sidewalks, and medians, or the addition of left turn lanes or parking. Reducing the number of lanes may reduce the potential for collisions or may decrease speeds and smooth traffic flow. However, reducing the number of lanes may also reduce the facility vehicular level of service, which may be acceptable to the community.

This strategy is typically considered as a highway transitions from rural to downtown conditions. The main street will typically have an Average Daily Traffic (ADT)[4] of fewer than 10,000 vehicles with approaching and departing two-lane segments and a four-lane facility through town. Consideration should be given to mobility impacts, congestion, collisions, maintainability (particularly sweeping and snow removal), pedestrians, bicyclists, and transit users, as well as adjacent land uses such as schools, parks, libraries, homes and businesses. It's important that strategies such as these be identified as early as possible in the planning and design process.

## Reducing Lane Width

Lane width plays an important role for both motorized and non-motorized users. Wider lanes tend to improve driver comfort. The operations and physical dimensions of cars, recreational vehicles, trucks and buses, the classification or use of the highway and prevailing speeds, all influence the selection of the appropriate lane width. For highways that serve as main streets, particularly those that operate at lower speeds, lane widths narrower than the standard 12 feet may be appropriate. Reduced lane widths in combination with other traffic calming measures may encourage slower speeds, which is desirable for a main street. Where existing right of way is limited, reducing lane widths can provide adequate shoulder width for bike lanes and sidewalks. When considering use of narrower lane widths, the designer should recognize that the narrower lane reduces vehicle separation. A standard 12 -foot outside lane width is preferred where there is significant recreational vehicle and truck traffic or the main street is a designated bus or truck route. The gutter pan is not considered part of the traveled way.

Lane width below 12 feet is a non-standard design feature, which must be approved on a case-by-case basis. A design exception will be required for all cases where lane width is below the minimum standard.

## Transverse Rumble Strips

Transverse Rumble Strips (TRS) are to be used selectively on approaches to a main street where a speed reduction is desired and where speed limit or warning signs are installed. On a state highway, a speed reduction will typically occur in a transition from rural to downtown conditions. The traffic operations personnel should consider a TRS that is compatible with motorcycle and bicycle use.[6] TRS will increase noise for the surrounding areas. Additionally, drainage should be considered, as a TRS might trap water, which could pond in the roadway. Raised TRS should not be used in snow areas because of the potential formation of ice patches. Speed bumps or humps are not approved for use on state highways and are appropriate only for residential, non-state highway use. There is a safety concern that drivers may swerve toward the shoulder to avoid them, decreasing safety for pedestrians, bicycles, and other non-motorized modes of transportation. Many vehicles (especially emergency services vehicles) may detour to other streets to avoid them, which simply shift traffic to other routes and slows emergency service response times. Speed bumps also increase noise for the surrounding area.

## Visual Cues

Visual cues help drivers recognize that they are entering an area of increased pedestrian, bicycle or other non-motorized activity, and in combination with other traffic calming measures may reduce vehicle speeds. Visual cues encourage motorists to park and experience the main street amenities. Examples of visual cues that can reinforce this transition include:

- **"Gateway" treatments, which are typically signs or monuments (see "Gateway Monuments" Section)**
- **Sidewalks, typically accompanied by curb and gutter, to designate portions of the roadway for motorized and non-motorized users**
- **Raised medians or traffic islands, typically installed as an access management technique and to provide a pedestrian refuge area or accommodate landscaping**
- **Landscaping in medians, sidewalk planting strips and planters**
- **Ornamental lighting, planters, benches, trash receptacles, light poles, traffic signals, overhead banners, artwork, bus shelters and other street furniture**
- **Pedestrian signs**
- **Textured crosswalks or intersection pavement**
- **Stop lines set back from crosswalks**
- **Transportation Art (see "Transportation Art" section)**

NOTE: All design elements that can be classified as fixed objects shall be located beyond the minimum horizontal clearance distance[7] or outside the clear recovery zone,[8] whichever is appropriate. Horizontal clearance varies, depending on whether or not the fixed object is adjacent to the sidewalk or the curb in the median.

## Roundabouts

Many communities are beginning to recognize the traffic calming effect of properly designed and located circular intersections. Although their use has been promoted primarily to improve safety, the modern roundabout can provide numerous advantages over conventional intersection traffic control treatments.

Roundabouts can reduce the number and severity of collisions for all highway users. Additionally, roundabouts help to address other benefits such as those described in the bulleted items.

Additional information on roundabouts can be found in Caltrans Design Information Bulletin (DIB) No. 80-01[9] and the FHWA publication: "Roundabouts: An Informational Guide," dated June 2000.[10]

- **Reduce speeds of vehicles**
- **Improve access and traffic circulation**
- **Reduce delay**
- **Reduce the number of through and channelization lanes**
- **Provide more space for bicycle and pedestrian facilities**
- **Improve pedestrian mobility**
- **Reduce fuel and/or energy consumption**
- **Lower vehicle emissions**
- **Provide unique opportunities for landscaping and other aesthetic treatments**
- **Have the unique ability to serve as a physical and operational interface or gateway between rural and urban areas where speed limits change**


## Lower Speed Limit

Caltrans recognizes that many communities would like to reduce the speed limit on their highway segments that serve as main streets. Changing the posted speed limit on a state highway requires an Engineering and Traffic Survey (ETS),[11] and consultation with and consideration of recommendations of the California Highway Patrol and/or local police department. The local city council or board of supervisors of a city or county through which the state highway passes may conduct a public hearing on the proposed change. The results of the public hearing shall be taken into consideration by the local police department in determining the change of the speed limit. Lacking an ETS that supports a lower speed limit, the speed reduction can more appropriately be achieved by creating a transition area using design elements and/or traffic control devices that will naturally reduce the speed of the motorist. If a speed limit is not established in accordance with California Vehicle Code (CVC),[12] such limits cannot be enforced by radar.

If changes are made to a section of the highway that are intended to lead to a speed limit reduction (for example, a roundabout), the District Division of Traffic Operations can recommend that the speed limit be reduced. In this case, Caltrans can place speed limit reduction signage in these areas as an interim solution with the understanding that the interim speed zone cannot be enforced with radar. Thereafter, Caltrans must complete an ETS within six months and the signage must comply with the ETS. Headquarters Traffic Operations staff should be consulted early in this process, and any changes should be approved by the District Director.

## Synchronized Signals

A series of synchronized traffic signals can maintain the vehicular Level of Service and facilitate traffic flow at a given speed.

# Parking


On-street parking may have a traffic calming impact. While parking is necessary to support business and main street uses, parked vehicles cannot be allowed to obstruct a driver's clear line of sight to an intersection. This is especially important for bicyclists traveling on the outermost portion of a roadway and pedestrians or disabled persons who may not be tall enough to be seen above a parked vehicle.

Some communities have expressed interest in angled parking to accommodate more parking spaces on the main street. Angled parking can be forward (nose-in) or reverse (back-in). However, it can create problems due to the varying length of vehicles and sight distance limitations associated with backing up against oncoming traffic.[13]

Angled parking is most feasible when an adequate buffer zone exists that allows vehicles to enter or exit the space without interfering with a bicycle lane[14] or, if there is no bicycle lane, the traveled way of the main street. A painted island is preferred, to separate the buffer area from the through traffic and bicycle lane. If a sufficient buffer area is not available, parallel parking should be used.

## Raised Median Islands

Communities often request raised median islands for several reasons: they provide pedestrian refuge, reduce the scale of the main street, and with added landscaping, make the public space more beautiful. Raised medians also channelize left turn lanes and create a unique visual identity to the corridor. Raised median islands help reduce conflicts between pedestrians and vehicles by allowing pedestrians to cross only one direction of traffic at a time. Raised median islands should be designed to provide enough refuge for pedestrians crossing the street at intersections and designated mid-block crosswalks.

A raised median island may be placed to divert all through traffic from side streets and all left turn movements to the nearest signal or intersection where turns are permitted. Designers must conduct proper analysis to ensure that these intersections can accommodate the added turning movements. Adequate left turn pockets will be needed to provide storage space for the additional vehicles making the left turns and U-turns. Circulation from the side streets may be affected, which could impact local businesses and neighborhoods.

Any enhancement in the island that can be classified as a fixed object, such as a tree, boulder, bollard, monument, signpost, or light pole, must be set back from the island curb face.[8]

Where the island width is insufficient to accommodate enhancements such as those previously described, other design considerations may include eliminating lanes, using vertical curbs, or planting large multi-stemmed shrubs rather than trees. The District Landscape Architect should be consulted about these types of plants. Landscaping within the raised island should not restrict sight distance.[16] The District Traffic Liaison must approve pedestrian crossings and end treatments that use high barriers or vertical curbs as a planter.

Access for maintenance workers and their equipment should be considered in the design of median islands and in the selection of paved surface treatments, plant materials and irrigation systems.[15] Maintenance-efficient curb island design, which may include using water-efficient plantings, is encouraged. Additionally, paving narrow areas less than four feet wide lessens maintenance personnel exposure. It is also important to minimize obstructions that may impair sight distance. Paving the island far enough back from the intersection to provide adequate sight distance can do this.

Areas that receive regular snowfall require careful evaluation for islands due to snow removal considerations.

If the curbed island includes a gutter pan, a shoulder of at least two feet shall be provided from the left edge of traveled way (ETW) to the face of the island curb. The ETW should be delineated with a yellow stripe. The nose of the island shall terminate so that vehicles can easily complete turning movements without obstruction.

**Sidewalks**[17] - For most communities, the preferred sidewalk width in a downtown environment is 10 feet. This width allows pairs of pedestrians to walk side by side or to pass comfortably. More width is desirable to accommodate high volumes of pedestrians, bus shelters, sidewalk cafes[18] and other outdoor users. Any improvements within the Caltrans right of way must follow state law. In general, the wider the sidewalk, the more pleasant the pedestrian experience. All sidewalks and curb ramp design must meet accessibility requirements of the Americans with Disabilities Act (ADA) of 1990.[19]

In general, the use of sidewalks for bicycle travel is not desirable due to conflicts between pedestrians and bicyclists. However, when a sidewalk is designated for bicycle use,[20] it is important to recognize that an extremely wide sidewalk does not necessarily add to the safety of all users. Wide sidewalks encourage higher bicycle speeds and can increase potential for conflicts with motor vehicles at intersections as well as with pedestrians and fixed objects. Also, wider sidewalks may draw other users, including skateboarders, push scooters and in-line skaters.

On-street parallel parking and landscaped sidewalk planting strips can provide a buffer between pedestrians and moving vehicles.

**Pedestrian Crossings** - The principles and practices described in this section apply to pedestrian crossings. However, they also may apply to other types of non-motorized crossings, such as equestrians and bicycles. This section does not apply to school crosswalks.[21] Pedestrian crossings include: markings, signing, overhead signing where the main street displays numerous business signs and other distractions, raised islands for pedestrian refuge, and traffic control systems (e.g., flashing beacons with warning signs or in-roadway warning lights).

**Intersections:** Pedestrian crosswalk markings may be installed where they are needed to channelize pedestrians into a preferred path at intersections. This is typically done when the intended course is not readily apparent or when, in the opinion of the engineer, the crosswalk would minimize pedestrian-auto conflicts. Pedestrian crosswalk markings are not required at every intersection and should not be used indiscriminately.

**Mid-Block Crossings:** Mid-block pedestrian crossings are generally unexpected by motorists and should be discouraged unless, in the opinion of the engineer, there is clear and reasonable justification. Particular care should be given to roadways with two or more traffic lanes in one direction as a pedestrian may be hidden from view by a vehicle yielding the right-of-way to the pedestrian.

**Textured Pavement in Pedestrian Crossings:**[22] In general, stamped concrete and asphalt concrete are preferred over brick or unit pavers when a textured/aesthetic surface treatment is desired. Brick or unit pavers are discouraged because of potential problems related to pedestrians, bicycles and ADA requirements for a continuous, smooth, vibration-free surface. Brick or unit pavers may cause more noise, have a higher initial cost, and in particular, have a potential high cost of maintenance. Installation and maintenance of brick pavers requires skilled labor, storage of replacement materials, extended traffic control, more worker exposure, and replacement will result in added public inconvenience. Any textured or aesthetic cross-

walk surface treatment must also have painted crosswalk markings. The use of textured surface treatments for crosswalks may be considered but requires approval from the District. Proposed textured/aesthetic surface treatment must meet structural section requirements as specified by the District Materials Engineer.

**In-Roadway Flashing Lights:**[23] In California, crosswalk-warning systems such as In-Pavement Flashing Lights are considered traffic control devices. They can be installed in the pavement to warn highway users of a condition that is not readily apparent and may require the road user to slow or come to a stop.[24] Such systems should be considered for use on a state highway only after consultation with the Headquarters Traffic Operations Liaison.[25]

**Sidewalk Bulbouts (Curb Extensions):** Sidewalk bulbouts are extensions of the sidewalk into the roadway at intersections. They are designed to give pedestrians greater visibility as they approach the intersection crossing, decrease the distance they must cross and slow traffic. They often have textured/aesthetic surface treatment and are integrated into the streetscape design.

Sidewalk bulbouts are to be approved for use on a case-by-case basis if they do not meet design standards. A design exception will be required for all cases where a bulbout reduces shoulder width below the minimum standard. Where a bicycle lane exists or is planned in the future, the bulbout shall be designed so as not to extend into the area reserved for the bike lane. It must provide the proper turn radius so that trucks can turn without driving over the curb. It must allow for adequate drainage to avoid ice, leaf and road debris buildup and to allow street sweeper accessibility. In areas of regular snowfall, curb extensions must be marked with objects visible to plow operators. Areas that receive regular snowfall require careful evaluation and may not be good candidates for sidewalk bulbouts due to snow removal considerations.

In areas that serve local schools, a state grant program, Safe Routes to School (SR2S),[26] has been established to fund projects where communities have developed an interest in engineering safer neighborhoods. One of the six categories of projects includes pedestrian and bicycle crossing improvements.

## Street Lighting

Main streets should have adequate lighting for pedestrians to feel secure at night. Decorative lighting fixtures enhance a downtown's unique sense of place. Decorative lighting or traffic signal fixtures may be used provided they meet current federal and state safety standards.[27] Poles and signal controller boxes must be placed outside of the pedestrian area of the sidewalk. Poles in the median must meet specific traffic safety standards. Caltrans staff will provide the appropriate information on safety requirements for lighting fixtures.

Caltrans is mainly involved in lighting for safety as warranted by federal guidelines. Continuous main street lighting that is not warranted by Caltrans is the responsibility of the local agency. Selection of decorative lighting fixtures should involve the local community and local agency. It will be the local community's responsibility to determine the type of fixtures and the local agency's responsibility to secure funding for installation, operation and maintenance of continuous main street lighting.

## Furnishings

Street Furnishings include benches, kiosks, bollards, bike racks, planters, etc. Street furnishings provide pedestrians a place to rest and socialize. To enhance pedestrian activity, a main street may include places to sit, such as benches, low walls, planter edges or wide steps. The presence of pedestrian gatherings reminds motorists that streets have other public uses. Furniture layouts for sidewalks must place these objects away from the pedestrian path. Tables for dining are not appropriate within Caltrans right of way except under a special event permit.

Bike racks and bollards should be placed beyond minimum horizontal clearance requirements[7] and away from the pedestrian area of the sidewalk. Bollards must be tall enough so they do not create a tripping hazard to pedestrians.

Furnishings must not compromise ADA requirements. If there is lack of adequate street lighting, the furnishings may have to be lighted by other means to avoid being a tripping hazard.

## Street Landscaping

Street landscaping makes downtowns more livable, beautiful and unique to the town. Quality landscaping along the roadway, close to the highway or in medians can increase driver awareness of the immediate environment and may alter driver behavior, resulting in slower speeds and a safer main street. A row of trees may calm traffic by making the road appear narrower. Street trees add an attractive canopy over the main street and may increase comfort for pedestrians. They create comfortable spaces


and soften lighting. They cool streets in the summer, and provide a windbreak in the winter. Trees also create distinctive identity and seasonal interest. However, caution should be exercised while considering trees along the roadway that might extend over the traveled way in snow areas. Snow accumulation may cause branches to break and fall. Also, shade from trees may cause "black ice" conditions in areas where freezing temperatures are prevalent.

For visibility, trees must be located and maintained properly, and not impair corner sight distance. Avoid blocking visibility for turns into and from intersections and driveways, obstructing driver's line of sight to oncoming traffic, blocking visibility of stop signs or other roadside signs, and decreasing visibility for pedestrians and bicyclists at intersections. Trees must also conform to Caltrans minimum setback requirements for clear recovery zones.[8]

Trees planted along a main street must not present a barrier for any mode of transportation on the highway. The District Landscape Architect should review any proposed plant material and recommend appropriate installations related to aesthetics, safety, cost, and maintainability.

The characteristics, growth habits, and species are very important when selecting street trees and other plant material. Special consideration should be given to the root system and the characteristics of the tree at maturity. All plant material requires regular maintenance. Contact the District Landscape Architect for technical expertise on plant characteristics that will suit specific site locations. Proper selection of plant material will ensure reduced maintenance problems and increase safety for highway users and workers.

## Banners and Decorations[28]

Caltrans reviews submittals and issues permits for the erection of banners, decorations and temporary signing over and within conventional highway rights-of-way for events sponsored by local agencies and nonprofit organizations. Banners, decorations and temporary signing must be placed beyond minimum horizontal and vertical clearance requirements.

Authorized banners and decorations over the roadway must have a minimum vertical clearance and be suspended securely from permanent structures or poles. Temporary supports are not allowed and the use of state facilities, including but not limited to intersection signals, overhead signs or light poles, is prohibited.

Permanent overhead signs or arches may not be erected or suspended over any state highway.

Non-Decorative Banners are intended to convey a message such as the occasion of an event or activity. Caltrans issues permits for non-decorative banners to local agencies or nonprofit organizations sponsoring an event the local agency has approved. Banners displaying private advertisements are not allowed except when used as part of an event's official title (e.g., Kellogg's Napa Valley Marathon).

Districts may issue biennial permits to local agencies for installation of non-decorative banners for recurring events. The local agency then authorizes each banner installation, notifies the state's representative, and provides traffic control.

Decorative red, yellow or green lights or decorations that may be confused with any traffic control device shall not be placed where they could interfere with the driver's perception of traffic signals.


Decorative Banners are intended to convey brief text or logos identifying the local agency. Decorative banner permits may be issued by a local agency for enhancement of its main street. As a minimum, decorative banners shall:

- **Be used exclusively on conventional state highways**
- **Not contain advertising whether in text or logo format**
- **Remain in place for periods up to two years - the normal biennial permit duration**
- **Have an approved Caltrans encroachment permit where the local agency is the applicant**

Decorations that extend beyond the curb line or cross the highway shall have a minimum vertical clearance above the highway pavement. Decorations attached to a non-state vertical structure such as power, telephone or light poles, or buildings are not to project beyond the curb line and meet the minimum vertical clearance requirements above the sidewalk. Decorations shall not be attached to State owned facilities such as traffic signals.

Holiday decorations are permitted on conventional state highways.

## Gateway Monuments[29]


A gateway monument is defined as any freestanding structure or sign, not integral or otherwise required for the highway facilities that communicates the name of a region, community or area.

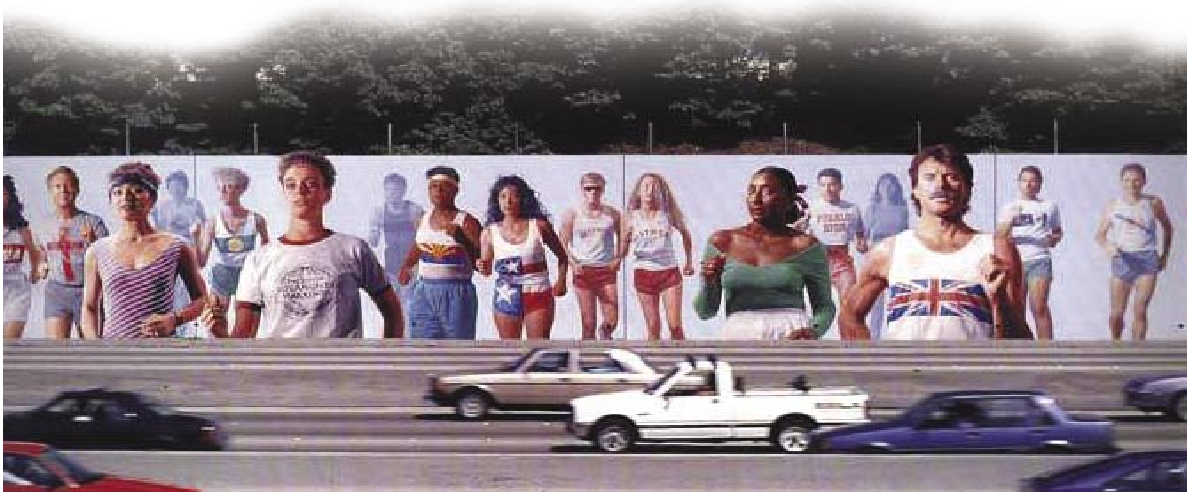
Guidelines for Gateway Monuments, issued in 2005, contain additional information.

## Transportation Art[30]

There is often a local desire to make existing transportation facilities more context sensitive to the local community to reflect the aesthetic, cultural and environmental values of the community through which the facility runs. Transportation Art is defined as authorized artwork created, constructed, or painted on structures or other facilities or spaces within Caltrans right-of-way.

It is Caltrans intent, by means of its Transportation Art Program, to encourage others to use its facilities, structures and right-of-way spaces for creative expression through the visual arts. Well-conceived art forms, properly located, can enhance the experiences of those using transportation facilities and enrich the environment of neighboring communities.

Placement of such artwork is conditional on appropriate maintenance agreements and assurance that its maintenance does not create safety concerns on the state highway.



## For Internet Access to references visit Caltrans websites:

Design Information Bulletins, Highway Design Manual, or Project Development Procedures Manual:
**http://www.dot.ca.gov/hq/oppd/guidance.htm**

Encroachment Permits Manual:
**http://www.dot.ca.gov/hq/traffops/developserv/permits/encroachment_permits_manual/index.html**

Traffic Manual:
**http://www.dot.ca.gov/hq/traffops/signtech/signdel/trafficmanual.htm**

FHWA Manual on Uniform Traffic Control Devices (MUTCD), 2003 Edition and the MUTCD 2003 California Supplement:
**http://www.dot.ca.gov/hq/traffops/signtech/mutcdsupp/supplement.htm**

For Internet Access to this booklet visit Caltrans website:
**http://www.dot.ca.gov/hq/oppd/context/main-streets-flexibility-in-design.pdf**

## References:


[1] Highway Design Manual Topic 82

[2] Highway Design Manual Topic 81

[3] Caltrans District Local Office website at: http://www.dot.ca.gov/localoffice.htm

[4] For a definition of Level of Service (LOS) and Average Daily Traffic (ADT), see Traffic Manual, Section 1-04

[5] ITE Journal, July 1997, p.23

[6] For further information on Transverse Rumble Strips (TRS), see MUTCD, 2003 Edition and MUTCD 2003 California Supplement, Section 3B.106

[7] Highway Design Manual Topic 309.1(3) (c)

[8] Highway Design Manual Topic 309.1(2)

[9] For more information, see Design Information Bulletin (DIB) 80-01 website at: http://www.dot.ca.gov/hq/oppd/dib/dib80-01.htm

[10] FHWA "Roundabouts: An Informational Guide" (June 2000) and other Roundabout guidance are available on FHWA's website at: http://www.tfhrc.gov/safety/00068.htm

[11] FHWA MUTCD, 2003 Edition and MUTCD 2003 California Supplement, Chapter 2B

[12] California Vehicle Code (CVC) section 22354 and 22354.5 at Department of Motor Vehicle's website: http://www.dmv.ca.gov/pubs/vctop/vc/tocd11c7a1.htm

[13] FHWA MUTCD, 2003 Edition and MUTCD 2003 California Supplement, refer to Parts 1A, 2B, 3B, 6C

[14] Highway Design Manual, Chapter 1000 – Figure 1003.2A for bike lane and parking configurations

[15] Highway Design Manual, Index 902.1(1) (b) and (c)

[16] Highway Design Manual, Index 902.2(2)

[17] Highway Design Manual, Topic 105

[18] Check with the District Encroachment Office for Permit Requirements at: http://www.dot.ca.gov/hq/traffops/developserv/permits/pdf/manual/Appendix_G_(WEB).pdf

[19] American Disabilities Act Title 28 of the Code of Federal Regulations (CFR) Part 35, all pedestrian facilities constructed must meet accessibility requirements

[20] Highway Design Manual, Index 1003.3

[21] FHWA MUTCD, 2003 Edition and MUTCD 2003 California Supplement, Part 7

[22] Must meet criteria specified for crosswalks in FHWA MUTCD, 2003 Edition and MUTCD 2003 California Supplement

[23] Chapter 4.L. "In-Roadway Lights" of the FHWA MUTCD, 2003 Edition and the MUTCD 2003 California Supplement

[24] For additional information see North Carolina Highway Safety Research Center Report on In-Pavement Flashing Lights Crosswalk Warning System, April 1998.

[25] For the appropriate Headquarters Traffic Operations Liaisons contact the District Traffic Office

[26] For more information on the Safe Routes to School (SR2S) Program see the website at: http://www.dot.ca.gov/hq/LocalPrograms/

[27] Caltrans adheres to lighting requirements as warranted in the FHWA MUTCD, 2003 Edition and MUTCD 2003 California Supplement

[28] Encroachment Permits Manual, Sections 501.7

[29] Encroachment Permits Manual, Section 501.3F
Project Development Procedures Manual, Chapter 29, Section 9

[30] Project Development Procedures Manual, Chapter 29, Section 6


## Caltrans Contact Information:

For additional copies of this document, please contact the publications staff.

(916) 323-5606 and (916) 445-3520 phone
(916) 324-8997 fax

California Department of Transportation
Publication Distribution Unit

1900 Royal Oaks Drive
Sacramento, CA 95815-3800
or view online at
http://www.dot.ca.gov/hq/oppd/guidance.htm

For individuals with sensory disabilities, this document is available in Braille, large print, on audiocassette, or computer disk. To obtain a copy in one of these alternate formats, please call or write to:

(916) 227-9408 Voice
(916) 227-8428 TTY

Caltrans Office of Equal Opportunity
1120 N Street, Rm. 1220, MS 48
Sacramento, CA 95814

# A Comparison of Transverse Tined and Longitudinal Diamond Ground Pavement Texturing for Newly Constructed Concrete Pavement

Prepared for:

The Transportation Research Board

November 2001

Paul L. Burgé
Senior Consultant
Acentech Incorporated
33 Moulton St.
Cambridge, MA 02138
Phone: 617-499-8012
Fax: 617-499-8074
E-mail: pburge@acentech.com

Keith Travis, P.E.
Senior Transportation Engineer
Parson Transportation Group
300 Cathedral Park Tower
37 Franklin Street
Buffalo, NY 14202
Phone: 716/853-6940 x221
Fax: 716-853-6192
E-mail: keith.travis@parsons.com

Dr. Zoltan Rado
Pennsylvania Transportation Institute
Penn State University
201 Transportation Research Building
University Park, PA 16802-4710
phone: 814-863-7925
fax: 814-865-3039
e-mail: zxr100@psu.edu

**ABSTRACT**

The purpose of this study is to provide a comparison of longitudinal diamond ground and transverse tined pavement surface texturing for newly constructed Portland Cement Concrete Pavement (PCCP). The study area is located along a test-section of I-190 in Buffalo, New York. The two PCCP surface treatment types being evaluated in this report are compared based on safety, noise, construction cost, service life, rideability, handling, and maintenance requirements. This paper documents the initial evaluation and also analysis of follow-up noise and skid resistance measurements conducted approximately one year later.

Analysis of the initial testing indicates that the relative skid resistance of the experimental longitudinal diamond ground surface is as good or better than that of the transverse-tined surface. The results of the noise analysis indicate that the longitudinal diamond ground surface is 2 to 5 decibels quieter depending primarily on the traffic vehicle mix. Noise and skid resistance measurements conducted one year later showed little change. While less construction time was required for the transverse tined pavement as compared to the diamond ground pavement, the actual cost difference is not quantifiable. However, a higher initial cost for longitudinal diamond grinding would likely be partially offset by an extended service life.

## INTRODUCTION

Surface texturing of concrete pavement is required on projects funded by the Federal Highway Administration (FHWA) to reduce skidding under wet pavement conditions. PCCP surfaces are often finished with a transverse tined texture during construction to increase skid resistance. Alternate pavement surface treatments are occasionally considered in an effort to reduce the tire-pavement noise associated with the traditional finish. However, a compromise in the safety or a reduction in the effective service life along with significant added construction costs would be undesirable side effects resulting from efforts to achieve a reduction in traffic-generated noise levels.

As part of a New York State Thruway Authority (NYSTA) highway reconstruction contract, a new PCCP surface texturing technique was implemented along portions of the Niagara Section of the NYS Thruway, Interstate 190 (I-190). The experimental surface treatment (longitudinal diamond ground texturing) was implemented adjacent to noise-sensitive areas in lieu of the conventional transverse tined concrete surface texturing method currently approved by the FHWA.

The purpose of this study is to provide a comparison of key performance characteristics between longitudinal diamond ground and transverse tined pavement surface texturing for newly constructed PCCP.

The test section of the highway included newly constructed segments of both traditional transversely tined PCCP and the experimental longitudinal diamond ground PCCP. Sample sections of both pavement types were included on both northbound and southbound lanes. The test-section of northbound pavement was opened to traffic in December of 1999. The test-section of southbound pavement was opened to traffic in December of 1998.

### Approach

The two PCCP surface treatment types evaluated in this study are compared based on safety, noise, construction cost, service life, rideability, handling, and maintenance requirements. Comparisons are made on a section of highway of the same construction (other than surface treatment) and exposed to the same traffic and weather conditions.

Skid testing and accident reports are used to evaluate safety characteristics. Noise measurements and analytical modeling are used to compare the traffic generated noise levels. The unit price bid by the awarded construction contractor is used to compare relative construction costs. User surveys are used to obtain feedback from highway maintenance personnel, state police and the general traveling public to assess differences in rideability, handling, and maintenance requirements. Each of the aforementioned characteristics will be monitored over a period of five years to assess the service life of each PCCP surface treatment.

This paper reports the results and analysis of construction cost data and the initial set of noise and skid resistance measurements plus follow-up measurements conducted approximately one year later. Additional follow-up noise and skid-resistance measurements will be conducted annually through 2005 in order to continue documenting changes in pavement properties.

## MATERIALS AND CONSTRUCTION DETAILS

Construction practices and materials used for the pavement test sections were kept as consistent as possible between the two pavement types except for the actual surface treatments, as detailed below.

### Materials

Characteristics of the PCCP used on the portions of the I-190 relative to this study are typical of new PCCP construction in this region.

### Construction

*Paving*

The unreinforced PCCP has transverse joints spaced at 5.5 meters. The transverse joints were saw-cut at a width of approximately 11 mm. Transverse joints were then beveled and a preformed neoprene joint sealer was installed leaving a 6.5 to 9.5 mm finished joint depth. The joint width and depth was kept as small as practical to help reduce wheel noise sometimes referred to as "tire-slap".

*Transverse Tined Texturing*

Transverse tined texturing was performed as per NYSDOT Special Specification: *Item 25502.070299 - Cement Concrete Pavement, Unreinforced, Class C, Profilographed*.

Immediately after finishing operations were completed and prior to the application of curing compounds, the surface of the concrete was textured with a set of randomly spaced spring steel tines in a direction perpendicular to the centerline of pavement (transverse). The individual tines were 3.1 mm wide, 0.71 mm thick, and 127 mm long. The tine spacing, size, and depth is a result of research that has been performed in an effort to minimize tire-pavement noise or "wheel-whine" characteristic of tined pavement surfaces (*1*). Although acoustical spectral data is not presented in this paper, we note that the randomly spaced tining effectively prevented audible whine and other tonal characteristics.

*Longitudinal Diamond Ground Texturing*

The longitudinal diamond ground texturing was performed as per NYSDOT Special Specification: *Item 25502.5010 - Full Diamond Grinding and Texturing of Concrete Pavement / Profilographe*d.

Diamond grinding involves the removal of a thin layer of the cured concrete surface using a machine with closely spaced diamond-coated circular saw blades. The diamond blades are spaced such that the thin fins of concrete left between the blade cuts break off during the grinding process, leaving a level surface with longitudinal texture. The grinding head contained 166 saw blades (3.18 mm thick), set at 2.67 mm spacing.

### Construction Duration and Cost

Both construction duration and bid price were compared to determine the cost differential between the two pavement surface treatments. Construction duration is an important factor because additional construction time would result in additional delays to the traveling public. Also, the contractor would include the cost of extended construction duration in the bid prices for maintenance and protection of traffic (MPT) and related construction items.

*Construction Duration*

For the subject contract (TAN 97-91), less construction time was required for the transverse tined pavement as compared to the diamond ground pavement.

The operation of tining was automated. It was performed from the same work-bridge and during the same work operation as the floating/finishing. Therefore, the production rate is only slightly increased over that where no tining is required (as would be the case in preparing the surface for diamond grinding).

The rate of the diamond grinding process varies depending on equipment horsepower, aggregate hardness, condition of the cutting blades, and the depth of the cut. For this project, the grinding rate was approximately 0.6 lane-Km per day (0.4 lane-miles/day). In addition there was a 7-day minimum curing time required prior to grinding. The diamond grinding process was completed over continuous highway sections during an independent construction sequence.

*Cost*

From the information available on the subject contract, there is inadequate information to determine the precise cost difference between the two surfacing techniques.

The price bid for the diamond grinding item on this project was \$3.15/m$^2$ (\$3.75/yd$^2$). The average industry cost is \$2.10/m$^2$ (\$2.50/yd$^2$) (*2*). The increased cost above the industry average is likely due to the fact that diamond grinding is a relatively new industry to the area. The subcontractor was brought in from out-of-state, and the test areas for grinding were relatively small, both of which cause the cost per square yard to be higher. Also, additional time to grind or float finish the pavement is sometimes needed to achieve required tolerances before tining.

## PAVEMENT NOISE ANALYSIS

Research has shown that different commonly used pavement materials and treatments can have a significant influence on highway-generated noise levels (*3*,*4*). The pavement noise analysis for this study uses a combination of noise measurements and analytical noise modeling to evaluate the relative acoustical performance for the two candidate pavement types for both empirical and theoretical highway traffic conditions.

### Noise Measurements

A series of traffic noise measurements were conducted along the northbound lanes of the test section between April 11 and April 20, 2000. Noise measurement and analysis procedures were consistent with specifications in *Measurement of Highway-Related Noise* (*5*) and *Development of National Reference Energy Mean Emission Levels for the FHWA Traffic Noise Model* (*4*). The measurement program included single vehicle pass-by measurements, drop-off vehicle noise measurements, and aggregate traffic noise measurements.

*Single Vehicle Pass-by Measurements*

Single vehicle pass-by measurements were conducted for both longitudinal ground, and transverse tined pavement types. Measurements were conducted between 11 PM and 6 AM, in order to better capture isolated individual vehicle events.

The single vehicle pass-by measurements were conducted in accordance with documented procedures for the development of Reference Energy Mean Emission Levels (REMEL's) used in the FHWA Traffic Noise Model. Due to project terrain constraints, the recommended 15 meter (50 foot) reference measurement positions were not available for both pavement types. Therefore, the single vehicle pass-by measurements were conducted at a distance of 7.5 m (25 ft) and adjusted to the 15 m (50 ft) reference distance using the measured drop-off correction.

The results of the single vehicle pass-by measurements (adjusted for the reference distance) were graphed to show individual vehicle data points. Linear regressions representing each pavement surface type were calculated for automobile, medium truck, and heavy truck types. An example of the data and regression curves for autos and light trucks care shown in Figure 1. Similar graphs were generated for medium trucks and heavy trucks.

*Drop-off Noise Measurements*

The primary single vehicle measurement site, near the interface of the two pavement types did not allow for the required 15 meter wayside measurement position due to an existing embankment. A secondary measurement location was selected in order to measure the single vehicle drop-off correction. An average drop-off correction value of 6.2 dB was measured for all vehicle types.

*Aggregate Traffic Measurements*

Long-term (24 hour) aggregate traffic noise measurements were taken in order to determine the loudest hour of the day for the study area.

Short-term (1-hour) aggregate traffic noise measurements were collected during the loudest hour of the day concurrently with classified traffic counts to identify time-averaged noise level for both pavement types and associated traffic mix.

**Traffic Noise Model Analysis**

The FHWA Traffic Noise Model (TNM) is a Windows computer based analytical model that predicts traffic generated noise levels. The program predicts hourly average noise levels in A-weighted decibels (dBA) based on traffic volumes and mix, roadway and landscape topography, and other factors. The program uses Reference Energy Mean Emission Levels (REMELs) for a variety of vehicle types (autos, medium trucks, heavy trucks, buses and motorcycles) for a number of standard pavement types, including standard PCCP, dense grade asphalt, open grade asphalt, and an average of all pavement types. The program also provides for the input of user-defined REMELs for special vehicle types.

*TNM User Defined Vehicles Parameters*

Using single vehicle pass-by measurement data for each pavement type, parameters required to specify user-defined vehicles in FHWA's Traffic Noise Model (TNM) were developed for each of the three primary vehicle types (autos, medium trucks, heavy trucks) . User-defined vehicle parameters were developed for both pavement types. Table 1 summarizes input parameters developed from the noise measurements, along with 95% confidence limits for the linear regression of each vehicle/pavement type.

The "minimum level" parameter specified in Table 1 is representative of low speed vehicle noise, where the noise level is assumed to be dominated by engine/exhaust noise (independent of tire-pavement noise contributions). Because the data collected for this study is limited to vehicles traveling at highway speeds (80 to 140 km/h), the published TNM standard minimum levels for each of the three vehicle types is used.

TNM runs using new REMEL parameters for the candidate pavement types were validated to within approximately one decibel when compared to aggregate noise measurements.

*TNM Vehicle Mix Scenarios*

Four theoretical traffic mix scenarios were developed as a comparison parameter for pavement noise levels as follows:

1. Parkway: 100% autos and light trucks.
2. Light truck usage: 95% autos and light trucks, 5 % medium and heavy trucks.
3. Moderate truck usage: 80% autos and light trucks, 20 % medium and heavy trucks.
4. Heavy truck usage: 60% autos and light trucks, 40 % medium and heavy trucks.

*TNM Predicted Noise Levels*

Employing the user-defined vehicle parameters generated from the pavement specific pass-by data (presented above), TNM was used to predict traffic noise levels for a variety of conditions. The scenarios evaluated include variations of the following factors:

- Pavement Type - Two candidate pavement surfaces (longitudinally ground and transverse tined) plus the standard TNM “average” pavement type.

- Vehicle Mix - Four different vehicle mix scenarios, as defined above. All vehicles are assumed to be traveling at a steady cruise speed of 108 km/h (65 mph).

- Receiver Distance - Receiver distances of 30, 60, and 90 meters from mainline traffic lanes.

- Line of Sight Obstructions - For each pavement type and receiver distance, both obstructed and unobstructed line of sight conditions are evaluated. For the unobstructed case, a clear line-of-site from traffic to the receivers is assumed. For the “obstructed” case, a typical 1 meter high “jersey barrier” at the edge of the pavement between the traffic and the receivers is assumed. Aside from the jersey barrier, all other elements (roadways, receivers) are modeled at zero elevation (all receivers are modeled to be 1.5 meters above the nominal elevation).

For modeling purposes using TNM, it is assumed that a total of 6000 vehicles per hour split evenly between northbound and southbound directions. Table 2 shows the predicted TNM noise levels at the modeled receiver locations for each of the modeled scenarios.

The results of the TNM modeled scenarios are shown in Figures 2, 3 and 4. Figure 2 shows the relative difference in noise level as a function of receiver distance from the roadway centerline. Two curves show the predicted difference for an unobstructed observer’s view of the roadway and for a view partially obstructed by a 1 meter high jersey barrier at the near edge of the roadway. Figure 3 shows the relative difference in noise level as a function of average vehicle speed, with difference curves for each of the four vehicle mix scenarios. Figure 4 shows the noise level difference as a function of percent heavy truck usage for typical highway speed.

## Noise Data Analysis and Results

The results of the analysis conclude that the longitudinally ground pavement is quieter than the transverse tined pavement by approximately 2 to 5 dBA, depending primarily on the vehicle mix.

The short-term aggregate traffic noise measurements conducted along the study test section during the peak noise hour (which generally corresponds to a light to medium truck usage mix scenario) show that the longitudinal ground pavement is about 3.0 dBA quieter than the transverse tined pavement. Aggregate traffic noise measurement conducted approximately one year later showed essentially no change in absolute or relative noise levels.

The single vehicle pass-by regression analysis indicates that the longitudinally ground pavement does not provide the same acoustic benefit to all vehicle types uniformly. The longitudinally ground pavement provides approximately 5 dBA noise improvement for automobiles and light trucks relative to the transverse tined pavement, but only about 2 dBA improvement for medium and heavy trucks. This result was expected since automobile noise levels are dominated by tire-pavement noise at highway speeds, while engine and exhaust noise (which is independent of pavement type) makes a significant contribution for heavy and medium trucks at highway speeds. This suggests that higher percentages of heavy and medium trucks using the roadway would diminish the relative acoustical advantage of the longitudinally ground pavement. This conclusion is supported by the TNM predicted noise levels, which indicate that the longitudinal ground pavement would be approximately 5.4 dBA quieter than the transverse tined pavement the parkway scenario (100% autos) but only about 2.2 dBA quieter for the heavy truck usage scenario (Figure 4). A 2 dBA difference in noise level is generally below the threshold of a perceptible difference to the average human ear.

The comparison of TNM predicted noise levels also suggests that receiver distance and small line of sight obstructions (such as a jersey barrier) play a lesser role in the relative noise levels of the two pavement types (Figure 2). The presence of a jersey barrier reduced the relative benefit of the longitudinally ground pavement by less than 0.5 dBA. The influence of distance on the relative difference in noise levels of the two pavement types was 0.3 dBA or less. The influence of vehicle speed on relative noise level was generally less than 0.5 dBA depending on vehicle mix, over the range of typical highway speeds (Figure 3).

## SKID TESTS AND MACROTEXTURE MEASUREMENTS

Skid resistance and macrotexture measurements were performed in April, 2000 and June, 2001. Tests were conducted on the longitudinal diamond ground and transverse tined PCCP surfaces in the northbound lanes (constructed in 1999) and the southbound lanes (constructed in 1998). Tests were performed in both the driving lane and passing lane.

Skid resistance measurements were made at 67, 83 and 100 km/h (40, 50, and 60 mph) on each surface treatment with both blank and ribbed test tires. Skid resistance is defined as the retarding force generated by the interaction between a pavement and a tire under a locked-wheel condition (*6*). To ensure that measurements made at various times and places can be compared with each other, a standardized tire was used and a standard amount of water was applied to the dry pavement ahead of the tire. The details of the skid resistance test procedure are described in the *ASTM E 274* (*7*). The details of the blank and ribbed standard test tires are described in the *ASTM E 524* (*8*) and the *ASTM E 501* (*9*) respectively. A minimum of five measurements per test section were conducted and used to calculate an average for each test section. The results of the pavement skid test are reported in Table 3 as the skid number (SN).

The values reported in Table 3 are reasonable and are considered accurate in accordance with ASTM standards. The effect of speed is consistent and as expected (SN decreases when speed increases) for the average SN. The acceptable precision of SN units can be stated in the form of repeatability. ASTM E 274 suggests an acceptable standard deviation of 2 SN units.

The two different test tires were used to measure two different pavement surface characteristics. Tests performed using the blank (smooth) test tire represent the pavement's macrotexture, while measurements made with the ribbed test tire best represent the pavement's microtexture. In general, microtexture provides the frictional capability of dry pavement. Macrotexture provides the drainage capability at the tire-pavement interface and therefore how effective the microtexture will be when the pavement is wet.

Good microtexture is obtained by using suitable aggregate in the pavement surface. Fine aggregates containing a minimum of 25% siliceous sand; durable non-polishing coarse aggregates, a low water to cement ratio, adequate air content, adequate cement factor, and good curing practices are all necessary to obtain high-quality durable concrete (*10*).

To further investigate the pavement surface's macrotexture, mean texture depth (MTD) measurements were performed. This measurement involves spreading a known volume of glass spheres on a clean, dry pavement surface, measuring the area covered, and calculating the average depth between the bottom of the pavement surface voids and the top of surface aggregate. Ten mean texture depth measurements were made in each of the eight test sections. The tests were conducted in accordance with *ASTM E 965* (*11*). The average mean texture depth for the longitudinal diamond ground surfaces was 0.58 mm in 2000 and 0.46 mm in 2001. The average mean texture depth for the transverse tined surfaces was 0.58 mm in 2000 and 0.53 mm in 2001. Data for both surfaces indicate a small drop in macrotexture for the one-year period.

The standard deviation of repeated MTD measurements by the same operator on the same surface can be as low as 1% of the average texture depth. The standard deviation of different measurements within the same site (pavement surface) may be as large as 27% of the average texture depth (*11*).

## Analysis of Data

Skid resistance becomes a major factor in traffic safety when the pavement is wet. However, skid resistance is not the only factor affecting wet pavement safety. Other factors include: traffic characteristics (speed, density, percentage of trucks), road geometric configuration (horizontal curvature, vertical alignment, and super-elevation), driving difficulty (signalization, presence of turning lanes and weaving movements, surrounding land use, and number of access points), and pavement wet time (average period of time during a year when the pavement is wet) (*12*). All of these factors interact in a manner that is very difficult to analyze in quantitative terms. This is the main reason for the lack of nationally accepted minimum skid resistance values that could be used as safety thresholds.

Having recognized that skid resistance alone does not determine the level of wet pavement safety, the ranges of 35 to 40 for ribbed tire skid resistance and 20 to 25 for blank tire skid resistance, (both measured at 65 km/h) have been recommended in the past as the minimum values that should apply to highway pavements in general (*13*). These values were based on a trend that was observed in a study of wet-to-dry pavement accidents versus skid number in the State of Kentucky. The Pennsylvania State Department of Transportation uses the recommended lower values (35 and 20) in addition to certain accident criteria as thresholds to erect "Slippery When Wet" signs until the pavement surface friction characteristics could be improved. All sites in this study have skid resistances above those ranges.

When arranging the mean texture depth data in an order from the most to the least exposure to traffic, the 2000 MTD data of the experimental longitudinal diamond ground surface demonstrate a decline from 0.71 to 0.53 mm. The transverse tined surface remained virtually unchanged at 0.56 mm. The data from 2001 testing shows the same trend for the experimental longitudinal diamond ground surface (0.51 to 0.43 mm); however, the transverse-tined surface demonstrates a reverse trend (0.48 mm on the least-traveled surface to 0.56 mm on the most-traveled surface). It should be noted that the operators reported a large variability in the surface macrotexture within a single test section. The 2001 measurements were obtained in the section as the previous year, but not in the exact same location (as it is difficult to locate the lock-up in the precise same location from year to year). However, many actual skid tests were performed within each section and were averaged to give the nominal values for the corresponding sections. The difference between 2001 measurements on all surfaces might simply demonstrate the variability of the surfaces rather than a trend related to traffic level. Initially, it appeared that the experimental surface was being affected more by traffic than the transverse tined surface. However, it is too early to speculate whether this is representative of a trend that might continue or level out over a period of time.

As seen in Figure5, the skid resistance levels of the driving lane ($SN_{D)}$ are generally lower than the skid resistance levels of the passing lane ($SN_{P)}$. This relationship is illustrated by the fact that almost all data points on the graphs are above the line traversing the plot at a 45-degree angle which represents the points at which the $SN_P$ and $SN_D$ are equal. This data is consistent with the general trend that higher average daily traffic levels are found in the driving lane rather than in the passing lane. Larger average daily traffic levels increase the rate at which the pavement surface becomes polished and thereby lowers the microtexture value of the surface at a faster rate.

As shown in Figure 6, there is an equal distribution of the ribbed tire SN data points about the line traversing the plot at a 45-degree angle. The line represents the points at which the $SN_{Longitudinal}$ and $SN_{Transverse}$ are equal. The 2000 blank tire SN data points are consistently higher for the longitudinal diamond ground pavement compared to those of the transverse-tined. The 2001 blank tire SN data show a general shift toward the line of equality with the exception of the data for the southbound passing lane. This suggersts that LDG macrotexture starts out better that TT but deteriorates more quickly, so that after one year, LDG and TT macrotextures are more equal."

In summary, initial results show a greater loss of macrotexture (MTD and $SN_B$) for the experimental longitudinal diamond ground surface than for the transverse tined surface. However, the relative skid resistance of the experimental longitudinal diamond ground surface tends to be higher than that of the transverse tined surface using a blank tire (representative of the surface macrotexture / resistance to wet pavement accidents). There is no significant difference in the skid resistance measured with the ribbed tire (representative of the surface microtexture), as would be expected since both pavements were constructed using the same mix design.

## DISCUSSION OF RELATIVE SERVICE LIFE

The pavement skid resistance is expected to change over a period of several years. Comparing the data for the experimental longitudinal diamond ground surface constructed in 1998 with that constructed in 1999 yields no significant difference in mean SN value (Table 3). Comparing the data for the transverse-tined surface constructed in 1998 with that constructed in 1999 yields a small difference in mean SN. The 2001 data shows even less difference in mean SN between the different construction years for the transverse tined surface. This would indicate that the small difference in skid resistance between the northbound surface and the southbound surface is diminishing.

Another consideration is the life-cycle cost. Similar studies (*14,15*) have shown a long-term benefit from diamond grinding. The studies speculate that the benefit is realized from reduced pavement joint fatigue that results from the smooth surface created by diamond grinding. Profilograph readouts from this project show that the diamond grinding creates a significantly smoother profile, so the diamond grinding process may show a long-term (20+ years) benefit due to the increased service life.

*Note that this data was collected from 177 rehabilitated highway sections in 26 states throughout the country. To date no known data is available on the longevity of newly constructed diamond ground pavements, which may differ from the rehabilitated highways in that the concrete is harder due to the additional curing time.*

## FUTURE RESEARCH (YEAR 2001)

Pavement noise and skid resistance testing is to be continued over the next several years on an annual basis in order to further document changes in these parameters over time. The data should be measured at the same time of the year (i.e., spring) to avoid changes in measured values caused by short-term and long-term seasonal variations. Traffic volumes and accident data will also be collected. Interviews with various highway users such as state troopers, maintenance personnel, and others will be conducted to determine if there are noticeable differences in maintenance requirements, vehicle operation, or rider comfort while traveling over the different pavement surfaces.

## CONCLUSIONS

### Construction Time and Cost

The longitudinal diamond ground pavement will require more construction time and will cost more than transverse tining. However, a higher initial cost for longitudinal diamond grinding would likely be partially offset by an extended service life.

### Pavement Noise

The longitudinally diamond ground pavement was shown to be 2 to 5 dBA quieter than the transverse tined pavement, depending mostly on the percentage of heavy trucks in the vehicle mix. The longitudinally ground pavement was approximately 3 to 4 dBA quieter for typical highway traffic mix and speed. Aggregate traffic noise measurements made after approximately one year showed virtually no difference in relative or absolute noise levels.

### Skid Resistance

Initial measurements show a greater wet skid resistance for the longitudinal diamond ground surface than for the transverse tined surface. The difference was shown to be less after about one year, but with the longitudinal diamond ground pavement still superior. The dry skid resistance for both pavement surface treatments was essentially the same.

## ACKNOWLEDGEMENTS

This study was administered by Christopher Waite, P.E., Director of Design, New York State Thruway Authority, and was funded by the New York State Thruway Authority and the Federal Highway Administration.

## REFERENCES


1. FHWA PCC Surface Texture Technical Working Group Findings - www.bts.gov/ntl/docs/79_tpave.html.

2. American Concrete Pavement Association, "*Diamond Grinding and Concrete Pavement Restoration*", ACPA Technical Bulletin TB-008P, 1990.

3. Wayson R.L. *Relationship Between Pavement Surface Texture and Highway Traffic Noise*, NCHRP Synthesis 268, TRB, National Research Council, Washington D.C. 1998.

4. Fleming, G.G., A.S. Raposa, and C.S. Lee. 1995. *Development of National Reference Energy Mean Emission Levels for the FHWA Traffic Noise Model (FHWA TNM), Version 1.0.* Cambridge, MA: John A. Volpe National Transportation Systems Center, Acoustics Facility. FHWA-PO-96-008

5. Lee, C.S. and G.G. Fleming. 1996. *Measurement of Highway Related Noise*. Cambridge, MA: John A. Volpe National Transportation Systems Center, Acoustics Facility. FHWA-PO-96-046

6. American Society for Testing and Materials, "*Standard Definitions of Terms Relating to Traveled Surface Characteristics, Designation: E 867*," in Annual Book of ASTM Standards, Vol. 04.03 (Philadelphia, PA: ASTM, 1999).

7. American Society for Testing and Materials, "*Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire, Designation: E 274*," in Annual Book of ASTM Standards, Vol. 04.03 (Philadelphia, PA: ASTM, 1999).

8. American Society for Testing and Materials, "*Standard Specification for Standard Smooth Tire for Pavement Skid-Resistance Tests, Designation: E 524*," in Annual Book of ASTM Standards, Vol. 04.03 (Philadelphia, PA: ASTM, 1999).

9. American Society for Testing and Materials, "*Standard Specification for Standard Rib Tire for Pavement Skid-Resistance Tests, Designation: E 501*," in Annual Book of ASTM Standards, Vol. 04.03 (Philadelphia, PA: ASTM, 1999).

10. U.S. Department of Transportation Federal Highway Administration, "*Portland Cement Concrete Mix Design and Field Control*," FHWA Technical Advisory T 5080.17, - 1994.

11. American Society for Testing and Materials, "*Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique, Designation: E 965*," in Annual Book of ASTM Standards, Vol. 04.03 (Philadelphia, PA: ASTM, 1999).

12. B. T. Kulakowski, et. al. Skid Resistance Manual, Report No. FHWA-IP-90-013 (Washington, DC: Federal Highway Administration, 1990).

13. W. E. Meyer and J. J. Henry. "*Tire-Pavement Traction, Demand and Availability*," SAE Technical Paper Series, Paper No. 840071, 7 pp., 1984.

14. Snyder, M.J. Reiter, K.T. Hall, and M.I. Darter, "Rehabilitation of Concrete Pavements, Volume I: Repair Rehabilitation Techniques," Report FHWA-RD-88-071, 1989.

15. S. Rao, H.T. Yu, and M.I. Darter, "*The Longevity and Performance of Diamond-Ground Pavements*," Research and Development Bulliten RD118, 1999.

## LIST OF TABLES



## LIST OF FIGURES

**TABLE 1 TNM User-Defined Input Data**

| ***Pavement Type*** | ***Vehicle Type*** | ***Min. Level*** | ***Intercept*** | ***Slope*** | ***95% Confidence Limit (dB)*** |
|---|---|---|---|---|---|
| Longitudinally Diamond Ground | Auto | 50.1 | 31.6 | 25 | ± 0.15 |
| | Medium Trucks | 68.0 | 66.3 | 9.5 | ± 0.90 |
| | Heavy Trucks | 74.3 | 8.6 | 43.7 | ± 0.30 |
| Transverse Tined | Auto | 50.1 | 28.3 | 29.8 | ± 0.12 |
| | Medium Trucks | 68.0 | 59.6 | 14.2 | ± 0.64 |
| | Heavy Trucks | 74.3 | 15.9 | 40.7 | ± 0.23 |

**TABLE 2 Predicted Absolute Noise Levels**

| ***Prediction Scenario*** | | ***Receiver*** | | | | | |
|---|---|---|---|---|---|---|---|
| | | ***Unobstructed*** | | | ***Jersey Barrier*** | | |
| ***Pavement*** | ***Traffic Mix*** | ***30m*** | ***60m*** | ***90m*** | ***30m*** | ***60m*** | ***90m*** |
| TNM Average | Parkway | 72.0 | 67.4 | 64.7 | 69.8 | 64.2 | 60.3 |
| TNM Average | Lt. Truck | 73.8 | 69.6 | 66.9 | 72.2 | 67.2 | 63.9 |
| TNM Average | Med. Truck | 76.8 | 73.0 | 70.4 | 75.7 | 71.3 | 68.2 |
| TNM Average | Hvy. Truck | 79.1 | 75.4 | 72.9 | 78.2 | 73.9 | 71.0 |
| Longitudinal Ground | Parkway | 72.2 | 67.6 | 64.9 | 70.1 | 64.4 | 60.6 |
| Longitudinal Ground | Lt. Truck | 74.6 | 70.4 | 67.8 | 73.1 | 68.3 | 65.0 |
| Longitudinal Ground | Med. Truck | 78.1 | 74.3 | 71.7 | 77.0 | 72.7 | 69.7 |
| Longitudinal Ground | Hvy. Truck | 80.6 | 76.9 | 74.4 | 79.7 | 75.5 | 72.6 |
| Transverse Tined | Parkway | 77.6 | 73.0 | 70.3 | 75.5 | 69.8 | 66.0 |
| Transverse Tined | Lt. Truck | 78.7 | 74.4 | 71.7 | 76.9 | 71.8 | 68.4 |
| Transverse Tined | Med. Truck | 80.9 | 77.0 | 74.4 | 78.6 | 75.1 | 72.0 |
| Transverse Tined | Hvy. Truck | 82.9 | 79.1 | 76.5 | 81.9 | 77.6 | 74.6 |

**TABLE 3** Summary of Calculated Skid Numbers.

| Test Tire | Lane | $SN_{40}$ | | | | $SN_{50}$ | | | | $SN_{60}$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LDG | | TT | | LDG | | TT | | LDG | | TT | |
| | | 2000 | 2001 | 2000 | 2001 | 2000 | 2001 | 2000 | 2001 | 2000 | 2001 | 2000 | 2001 |
| Blank | SB DRV | 37.2 | 35.7 | 30.6 | 33.7 | 30.5 | 24.4 | 23.8 | 20.0 | 27.0 | 18.6 | 24.2 | 20.1 |
| | NB DRV | 37.6 | 29.9 | 32.5 | 29.1 | 31.6 | 24.6 | 27.7 | 25.6 | 25.8 | 19.3 | 22.7 | 19.4 |
| | SB PAS | 44.7 | 39.8 | 33.7 | 29.9 | 37.1 | 36.7 | 26.5 | 24.9 | 31.3 | 23.8 | 22.4 | 19.1 |
| | NB PAS | 46.8 | 34.6 | 34.4 | 34.3 | 36.3 | 31.2 | 31.7 | 27.6 | 29.1 | 22.3 | 30.5 | 21.3 |
| | Average | 41.6 | 35.0 | 32.8 | 31.8 | 33.9 | 29.2 | 27.4 | 24.5 | 28.3 | 21.0 | 25.0 | 20.0 |
| Ribbed | SB DRV | 41.5 | 38.0 | 40.6 | 39.7 | 39.2 | 35.0 | 38.9 | 35.6 | 35.4 | 31.2 | 36.2 | 33.0 |
| | NB DRV | 41.4 | 40.9 | 42.9 | 42.1 | 38.4 | 35.5 | 43.4 | 36.9 | 40.1 | 34.2 | 38.1 | 34.7 |
| | SB PAS | 48.5 | 45.3 | 43.5 | 45.5 | 43.2 | 43.9 | 39.7 | 42.9 | 38.5 | 35.6 | 38.8 | 38.0 |
| | NB PAS | 49.1 | 45.0 | 49.7 | 46.8 | 44.6 | 40.5 | 47.4 | 43.3 | 40.0 | 38.0 | 45.0 | 43.4 |
| | Average | 45.1 | 42.3 | 44.2 | 43.5 | 41.4 | 38.7 | 42.4 | 39.7 | 38.5 | 34.8 | 39.5 | 37.3 |

LDG = longitudinal diamond ground
TT = transverse tined
SB = southbound
NB = northbound
DRV = driving lane
PAS = passing lane

Southbound lanes opened to traffic December, 1998.
Northbound lanes opened to traffic December, 1999.

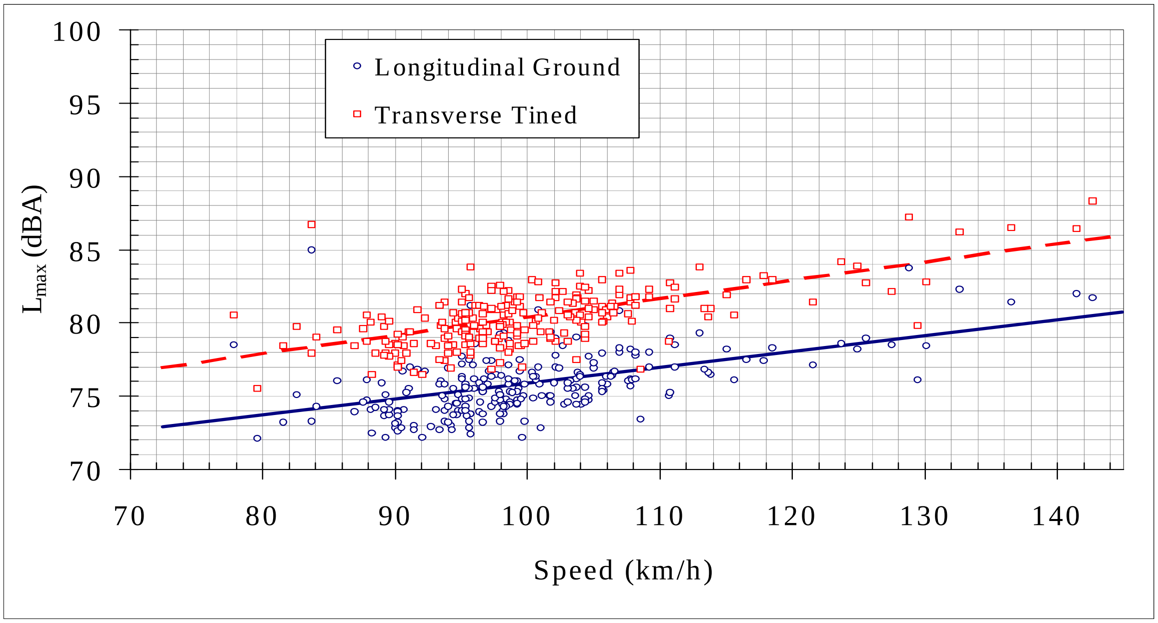



**FIGURE 1. Single Vehicle Pass-by Noise Measurements for Automobiles**

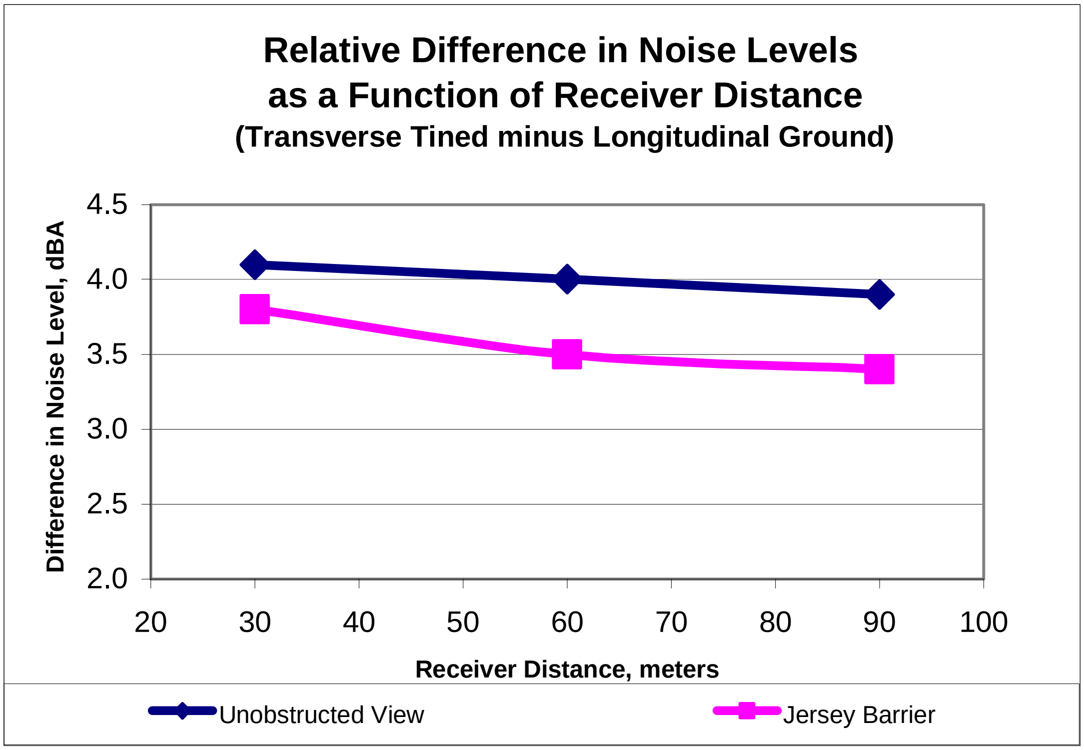



**FIGURE 2. Relative Difference in Noise Level as a Function of Receiver Distance**

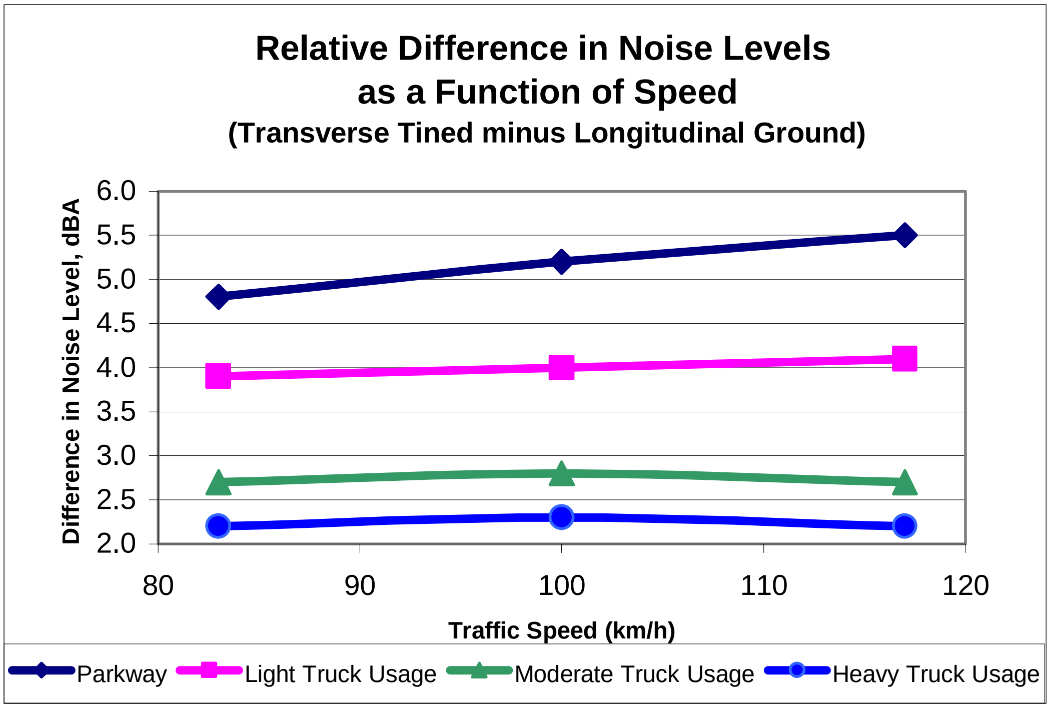



**FIGURE 3. Relative Difference in Noise Level as a Function of Vehicle Speed**

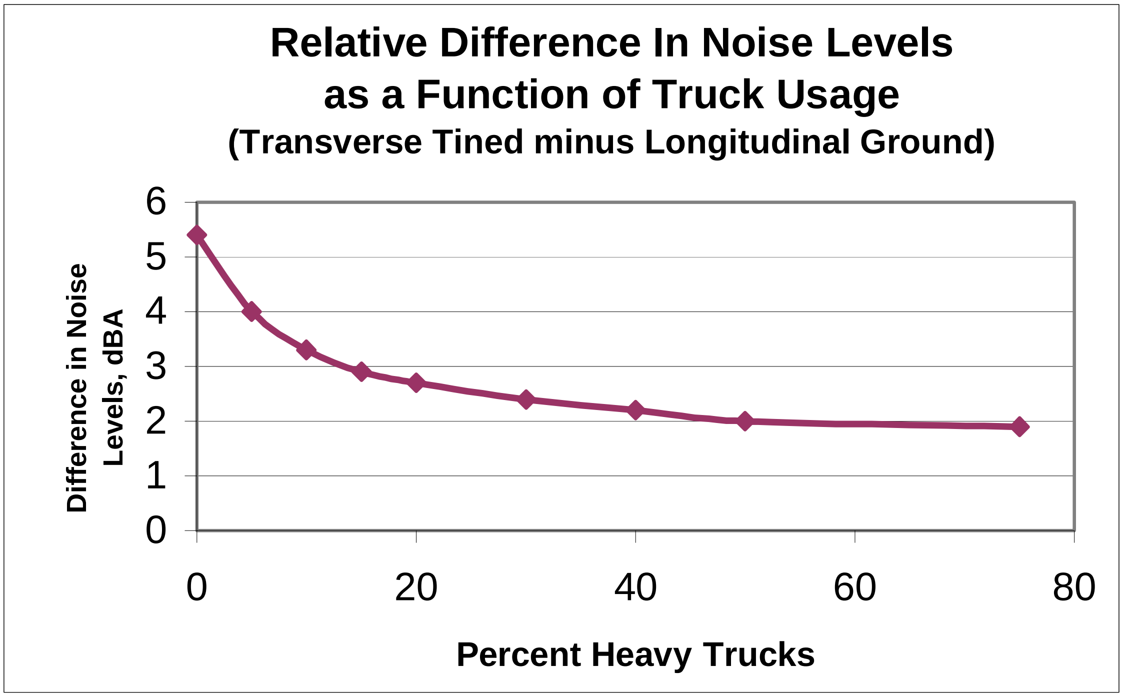



**FIGURE 4. Relative Difference in Noise Level as a Function of Heavy Truck Usage**

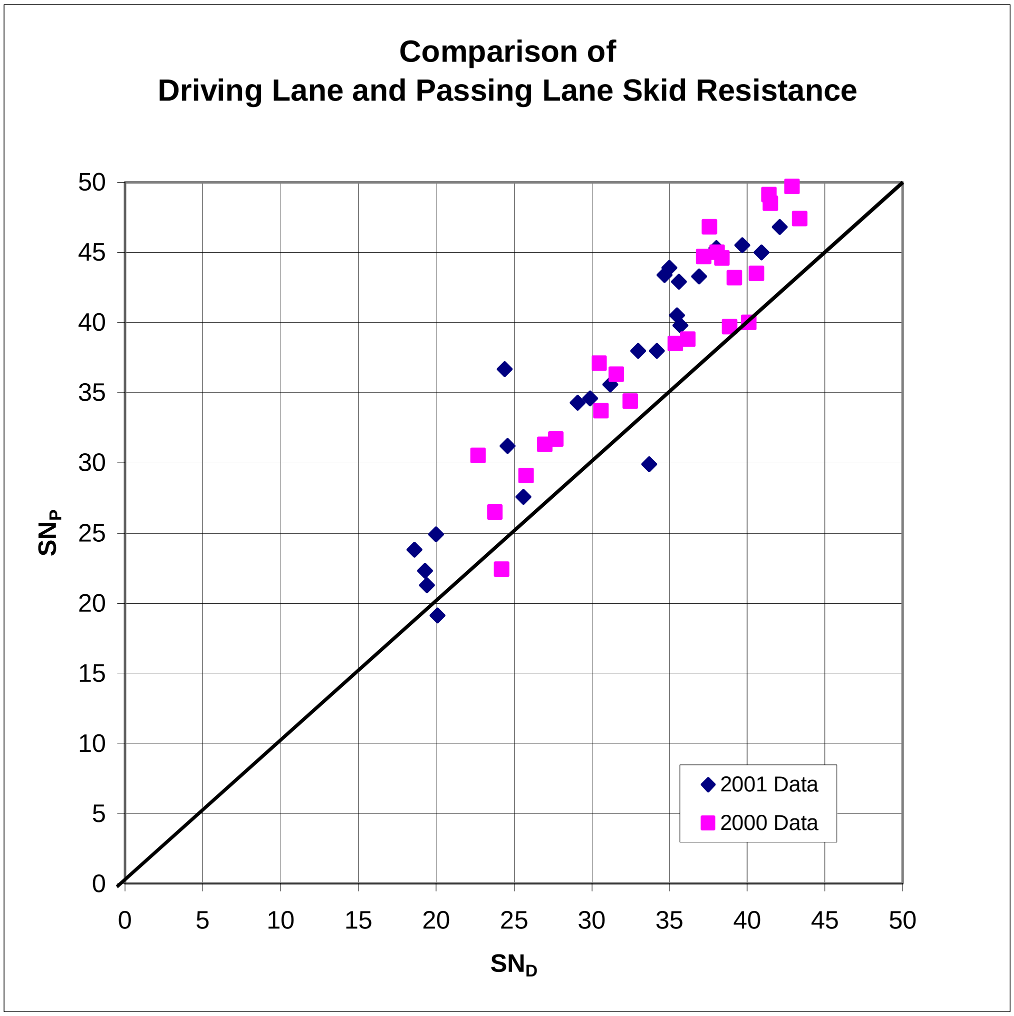



**FIGURE 5. Skid Resistance for Driving Lane versus Passing Lane**

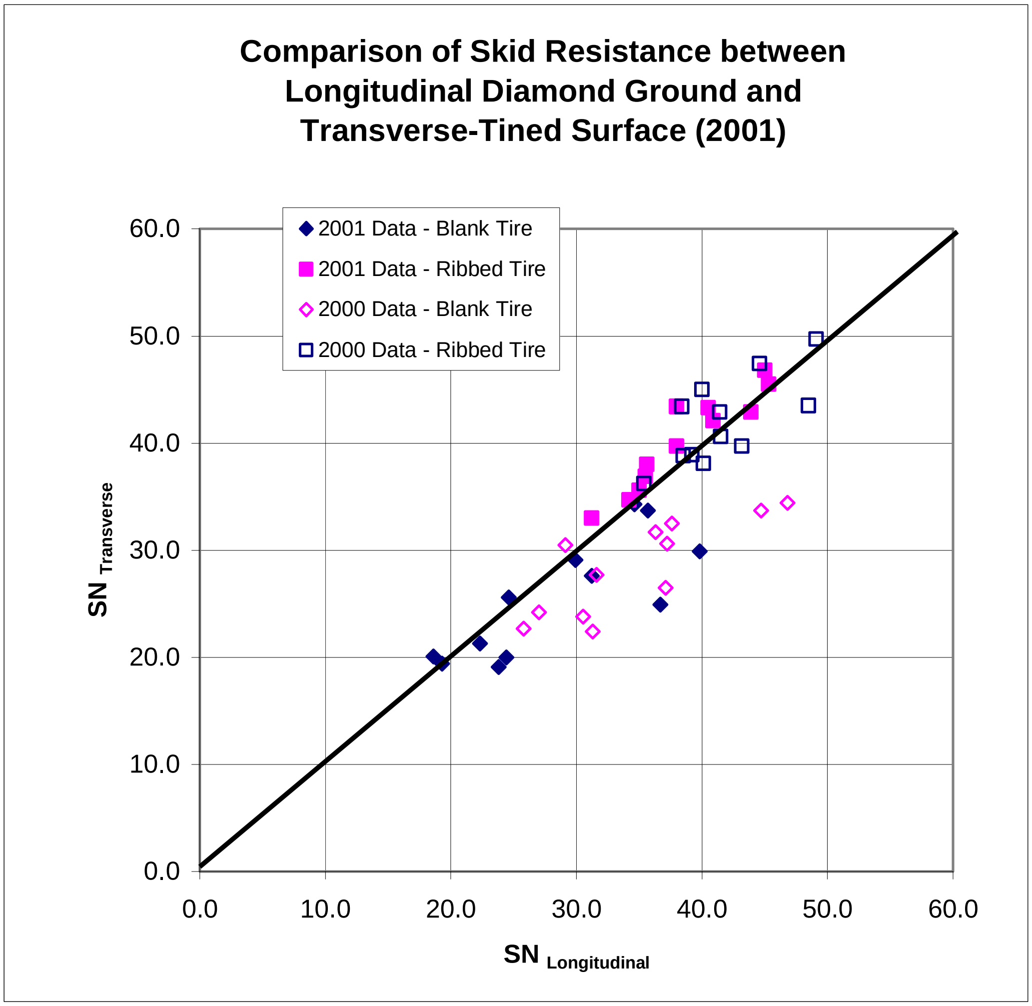



**FIGURE 6. Skid Resistance for Longitudinal Diamond Ground versus Transverse Tined PCCP**

Center for Transportation Research
The University of Texas at Austin

CENTER FOR TRANSPORTATION RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

Project Summary Report 0-1846-S
Project 0-1846: Development of Design Guidelines for the Provision of Median Access on Principal Arterials
Authors: Jillyn K. O'Shea, Thomas W. Rioux, Randy B. Machemehl
August 2001

# DESIGN OF MEDIANS FOR PRINCIPAL ARTERIALS

PROJECT SUMMARY REPORT

## WHAT WE DID ...

Public highways and streets have dual but competing roles: to provide property access and to move through traffic. Highway functional classification systems recognize the competition between access and flow, generally specifying that principal arterial streets primarily move traffic and secondarily provide access, while local streets primarily provide access and secondarily move traffic. Access provision is problematic for traffic flow because right turns, and especially left turns, into and out of driveways create traffic stream friction that often totally blocks through movements. Practical ways of controlling flow potential loss include limiting the number of property access driveways, restricting left-turn opportunities, and using good driveway geometric standards. Although the current criteria are appropriate, they lack the specificity needed by busy designers dealing with property owners and developers. This study provides specific guidance about safety, mobility, and economic impacts regarding:

1. Divided roadway and continuous center left-turn lane treatments,
2. Acceleration and deceleration lane design,
3. Raised and flush median treatments, and
4. Spacing between adjacent access points.

This process is applicable to four-lane, two-directional cross sections. The application method will follow a step-by-step instructional pattern that mimics the decision process that would be executed by a designer.

## WHAT WE FOUND ...

### Necessary Information

Information required to complete the application process includes:

- Directional 24-hour volume (two-lanes)
- Arterial speed
- Left-turn demand
- Driveway location(s) and distance(s) from the upstream intersection

This process assumes that the necessary right-of-way is available for left-turn treatment if it is required.

### Task 1: Determining Whether Left-Turn Treatment is Required

The first step in median design, provided that the necessary right-of-way is available, is to determine whether left-turn treatment is required, given the roadway and adjacent driveway characteristics. There are several ways to accomplish this task.

#### 1a: Safety Criteria

Several studies have determined that median treatment, regardless of type, is a safer alternative to no median treatment (Stover 1994). Therefore, if a disproportionate number of accidents occur in the vicinity of the driveway location as a result of left-turn-related maneuvers, then left-turn treatment is warranted without regard to operational criteria.

The Manual on Uniform Traffic Control Devices (MUTCD) uses five or more accidents within a 12-month period as a threshold for intersection signalization. Therefore, the four accidents per year criterion could appropriately be applied to an unsignalized inter section consisting of a driveway and a street.

If the left-turn-related accident rate is equivalent or exceeds 4/year, median treatment is warranted. If the safety criterion is satisfied, then proceed to Task 2; otherwise continue with 1b.

#### 1b: Operational Criteria

The researchers developed three sets of decision charts to indicate if median treatment is required based on operational criteria. One chart set addresses excessive delay problems experienced by left turners.The delay threshold considered as excessive is average left-turn delays exceeding 35 seconds per vehicle (sec/veh). A second chart set relates operational problems incurred by the through-traffic stream. These charts identify conditions causing unacceptable through-traffic delay increases.

If a box is shaded, median treatment is warranted. If the operational criterion is satisfied, then proceed to Task 2.

### 1c: Calculation of Capacity and Delay

The designer may wish, however, to obtain more detail or may be unsure of the results given by the charts. In this situation, the decision can be made through a series of calculations that have been developed in this research effort. The first step is to determine the left-turn capacity of the driveway opening, which may be determined by using provided equations. Once the capacity of the driveway has been determined, the utility ratio (UR), which is the left-turn driveway demand divided by the capacity, is calculated. In cases where left-turn driveway demands have been unknown, the ITE Trip Generation Manual has been used to estimate left-turn driveway demands for selected land-use scenarios.

If the UR is equivalent to or exceeds 1, left-turn treatment is warranted. The designer should proceed to Task 2.

The next step is to predict the delay that will be experienced by left-turning vehicles or through traffic. This step is accomplished through the use of two sets of equations that were developed through the study. The designer can use either set of equations to determine if treatment is warranted or choose to compute both delays to identify a "worst case" scenario.

If $Delay_L$ or $Delay_T$ is equivalent to or exceeds 35 sec/veh, median treatment is warranted. The designer should proceed to Task 2.

## Task 2: Raised Median or Flush Median Design

There are several criteria one should consider when selecting a raised median or a flush median design. Many attempts have been made to quantify the choice of median design, but there are many characteristics that are difficult to measure. Both types of designs have positive attributes and both have drawbacks.

Overwhelmingly, studies have favored raised medians over TWLTLs for safety considerations. However, all agree that some median treatment is better, in terms of both safety and operations, than the undivided cross section. Operationally, both designs are equivalent under low driveway density, low traffic volume, and moderate speed conditions. The literature states that raised medians are generally preferred when through volumes and driveway densities are high. TWLTLs are preferred under lighter through-volume conditions, though there is some debate surrounding the preferred driveway spacing and left-turn volume.

### 2a: Safety Considerations (Raised vs. Flush Median)

Flush median designs, continuous one- or two-way left-turn lanes (OWLTL, TWLTL), are not recommended where through-traffic speeds exceed 45 mph. A study of accident occurrence on continuous-turn lanes found accident rates only marginally higher compared to raised median sections. However, that study recommended limited continuous left-turn lane use under high-speed conditions because of the potentially catastrophic results of high-speed accidents.

If through-traffic speeds are greater than 45 mph, the designer should choose the "raised median" design.

As previously mentioned, research efforts have also shown that raised medians are safer at higher traffic volume conditions than TWLTLs. One criterion that has been used as a threshold value for choosing median designs is a 24-hour design volume of 24,000 vehicles.

If the 24-hour design volume is equivalent to or exceeds 24,000 vehicles, the designer should choose the "raised median" design.

### 2b: Operational Considerations

Flush median designs are generally not recommended along facilities that have significant traffic congestion. Since potential flow along arterials is limited by intersection capacity, congestion usually propagates upstream and downstream from intersections. One criterion for congestion identification is queues of more than ten vehicles in all intersection approach lanes or queues that cannot be dissipated during the green signal phase.

If intersection queues are greater than ten vehicles or queues are not dissipated during the signal green time, the designer should choose the "raised median" design.

If the median design is being developed for a new facility, or for any reason queues cannot be counted, congestion potential can be estimated using the ratio of demand to capacity. *The Highway Capacity Manual* is recommended as an easier way to estimate intersection capacity. If expected demand approaches calculated capacity, significant queues can be expected and conditions would likely exceed the threshold for significant congestion. Experience indicates, however, that a demand-to-capacity ratio exceeding 0.9 for a planned facility should be adequate justification for choosing a raised median design.

If intersection demand-to-capacity ratio exceeds 0.9, the designer should choose the "raised median" design. For the flush median design, proceed with tasks followed by an F and for raised median designs follow tasks marked with an R.

## Task 3R: Determining the Necessity of Left-Turn Bays at Intersections

The flow of traffic on the network should take precedence over midblock turning movements. Therefore, once the general type of median design has been determined, it is important to establish the necessity of a left-turn bay at the intersection because it will affect the design of upstream median openings. This task can be accomplished by a number of means. Criteria for determining the requirement of left-turn bays have been outlined in numerous documents, such as the Highway Capacity Manual, Center for Transportation Research Report 258-1, and many state agency design manuals. The complete procedure described in the CTR 258 study is included in the 1846-1 report.

If left-turn demand is greater than the warranted left-turn volume $Q_W$, a left-turn bay is required at the intersection. The designer should proceed to the next task. Otherwise skip to task 5R.

### Task 4R: Calculating the Length of the Intersection Left-Turn Bay

If a left-turn bay is necessary at an adjacent intersection, then it is important to size the bay before proceeding with median design, as this will directly impact driveway openings and placement along the roadway. Once again, this procedure has been well documented in other research efforts. The procedure that was developed in Research Report 258-1 from the Center for Transportation Research at The University of Texas at Austin is included in the complete 1846 report.

### Task 5R: Assessment of Midblock Opening

In determining the location of a midblock opening, the designer must first ensure that the proposed opening will not infringe on the left-turn bay that has been established for the intersection. The placement of a median opening is infeasible if the proposed median location encroaches on the intersection left-turn bay. Provided that the median opening is viable, the operational characteristics of the driveway can be examined. There are three criteria to consider: the delay incurred by the left-turning vehicle, the storage area, and the distance between the intersection and other median openings.

### Task 5Ra: Delay to the Left-Turner

Theoretically, if a left-turner waits for a traffic-stream gap in a bay or storage lane, then operationally there is no reduction in the level of service to the network through traffic if the vehicle driver waits indefinitely to complete his/her maneuver. Realistically, however, the driver will become impatient after a period of time and risk an accident by choosing a gap of insufficient size. The researchers developed a series of decision charts based on delays incurred by the left turner. These charts describe conditions under which unacceptable levels of delay are experienced.

If box is shaded, the designer should not provide a median opening; left-turn delays will likely exceed 96 seconds/vehicle.

If the designer is unsatisfied with the results of the charts because roadway conditions require interpolation between shaded and unshaded boxes, then he or she may calculate the left-turn delay with equations that were also developed.

If $Delay_L$ equals or exceeds 96 sec/veh, the designer should not provide a median opening.

### Task 5Rb: Storage Area or Bay Length

Adequate procedures for determining the length of storage for the medians are similar to those used in determining the left-turn bay length at the intersection. The pocket length should be sized according to the entrance speed and to the ability of a vehicle to come to a stop before reaching the end of the queue. If the left-turn demand is unknown, estimates based on the *ITE Trip Generation Manual* are provided. See Task 4R for instructions on proper left-turn bay sizing.

### Task 5Rc: Distance to the Intersection or Additional Median Opening

No median opening should be allowed to interfere with the functional area of another median opening or intersection left-turn bay. The functional area is defined as the distance required for channelization markings, queuing, and storage of vehicles wishing to complete a left-turn maneuver. Additionally, median openings should be prohibited in locations where a queue from an adjacent intersection would habitually form across the opening. The Florida DOT has defined a classification system of its roadways that is based on function. Using these access classes, the Florida engineers have set the following minimum median opening spacing criteria for arterials with both directional and full movements.

### Task 5F: (OWLTL or TWLTL) Choosing One-Way or Two-Way Left-Turn Lanes

Few studies have been conducted concerning the choice between OWLTL and TWLTL. A TWLTL is generally chosen in areas of strip commercial development. An OWLTL is more beneficial at major intersections having high left-turn demand or where there are driveways on only one side of the street.

## THE RESEARCHERS RECOMMEND ...

This document summarizes a process that can be used by the practitioner to design median treatments for a four-lane, bi-directional arterial roadway. The tasks required to complete this process are described with supporting information.

## For More Details ...

Research Supervisor: Dr. Randy Machemehl, P.E., phone: (512) 232-3107, email: rbm@mail.utexas.edu

TxDOT Project Director: Gustavo Lopez, P.E., Pharr District Office, phone: (956) 702-6159, email: glopez@dot.state.tx.us

The research is documented in the following reports:
Report 1846-1, *Design Guidelines for Provision of Median Access on Principal Arteries,* Draft February 2001

**To obtain copies of the report, contact: CTR Library, Center for Transportation Research, phone: 512/232-3138, email: ctrlib@uts.cc.utexas.edu.**

## TXDOT IMPLEMENTATION STATUS AUGUST 2001

The research developed new design guideline criteria to aid in the decision making process for selecting the proper median type for principal arterials.

The research resulted in a decision tree and implementation guide for the application of various types of median design and geometric guidelines for median openings. The median design decision tree is being incorporated into TxDOT geometric design practices.

For more information, please contact Bill Knowles, P.E., Research and Technology Implementation Office (512) 465-7648 or email: wknowle@dot.state.tx.us.

## YOUR INVOLVEMENT IS WELCOME!

## DISCLAIMER