Report on the Status of Rubberized Asphalt Traffic Noise Reduction in Sacramento County

Prepared For:

Sacramento County
Public Works Agency - Transportation Division

Prepared by:

Sacramento County
Department of Environmental Review and Assessment

And

Bollard & Brennan, Inc.
Consultants in Acoustics and Noise Control Engineering

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ACKNOWLEDGEMENTS

Sacramento County Public Works Agency
Transportation Division
906 G. Street, Suite 510
Sacramento, California 95814
(916) 874-6291
Chief: Thomas Zlotkowski
Senior Engineer: Theron Roschen

Sacramento County Department of Environmental Review and Assessment
Public Projects Division
827 7th Street, Room 220
Sacramento, California 95814
(916) 874-7914
Environmental Coordinator: Dennis Yeast
Division Manager: Bob Caikoski
Project Leader: Antonia Barry
Student Intern: Melinda Coy

Bollard & Brennan, Inc.
Consultants in Acoustics and Noise Control Engineering
3805 Taylor Road, Suite 2
Loomis, California 95650
(916) 660-0191
President: Paul Bollard

EXECUTIVE SUMMARY

This report is a joint study prepared for the Sacramento County Public Works Agency, Transportation Division by the Sacramento County Department of Environmental Review and Assessment and Bollard and Brennan, Inc., consultants in acoustics and noise control engineering.

The purpose of this report is to document the effectiveness of rubberized asphalt as a traffic noise mitigation measure. Rubberized asphalt is a bituminous mix, consisting of blended aggregates, recycled rubber and binding agents. The rubber is often obtained from used tires. Studies conducted locally, nationally, and internationally, have shown that rubberized asphalt can reduce the noise pollution that is associated with roadway traffic.

The specific findings of this analysis are based primarily on a series of traffic noise level measurements conducted along the Alta Arden Expressway, between Howe and Watt Avenues, from 1993 to the present. Although similar noise measurements have been conducted along a segment of Antelope Road, the smaller number of variables affecting the measured traffic noise levels along the Alta Arden Expressway before and after paving with rubberized asphalt made that roadway a more statistically reliable test subject. Therefore, this analysis focuses on the series of test results for Alta Arden Expressway.

Bond Road between Stockton Boulevard and Florin Road, was used as the control site for conventional (non-rubberized) paving. Although the Bond Road test segment was widened at the time of paving with conventional asphalt, the relationship of the roadway to the noise measurement site remained relatively unchanged.

The conclusions of the 6-year study indicate that the use of rubberized asphalt on Alta Arden Expressway resulted in an average four (4) decibel reduction in traffic noise levels as compared to the conventional asphalt overlay used on Bond Road. This noise reduction continued to occur six (6) years after the paving with rubberized asphalt. This degree of noise attenuation is significant, as it represents a 60% reduction in traffic noise energy, and a clearly perceptible decrease in traffic noise. This traffic noise attenuation from rubberized paving is similar to the results documented in several non-related studies conducted in recent years at other locations, both nationally and internationally.

The conclusions of this study are based on tests conducted in Sacramento County on the Alta Arden Expressway and Bond Road. Attenuation provided by rubberized asphalt may vary in other locations with different climates and different percentages of medium duty and heavy-duty trucks.

INTRODUCTION

The main theme of this report is the effectiveness of rubberized asphalt as a traffic noise mitigation measure. Locally collected noise information is supplemented with general noise test results from various locations, both nationally and internationally, where other jurisdictions are exploring the use of rubberized asphalt. However, this report does not attempt to reproduce the result of those other studies herein. The interested reader is encouraged to contact those entities or jurisdictions where other studies were performed for further information. This report is primarily meant to provide information on the studies conducted in Sacramento County.

In addition to the various noise test results, this report offers an overview of the factors that contribute to traffic noise generation. The report also contains the Sacramento County, State and Federal noise standards, which mandate the consideration of noise abatement measures in cases where traffic noise levels exceed acceptable limits. The noise standards are provided to illustrate the importance that is given to traffic noise impacts in Sacramento County, which in turn has led to substantial requirements for traffic noise abatement.

In recent years, Sacramento County has relied upon noise barriers as the primary noise mitigation option, and often times the only viable noise mitigation option, for roadway improvement projects in the County. As a result, a substantial number of noise barriers have, and continue to be, constructed in areas where traffic noise is determined to be excessive. Concerns regarding the proliferation of noise barriers have resulted in the investigation of rubberized asphalt paving as a viable noise mitigation alternative. This investigation has been ongoing since the paving of Alta Arden Expressway with rubberized asphalt in October of 1993. This report summarizes the results of Sacramento County’s ongoing investigation to date.

HISTORY OF NOISE REDUCING PAVEMENT

The history of adding recycled tire rubber to asphalt paving material can be traced back to the 1940's when the U.S. Rubber Reclaiming Company began marketing a devulcanized recycled rubber product, called Ramflex TM, as a dry particle additive to asphalt paving mixture. In the mid-1960's, Charles McDonald began developing a modified asphalt binder using crumb rubber. This product was marketed by Sahuaro Petroleum and Asphalt Company as Overflex TM.

The Arizona Refining Company Inc., created the second modified binder in the mid-1970's, replacing a portion of the crumb rubber with devulcanized recycled rubber and marketing it under the name Arm-R-Shield TM. Both Overflex TM and Arm-R-shield TM were patented and eventually brought under single ownership. The companies marketing these two products founded a trade association known as the Asphalt Rubber Producer Group in the mid-1980's. Ramflex TM disappeared from the market when its parent corporation sold the U.S. Rubber Reclaiming Company.

In addition to the US, Sweden also made tremendous contributions to the development of rubberized asphalt. In the 1960's, two Swedish companies began developing an asphalt paving surface mixture that would resist studded tire and chain wear. The mixture included a small amount of crumb rubber as an aggregate and was named RubitTM. In the late 1970's this product was introduced and patented in the United State as PlusRideTM . It evolved in a series of field projects in Alaska and other states from 1979 through 1985. PlusRide TM has been managed by a number of firms and is presently marketed by Envirotire, Inc.

In recent years there has been a great surge to make use of the used tires that are being stockpiled all around the world. This is primarily due to the advancement in technology and realization of benefits associated with application and reduction of used tires. Because of the increase in the number of tires accumulating around the world, and environmental hazards associated with them, more nations are looking for ways to make use of this tremendous resource.

THE PROCESS OF PRODUCING RUBBERIZED ASPHALT

Rubberized asphalt is a process of incorporating crumb rubber (CRM) with asphalt paving materials. Crumb rubber consists of recycled rubber that has been reduced in sizes less than 6.3mm. Crumb rubber can be incorporated by a wet process or a dry process. In 1991, the Federal Highway Administration (FHWA) introduced standard terminology to improve the ability to communicate the experience of highway agencies when evaluating CRM processes.

Wet Process

Wet process refers to modification of asphalt cement binder with 5-25%wt of fine tire rubber crumb modifier (CRM) at an elevated temperature. The wet process includes the blending of the crumb rubber with the asphalt. The method of blending can be divided into three categories: batch blending, continuous blending and terminal blending. Batch blending defines those wet process technologies that mix batches of CRM and asphalt in production. Continuous blending describes those wet process technologies that have a continuous production system. Terminal blending is associated with wet process technologies that have product with extended storage (shelf life) characteristics and are produced at an asphalt cement supply terminal.

Dry Process

The dry process includes mixing the rubber particles with aggregates prior to addition to asphalt. This process provides a way to blend the crumb rubber with the asphalt and aggregate without the use of the special equipment needed in the wet process. There are some technical problems associated with this method, but new technologies are being introduced that are improving the process. Currently, the only process approved for use by the California Department of Transportation (Caltrans) is the wet process.

CURRENT USES OF RUBBERIZED ASPHALT

Although the idea of using old tires to make asphalt was started in United States in 1940's the idea has not gained much momentum. One reason is due to the FHWA position against the use of the rubberized asphalt as a noise mitigation measure. Rubberized asphalt continues to be labeled as experimental and thus funding for its use can be hard to obtain. Other reasons for its less than wide spread use include state preferences for the use of older methods for pavement, 'impostor' projects that don't adhere to standards, thereby resulting in failures, and the Interstate Surface Transportation Efficiency Act (ISTEA), mandate.

ISTEA provides federal funding through the FHWA for transportation projects and was superceded by Tea-21 in May of 1999. The ISTEA mandate holds that funding must be used to research and implement studies on the use of rubberized asphalt.

ISTEA, Section 1038(d), mandated the States use recycled tires in asphalt paving. Through 1995, Congress provided moratoriums on implementation but the section remained as federal law. There were also specific penalties for those States unable to comply. In 1995, Section 1038 was modified by striking subsection (d). This eliminated the rubber mandate and all associated penalties. It was further amended to require research and development of tests and specifications for rubberized asphalt. This research requirement was aimed primarily at cost and performance; traffic noise reduction was not an issue.

There were two consequences resulting from this mandate. First, the mandate caused political fallout within the industry and thus created a rift within its parent industry. Secondly, the revocation of this mandate caused funding and projects to be dropped in favor of more traditional practices. However, the FHWA allows the use of rubber asphalt where it is both cost effective and it can be properly engineered mainly as a tire waste management mitigation program. It is not allowed as a noise mitigation measure in National Environmental Policy Act (NEPA) documents.

The use of rubberized asphalt is becoming more popular as countries around the world are faced with the problem of noise pollution and excess used tires. They are beginning to rely on rubberized asphalt to mitigate the noise problems associated with roadway transportation. This phenomenon was first noted in Brussels, Belgium, in 1981, in asphalt rubber hot mix called "Drainasphalt". The study showed a dramatic reduction in traffic noise levels. As a result, numerous countries around the world have started noise level studies to evaluate the validity of claims being made.

In 1984, an investigation was made by the French to determine hydrostatic pressure in and under Drainasphalt on City Street along the Seine River. Their findings showed a reduction of 3 to 5 dB with no trucks, and a 2 to 3 dB reduction with five percent trucks. As a result of their findings, the researcher made a proposal to overlay the Paris Loop with open graded Asphalt-Rubber.

As a result of these findings, other countries, such as Canada, were convinced to do further research on the benefits of using rubberized asphalt. In 1994-1995 Canada started the full-scale use of the rubberized asphalt. In the full-scale phase six streets were paved using rubberized asphalt. Table 1 lists international projects carried out or under way.

Table 1

Countries Used/Using Rubberized Asphalt and Resulting Noise Reduction

Country	Year Reported	Noise level Reduction
Belgium	1981	8-10 dB (65-85%)
Canada	1991	Shown noise reduction
England	1998	Project not completed
France	1984	2-3dB/3-5dB (50-75%)
Germany	1980	3dB (50%)
Austria	1988	3+ dB
Netherlands	1988	2.5dB

Within the US, some of the cities and counties that are currently evaluating the use of rubberized asphalt include Tucson AZ, Phoenix AZ, Sacramento CA, Orange CA, Los Angeles CA and San Diego CA.

Table 2

States Using Rubberized Asphalt and Resulting Noise Reduction

State	Counties & Cities	Year	Noise Level Reduction
Arizona	Phoenix, AZ	1990	10dB (88%)
Tucson,	AZ	1989	6.7dBs (78%)
California	Sacramento County	1993	7.7 - 5.1 dB
California	Orange County	1992	3-5 dB on Open Graded asphalt
California	Los Angeles County	1991	3-7 dB
California	San Diego County	1998	Project in process
Texas	San Antonio	1992	Data not Provided
Oregon	Corvallis	1994	Data not Provided

* Table is not comprehensive. Studies may have taken place in other states.

Since 1992, rubberized asphalt has been used in Sacramento County. Table 3 shows the locations where it has been used.

Table 3

Rubberized Asphalt Usage in Sacramento County

Year/s	Location
1992 / 1994	Auburn Boulevard
1992	Folsom Boulevard
1992 / 1993	Alta Arden Expressway
1992	Arden Way
1992	South Watt Avenue
1992 / 1995	Watt Avenue
1002	Van Maren Way
1992	Sunset Ave
1993	Air Base Drive
1993	Chase Drive
1993	Coloma Road
1994	Antelope Road
1996	Marconi Avenue at Watt Avenue
1996	Arden Way at Watt Avenue
1996	Greenback Lane at Hazel Avenue
1996	Fair Oaks Boulevard at Watt Avenue
1996 / 1998	Elkhorn Boulevard
1997	Orange Grove Avenue
1997	Roseville Road
1997	Sly Parkway
1998	Engle Road
1998	San Juan Avenue
1999	Calvine Road

STUDIES OF RUBBERIZED ASPHALT OUTSIDE OF SACRAMENTO COUNTY

Rubberized Asphalt Studies in Other California Counties

Rubberized asphalt has been studied in other California counties outside of Sacramento. Orange County studied the effectiveness of rubberized asphalt as a noise mitigation measure in a report entitled Mixed Roadway Surface Noise, prepared by Mestre Greve Associates in February of 1992. The City of Thousand Oaks also conducted a study in 1992 entitled Asphalt Rubber Overlay Noise Study, prepared by Acoustical Analysis Associated, Inc. Both studies determined that rubberized asphalt successfully mitigated traffic noise.

The study conducted for the County of Orange looked at the difference in noise levels between four different pavement types: dense grade asphalt, rubber asphalt (gap graded), rubber asphalt (open graded), and open grade (with latex). The goal of this analysis was to eliminate the effect due to different traffic conditions at each segment of roadway thus resulting in a different noise level due specifically to the asphalt type. *The study concluded that rubber asphalt-open graded was 3.9 dBA quieter than new dense grade asphalt.*

The noise study conducted for the City of Thousand Oaks measured the reduction in traffic noise levels experienced due to resurfacing. The street conditions before resurfacing were poor and therefore, noise reduction due to the new paving was striking. *Noise reduction on the six sites tested ranged from 3-7 dBA, depending on traffic and speed. When compared with the new standard asphalt, rubberized asphalt was found to be 2-5 dBA quieter.*

National Rubberized Asphalt Studies

On a national scale, rubberized asphalt has been studied by many states as well as the federal government. Arizona has been the leader in the production and use of rubberized asphalt. In March 1990, Western Technologies Inc. performed a sound level survey to determine the noise levels produced during peak traffic flow on different types of pavement, including rubberized asphalt. In November of 1995 the Texas Department of Transportation conducted a study on the crumb rubber modifier used in rubberized asphalt as a successful method to reduce tire noise. Finally, the National Research Council conducted a study in 1997 entitled the Relationship between Pavement Surface Texture and Highway Traffic Noise.

Two studies were conducted in Arizona. One was prepared for the City of Phoenix and the other was prepared for the City of Tucson. The study in the City of Phoenix compared standard chip seal asphalt laid in 1984 and rubberized asphalt that was laid in 1989. *The study concluded that there was an approximate 10 dBA reduction in noise with the rubberized asphalt compared with the chip seal asphalt.* The study prepared for the City of Tucson compared asphalt rubber concrete pavement and standard concrete pavement. *The study* *showed that the asphalt rubber concrete was 6.7 dBA quieter than the concrete pavement.*

In 1995, the Texas Transportation Institute conducted a study to identify potential problems with the current rubberized asphalt mix design, develop recommendations on those problems, develop recycling guidelines, and evaluate alternatives. Researchers monitored CRM mixtures paved in 1992 and 1993 in San Antonio, Texas. *The results of the these tests concluded that rubberized asphalt performed well in construction practices, and that the rubberized asphalt mixes gives a higher durability with better stability than dense-grade mixes.*

The National Research Council conducted a study showing the effect of different surface types on noise levels. *The Council studied many types of roadway surfaces and determined that open graded asphalt showed the greatest potential for noise reduction when compared to dense graded asphalt.* The study examined research done by the Kansas Department of Transportation in 1990/1991, that studied the effects of rubberized asphalt. The results in Kansas showed that the open graded asphalt always showed a decrease in noise level. In contrast, when the asphalt rubber pavement was compared to the asphalt surface, there were both reductions and increases in noise level. *Thus, the results of this Kansas study did not show a clear noise reduction trend with rubberized asphalt.* However, the study done by the National Research Council did not examine any other research than the Kansas study.

Global Studies

Rubberized asphalt is a process that is not only of interest in the United States but also globally. In 1995, the Canadian Technical Asphalt Association performed a study for British Columbia on rubberized asphalt. Their study entitled, The Full Scale Evaluation of Rubberized Asphalt Concrete in British Columbia*,* was a response to the need for improvement of binders in the road building industry. In a paper done by Netherlands researchers, entitled Open Grade Rubberized Asphalt for Traffic Noise Reduction in Urban Areas, research was conducted to analyze the development of rubberized asphalt as a mitigation measure. Other studies have been done in Great Britain, West Germany, Belgium, and other European Countries.

The study conducted in British Colombia compared conventional pavement binders to Rubberized Asphalt (Rub-Arb [TM]) in various locations throughout British Columbia over a period of five years. This study concluded that within the laboratory, the asphalt rubber binder showed improved properties at extreme temperatures compared to convention asphalt. This study also concluded, that modified asphalt rubber binders can be manufactured for a wide range of climate conditions and requirement, it is more flexible at low and sub-zero temperatures, and that the thickness of the asphalt rubber concrete overlay can be reduced from the traditional 50mm overlay down to 38mm of modified asphalt rubber concrete.

In Dordrecht, Belgium a test was conducted using open graded rubberized asphalt in order to study the effectiveness of rubberized asphalt on noise. In this study the researchers concluded that it is possible to design an asphalt mix to reduce traffic noise in urban situations where the traffic noise is dominant. *The study found, that a noise reduction can be achieved of between 2.1 and 3.2 dBA at the speeds of around 50 km/h.*

Additional studies have been conducted in other European countries. *The Societe des Autoroutes du Nord et de l'Est de la France, Paris conducted a study that showed a noise reduction level of 2-3 dBA with rubberized asphalt along the Seine River.* In a paper presented at the 1988 Asphalt-Rubber Conference in Graz, Austria, Helmut Prager, Engineer of Austrian Highways and Bridges showed how the rubber overlay provides better noise reduction. Finally, in Bonn, Germany a study showed that using rubberized asphalt as a sound mitigation measure is more cost effective than using sound barriers. *Most of these studies concluded that rubberized asphalt could reduce noise by 2-3 dBA with few technical problems.*

Finally, The European Commission Green Paper, published in the June 1997 edition ofNoise/News International, cites the following on Page 87:

“Low-noise porous road surfaces have been the subject of much research. These porous road surfaces reduce both the generation and propagation of noise by several mechanisms – which can be related to the open structure of the surface layer. Results have shown that the emission noise levels can be reduced from levels generated on equivalent non-porous road surfaces by between 3-5 dB(A) on average; by optimizing the surface design, larger noise reductions are feasible. At present, the cost of porous asphalt surfacing is higher than conventional surfaces (for resurfacing, but for new roads, the cost is minimal), but may drop as contractors gain experience with porous surfaces. The material is also less durable. However, improvements are being made to durability and, in many countries, these materials are already being used as part of normal road construction in noise-sensitive areas.”

SACRAMENTO COUNTY RUBBERIZED ASPHALT NOISE STUDIES

Overview of Noise and Rationale for Rubberized Asphalt Noise Studies

Noise pollution is the presence of intrusive and unwanted sounds that can seriously affect physical and psychological health. Some examples of the effects from noise pollution include the loss of hearing, anxiety, sleeplessness, aggression, increase in heart rate, and stress. Noise is measured by decibels (dBA) which are a logarithmic function of the ratio of the sound pressure squared over the reference pressure squared. Appendix A provides definitions of acoustic terminology used in this report. Levels of noise can range from very faint to painful and dangerous. For example, human breathing has a dBA of 10 which is considered very faint, office activities have an average dBA of 50, which is considered moderate, and a jet engine at 75ft has a dBA of 140 which is considered painful or dangerous. Because noise has potentially harmful effects, local, state, and federal agencies established noise thresholds beyond which traffic noise abatement must be considered.

Specific noise policies and standards which affect decisions regarding noise mitigation in Sacramento County are provided in Appendix B. It is evident from the various noise standards shown in Appendix B which apply to both development and roadway construction projects in Sacramento County, that this topic is given considerable attention in the environmental review process. The comprehensive County noise criteria has set standards that are often exceeded due to the ever increasing traffic noise levels that cannot be mitigated in traditional ways.

In light of this routine occurrence, the investigation into alternative noise abatement options, other than barriers, was considered to be warranted by Sacramento County. The initial studies of rubberized asphalt were commissioned by the County in 1993. Subsequent testing has been commissioned by the County twice since the initial tests were conducted in 1993. The following sections provide an overview of how traffic noise is generated, followed by the detailed rubberized asphalt test procedures and results of those tests.

How Traffic Noise is Generated and the Implications for Rubberized Asphalt

Traffic noise is generated primarily by the interaction of the tires and pavement, by the internal combustion engine of the vehicle, and by the engine exhaust. For automobiles, the vast majority of the noise is generated by the interaction of the tires and pavement due to quieter engines and exhausts on modern vehicles. As a result, the effective noise source height for automobiles is considered to be zero (0) feet above the pavement, or right where the tire meets the road.

For medium duty trucks (2 axle trucks), there is a slightly larger contribution of noise from the engine compartment and exhaust pipe, so the effective noise source height is considered to be an average of those sources at two (2) feet above the pavement. For heavy trucks, not only is there a greater contribution of noise from the engine and exhaust, the exhaust stack opening is typically 11 feet or so above the pavement. Therefore, the effective noise source height for heavy trucks (3 axles or more), is considered to be eight (8) feet above the pavement, or the weighted average heights of the tires, engine and exhaust stacks.

This information pertaining to the noise generation of the various vehicle types is relevant in that rubberized asphalt is believed to obtain most if its' noise-reducing properties from a combination of the porosity and ductility of the rubberized roadway surface. As a result, tire noise is reduced, but engine and exhaust noise is not appreciably affected by the rubberized surface. Therefore, a roadway containing primarily automobile traffic would be expected to exhibit greater decreases in traffic noise following paving with rubberized asphalt that would a roadway that has a high percentage of heavy trucks.

Traffic Noise Prediction Model

A discussion of the method by which traffic noise is predicted is appropriately included in this report in that normalization of the traffic conditions present during the various noise measurement surveys was accomplished using the Federal Highway Administration Highway Traffic Noise Prediction Model (FHWA-RD-77-108). This normalization was required to isolate the effectiveness of the rubberized paving from the other variables affecting traffic noise generation which were present during the noise tests.

The FHWA Model is the traffic noise prediction model used by Sacramento County for traffic noise assessment. Several adaptations of the model have been developed, including Stamina and Sound 32, but these models are all fundamentally based on FHWA-RD-77-108.

The Federal Highway Administration is currently working on a new traffic noise prediction model which will theoretically replace the existing model, called the Traffic Noise Model (TNM). The TNM will reportedly make adjustments to traffic noise predictions based on roadway surface, but it is not known whether rubberized asphalt will be included in those surfaces. According to FHWA officials, the new TNM has been released and is in use by various State Departments of Transportation (DOT's). It is likely that the new TNM will be required in situations where state or federal funding is involved, but it remains to be seen whether the complexity of the new model will be required for all traffic noise modeling efforts. At the time of this writing, the new TNM has not been adopted for use on California roadways by Caltrans.

Traffic Noise Prediction Model Calibration

The FHWA Model provides reasonably accurate traffic noise predictions under "ideal" roadway conditions. Ideal conditions are generally considered to be long straight roadway segments with uniform vehicle speeds, a flat roadway surface, good pavement conditions, a statistically large volume of traffic, and a unimpeded view of the roadway from the receiver location. However, ideal conditions are more the exception than the rule. As a result, it is often necessary to calibrate the FHWA Model through site-specific traffic noise level measurements and concurrent traffic counts.

The calibration process is performed by conducting concurrent traffic noise level measurements and vehicle counts, and comparing the measured level with that predicted by the Model for the given traffic conditions. This calibration procedure can be used to normalize the model output for varying traffic volumes, speeds, and truck compositions present during the noise measurement samples. Once these factors have been normalized, and the other variables affecting measured traffic noise levels (measurement equipment, distances, measurement technique, etc.) held constant, the differences between measured traffic noise levels before and after the paving with rubberized asphalt can be attributed to the roadway surface. This calibration procedure is the basis for the assessment of the noise reducing properties of rubberized asphalt reported in this report.

Traffic Noise Prediction Model Inputs

Inputs to the FHWA Model include the number of vehicles per hour, the percentages of medium (2 axle) and heavy (3 or more axles) trucks, the average vehicle speeds, the distance between the traffic and receiver, and the characteristics of the intervening ground located between the roadway and the receiver (hard vs. soft site). During the calibration procedure described above, each of these factors was accounted for.

Specific Rubberized Asphalt Test Procedure

The fundamental methodology employed to determine the effectiveness of rubberized asphalt in reducing traffic noise levels in Sacramento County was to take the difference between normalized traffic noise levels measured before and after paving of certain County roadways with rubberized and conventional asphalt overlays. As stated previously, there were several factors which influenced traffic noise generation which needed to be carefully considered in the analysis. Those factors, which include test roadway geometries, noise level measurement equipment location and configuration, atmospheric conditions, and traffic volume, speed, and heavy truck usage, are discussed below.

Test Roadways Evaluated in the Sacramento County Studies: The roadways selected by Sacramento County for assessment of the noise reducing properties of rubberized asphalt were Alta Arden Expressway between Howe and Watt Avenues, and Antelope Road between Auburn Boulevard and Old Auburn Road.

The paving of Alta Arden Expressway was completed in October of 1993, and was not associated with any other widening or reconstruction of that roadway. Therefore, the effects of rubberized asphalt in reducing traffic noise levels on this roadway could be studied without complications which arise from additional travel lanes, roadway realignment, or substantial changes in speeds which could result from such modifications.

The paving of Antelope Road with rubberized asphalt was completed following a roadway widening project on this roadway around April of 1995. As a result, the roadway geometry varied considerably between the pre- and post-paving noise level measurement periods. An effort was made to conduct the noise level measurements at the same distance from centerline before and after the paving. However, due to the widening, the near travel lane moved closer to the noise measurement sites, and speeds increased due to reduced congestion on this roadway. It is not specifically known to what degree the change in roadway geometry and speeds affected the noise measurement results. It is likely, however, that the post-paving noise levels were marginally higher than had the widening not occurred.

The paving of the Bond Road control segment with conventional (non-rubberized) asphalt occurred as part of a roadway widening project in August of 1995. As a result of the roadway realignment, the roadway geometry varied considerably between the pre- and post-paving noise level measurement periods. An effort was made to conduct the noise level measurements at the same distance from centerline before and after the paving. However, due to the widening, the near travel lane moved closer to the noise measurement sites, and speeds increased due to reduced congestion on this roadway as well. It is not specifically known to what degree the change in roadway geometry and speeds affected the noise measurement results. It is likely, however, that the post-paving noise levels were marginally higher than had the widening not occurred, as was the case for Antelope Road.

Elapsed Time Between Measurements: In the Alta Arden assessment, the traffic noise measurement survey was conducted one month prior to the paving with rubberized asphalt. The survey was repeated one month after paving, 16 months after paving, and six (6) years after paving with rubberized asphalt.

In the Antelope Road assessment, a period of 16 months elapsed between the “before” and “after” noise measurements. The asphalt overlay was installed approximately 10 months into this period, around April of 1995. Therefore, the “before” measurements were conducted approximately 10 months prior to the paving, and the “after” measurements were about 6 months after the paving with rubberized asphalt. The measurement survey was subsequently repeated in September of 1999, approximately 4 1/2 years after the paving with rubberized asphalt.

In the Bond Road assessment, the traffic noise measurement survey was conducted one month prior to the paving with conventional asphalt. The survey was repeated one month after paving, and again four (4) years after paving with conventional asphalt

Asphalt Compaction: Compaction of the asphalt overlay reduces the porosity of the road surface, which is believed to account for some of the noise reduction properties of the rubberized asphalt pavement. According to Sacramento County Public Works Agency, Transportation Division staff, the compaction of the paving material is essentially complete within one year of the paving. Therefore, the varying periods of time which elapsed between the paving of the test roadways and the follow-up measurements provides insight into the effects of compaction on the noise-reducing properties of rubberized asphalt. The specific findings regarding compaction follow in a later section of this analysis.

Noise Measurement Duration, Equipment Locations and Configurations: The noise level measurement surveys initially consisted of continuous measurements over a minimum period of 24-hours, and short-term (15-minute) measurements at various locations along each of the three test subject roadways. The continuous noise level measurements were conducted to evaluate the differences in noise levels over 24-hour periods before and after the paving. A benefit of the continuous noise level measurements was that a statistically large sample of noise level data was obtained by which the effects of the rubberized asphalt could be generally evaluated. However, it was not practical to monitor and account for all of the factors which affected the measured noise levels over the continuous sampling periods. Therefore, the findings based on the continuous sampling are considered approximate and relevant only to the measurement periods which were not separated by extensive periods of time (i.e. periods during which traffic volumes and compositions would be expected to be relatively similar).

The short-term noise level measurements were conducted at various distances from the roadway centerlines. The continuous and short-term traffic noise measurements were conducted at a microphone height of 5 feet above ground. These measurements provided a statistically smaller sample of data by which to evaluate the effects of rubberized asphalt than did the results of the continuous monitoring, but traffic counts conducted during the short-term samples allow normalization of the measurement data as discussed previously in this report. The short-term sampling periods also allow for monitoring of all factors, which affect the traffic noise measurement results. Therefore, the normalized results of the short-term samples are believed to provide a more reliable indication of noise reduction attained by the use of rubberized and conventional asphalt paving materials on the test subject roadways.

Larson Davis Laboratories (LDL) Model 870, 700 and 820 integrating sound level meters were used for the continuous and short-term noise level measurements. The meters were calibrated before use with LDL acoustical calibrators to ensure the accuracy of the measurements. The equipment used meets all applicable specifications of the American National Standards Institute for precision sound level measurement systems. The equipment configurations were identical for all of the before and after measurements, with the meters set to the A-weighting network and slow response.

Atmospheric Conditions: Weather conditions were considered to be effectively similar for the before and after short-term traffic noise level measurements at each location. However, due to the close proximity of the noise level measurement microphones to the roadway centerlines, variations in weather conditions between the before and after noise level measurement periods are not believed to have significantly affected the measurement results. In all cases, the measurements were conducted on dry pavement.

Traffic Volume, Speed and Heavy Truck Usage: The continuous and short-term noise level measurements were conducted during typical weekday periods. Given the relatively long period between the initial and final noise measurement periods (4 to 6 years), the traffic volumes are believed to have varied significantly. Therefore, continuous noise level measurements were not used during the 1999 measurement surveys as use of such data could lead to erroneous conclusions regarding the noise-reducing properties of rubberized asphalt.

Traffic counts conducted during the short-term samples indicated that heavy truck traffic accounted for a very low percentage of the total traffic on each of the test subject roadways during those measurement periods. This finding is important in that heavy trucks generate considerably more engine and exhaust noise than automobiles, as stated previously. As a result of the low number of heavy trucks, the traffic noise was generated primarily by the interaction of tires and pavement, which is the component of the traffic noise intended to be isolated in this study.

Average vehicle speeds were observed to be marginally after paving at the test subject roadway locations where an additional lane was added, and fairly similar at the locations where the roadway geometry was not significantly altered. This assumption is based on observations and speedometer checks.

Specific Sacramento County Rubberized Asphalt Test Results

The normalized and averaged results of the various traffic noise surveys conducted on the three test subject roadways are presented in Table 4. The Table 4 data is presented in the form of changes in traffic noise levels relative to pre-paving conditions.

Table 4

Rubberized and Conventional Asphalt Noise Test Results
Sacramento County Roadways

Roadway	Pavement Type	Duration of Time Elapsed After Paving	Change in Noise Levels, dB Leq
Alta Arden Expressway	Rubberized Asphalt	1 month	-6 dB
Alta Arden Expressway	Rubberized Asphalt	16 months	-5 dB
Alta Arden Expressway	Rubberized Asphalt	6 years	-5 dB
Antelope Road	Rubberized Asphalt	6 months	-4 dB
Antelope Road	Rubberized Asphalt	5 years	-3 dB
Bond Road	Conventional Asphalt	1 month	- 2 dB
Bond Road	Conventional Asphalt	4 years	0 dB

Notes:

The change noise levels shown in the far right column represents the average change in noise levels observed on the roadway test site at the nearest measurement locations to the roadways. For Alta Arden and Antelope Road, the change represents the average noise reduction of three test locations for each roadway. For Bond Road, there was only one test location. Due to the time elapsed between the earliest and latest noise measurements, the results were normalized for speed and traffic volume to isolate the noise-reducing properties of the paving materials.

Evaluation of the Table 4 data indicates that, immediately after paving the test roadways with rubberized and conventional asphalt, traffic noise decreased along all three roadways. However, once a sufficient amount of time had elapsed for the various roadways to be fully compacted, the roadways paved with rubberized asphalt still exhibited good traffic noise reduction, whereas the noise reduction of the conventional asphalt overlay was lost.

As stated previously, the Antelope Road test procedure was complicated in that the pre and post-paving tests were conducted on different roadway geometries. Because of this change in geometries, the noise reducing properties of the rubberized asphalt on that roadway may have been slightly understated as post-paving traffic was considerably closer to the measurement sites that pre-paving conditions. The changes in noise reduction of the rubberized asphalt on Alta Arden and Antelope noted between the tests conducted shortly after the paving and those conducted several months and years later (1 dB drop in noise reduction), is believed to be due to compaction of the roadway surfaces.

CONCLUSIONS OF THE STUDIES CONDUCTED IN SACRAMENTO COUNTY

This analysis concludes that the use of rubberized asphalt on Alta Arden Expressway and Antelope Road resulted in a net decrease in traffic noise levels of approximately 4 dB over that provided by conventional asphalt. These conclusions hold for both the near and long-term conditions. The noise reduction provided by the rubberized paving was achieved predominately in the 500 to 4,000 Hertz frequency bands, which is consistent with the frequency character of tire noise.

These local test results, when considered with other studies conducted nationally and internationally, support the use of rubberized asphalt as a viable noise mitigation option. Its use could, in some cases, eliminate the need for noise barriers or reduce the heights of the barriers required to achieve satisfaction with local, state and federal noise standards.

It should be noted that the effectiveness of rubberized asphalt in reducing traffic noise levels would be highest on roadways with relatively low percentages of heavy duty trucks, as truck engine and exhaust stack noise is not believed to be substantially affected by rubberized paving.

- Appendix A -
Acoustical Terminology

Acoustics	The science of sound.
Ambient Noise	The distinctive acoustical characteristics of a given space consisting of all noise sources audible at that location. In many cases, the term ambient is used to describe an existing or pre-project condition such as the setting in an environmental noise study.
Attenuation	The reduction of an acoustic signal.
A-Weighting	A frequency-response adjustment of a sound level meter that conditions the output signal to approximate human response.
Decibel or dB	Fundamental unit of sound, A Bell is defined as the logarithm of the ratio of the sound pressure squared over the reference pressure squared. A Decibel is one-tenth of a Bell.
CNEL	Community Noise Equivalent Level. Defined as the 24-hour average noise level with noise occurring during evening hours (7 - 10 p.m.) weighted by a factor of three and nighttime hours weighted by a factor of 10 prior to averaging.
Frequency	The measure of the rapidity of alterations of a periodic signal, expressed in cycles per second or hertz.
L_{dn}	Day/Night Average Sound Level. Similar to CNEL but with no evening weighting.
L_{eq}	Equivalent or energy-averaged sound level.
L_{max}	The highest root-mean-square (RMS) sound level measured over a given period of time.
Loudness	A subjective term for the sensation of the magnitude of sound.
Masking	The amount (or the process) by which the threshold of audibility is for one sound is raised by the presence of another (masking) sound.
Noise	Unwanted sound.

Peak Noise	The level corresponding to the highest (not RMS) sound pressure measured over a given period of time. This term is often confused with the AMaximum@ level, which is the highest RMS level.
Threshold of Hearing	The lowest sound that can be perceived by the human auditory system, generally considered to be 0 dB for persons with perfect hearing.
Threshold of Pain	Approximately 120 dB above the threshold of hearing.

- Appendix B -
Noise Standards Commonly Applied in Sacramento County

Sacramento County Noise Element Policies

The Sacramento County Noise Element establishes land-use compatibility criteria for both interior and exterior areas of various land uses. The County Noise Element policies which pertain to transportation noise follow.

NO-1: Noise created by new transportation noise sources should be mitigated so as not to exceed 60-dB Ldn/CNEL at outdoor activity areas of any affected residential lands or land use situated in the unincorporated areas. When a practical application of the beast available noise-reduction technology cannot achieve the 60-dB Ldn/CNEL standards, then an exterior noise level of 65-dB Ldn/CNEL may be allowed in outdoor activity areas.

NO-4: Where residential land uses are proposed in areas exposed or projected exterior noise levels exceeding 60 dB Ldn / CNEL or the performance standards described above, an acoustical analysis shall be required as part of the environmental review process.

NO-6: The compatibility of proposed nonresidential projects with existing and future noise levels due to transportation noise sources shall be evaluated through a comparison to the standards described in Table 5 (below) and Table II-3 found in the Sacramento County Noise Element of the General Plan.

NO-7: Proposed Development of Residential land uses should not be permitted in areas exposed to existing or project levels of noise from transportation which exceed 60 dB to 65 dB Ldn / CNEL unless the project design includes effective mitigation measures to reduce noise.

Table 5

Sacramento County Noise Element Noise Standards

Exterior Noise Level Standard, Ldn

Land Use Category	Acceptable	Conditionally Acceptable
Residential	60	75
Agriculture Residential	65	75
Churches	60	70
Golf Courses	75	80
Office/Commercial/Professional	65	75
Industrial/Utilities/Agriculture	70	80

Source: Sacramento County Noise Element

In addition to the Noise Element Noise Standards above, the General Plan Noise Element includes standards for acceptable noise levels for the interior spaces of noise-sensitive land uses affected by Transportation Noise. Those interior noise level standards are shown in Table 6.

Table 6

Acceptable Noise Levels In Unoccupied Rooms Affected By Transportation Noise

Location	Average Sound Level1 dBA
Radio studies, recording studios	25-30
Music Rooms	30-35
Concert halls, auditoriums	30-35
Theaters (speech)	30-35
Motion picture theaters	40-45
Churches	35-40
Conference rooms, small offices	40-45
Classrooms	35-45
Public offices, banks, stores	45-50
Hospitals	40-45
Restaurants, cafeterias	45-50
Court rooms	40-45
Libraries	40-45

1. Leq in worst-case hour during periods of use.

California Environmental Quality Act Guidelines (CEQA)

The California Environmental Quality Act guidelines state that transportation noise will have a significant impact if it "Increased substantially the ambient noise levels for adjoining areas". There are several criteria CEQA uses to access the transportation noise impact on a project.

1. If the exposure of persons to or generation of noise levels result in an excess of standards established the local general plan or other applicable standards
2. If the project results in a substantial permanent increase in ambient noise levels in the project vicinity above levels existing without the project.
3. If the project results in substantial temporary or periodic increase in ambient noise levels in the project vicinity above levels existing without the project.

Federal Policies

The criteria for evaluating noise impacts that are used by the Federal Highway Administration and Caltrans are contained in the Caltrans Traffic Noise Analysis Protocol (the Protocol). The Protocol establishes Noise Abatement Criteria (NAC) for various land uses. Table 7 presents a summary of the Federal Noise Abatement Criteria.

Table 7

Federal Noise Abatement Criteria
[Hourly A-Weighted Sound Level-decibels (dBA)1]

Activity Category	Leq (h), dBA	L10(h), dBA	Activity Category Description
A	57 (Exterior)	60 (Exterior)	Lands on which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.
B	67 (Exterior)	70 (Exterior)	Picnic areas, recreation areas, playgrounds, active sports areas, parks, residences, motels, hotels, schools, churches, libraries, and hospitals.
C	72 (Exterior)	75 (Exterior)	Developed lands, properties, or activities not included in Categories A or B above.
D	C	C	Undeveloped Lands.
E	52 (Interior)	55 (Interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums.

1 Either L10(h) or Leq(h) (but not both) may be used on a project.

- Appendix C -
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