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| 16. Abstract This report summarizes the first phase of a three-phase research program intended to evaluate the use of recycled materials in roadside safety devices. Researchers obtained information regarding existing products manufactured in part or in whole from recycled materials through an extensive computerized literature review and a survey of research organizations, government/state agencies, professional and trade societies, and manufacturers. They emphasized obtaining information for those materials and products believed to have application in the roadside safety area. Roadside safety features of interest include, but are not limited to, guardrail support posts and rail-to-post offset blocks, sign blanks and their supports, energy absorbing elements in crash cushions, flexible delineator posts, mailbox supports, and work zone traffic control devices such as drums, cones, and barricades. Based on this evaluation scheme, researchers identified specific products considered suitable for immediate implementation and categorized them by application type. They recommend further evaluation in Phase II of this study for some products lacking the desired data to make a conclusive decision regarding their suitability for implementation. Phase III of the study will consist of full-scale crash testing of selected products to verify their crashworthiness. Researchers will then prepare performance specifications for those applications for which suitable alternatives have been identified. | | | |
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**APPLICATIONS OF RECYCLED MATERIALS IN
ROADSIDE SAFETY DEVICES**

by

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and

Barbara G. Butler

Research Report 1458-1
Research Study Number 0-1458
Research Study Title: Recycled Materials in Roadside Safety Devices

Sponsored by the
Texas Department of Transportation
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TEXAS TRANSPORTATION INSTITUTE
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College Station, Texas 77843-3135

IMPLEMENTATION STATEMENT

This report summarizes the first phase of a three-phase research program which evaluates the use of recycled materials in roadside safety devices. The objective of Phase I was to identify existing or commercially available roadside safety products manufactured from recycled materials and evaluate their suitability for implementation. Specific products considered suitable for immediate implementation were identified and categorized by application type. The evaluation was based primarily on the ability of the product to meet nationally recognized safety standards and on field experience reported by other agencies. Researchers did not consider factors such as cost, availability, and ease of handling due to lack of information in these areas.

Roadside safety applications for which researchers have identified products considered suitable for implementation include: barricades, bollards, traffic cones, channelizing drums, flexible delineator posts, and guardrail offset blocks. For some of these devices, however, information regarding long-term performance and durability is lacking. It is therefore recommended that these products initially be implemented and monitored on an experimental basis. If in-service performance is judged to be satisfactory, the devices could then be upgraded to full operational status.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT) or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation, nor is it to be used for construction, bidding, or permit purposes. The engineers in charge of the project are R. P. Bligh, P.E. #78550, H. E. Ross, Jr., P.E. #26510, and D. C. Alberson, P.E. #74891.

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SUMMARY

This report summarizes the first phase of a three-phase research program intended to evaluate the use of recycled materials in roadside safety devices. Researchers obtained information regarding existing products manufactured in part or in whole from recycled materials through an extensive computerized literature review and survey of research organizations, government/state agencies, professional and trade societies, and manufacturers. They emphasized obtaining information for those materials and products believed to have application in the roadside safety area. Roadside safety features of interest include, but are not limited to, guardrail support posts and rail-to-post offset blocks, sign blanks and their supports, energy absorbing elements in crash cushions, flexible delineator posts, mailbox supports, and work zone traffic control devices such as drums, cones, and barricades. The number and cost of these devices installed and replaced annually within Texas and the rest of the nation are significant, and the potential exists for effecting a measurable and positive impact on environmental problems in a cost-effective manner.

The information was summarized and categorized into two distinct areas: (1) commercially available roadside safety products and traffic control devices having the potential for immediate implementation, and (2) other products and materials not specifically designed for use in roadside safety devices, but having potential use in such applications.

The project team developed a prioritization scheme to assist in the evaluation of the existing products. Fulfillment of specified safety requirements was ranked first in importance. Relevant field experience reported by state agencies, and the availability of physical and mechanical properties from laboratory testing were also weighed heavily in the evaluation process. Factors such as cost, availability, and ease of handling were not directly considered due to lack of information in these areas.

Based on this evaluation scheme, researchers identified specific products considered suitable for immediate implementation and categorized them by application type. They recommend further evaluation in Phase II for some products lacking the desired data to make a conclusive decision regarding their suitability for implementation. Phase III of the study will consist of full-scale crash testing of selected products to verify their crashworthiness. Researchers

will then prepare performance specifications for those applications for which suitable alternatives have been identified.

I. INTRODUCTION AND OBJECTIVES

STATEMENT OF PROBLEM

Recently, environmental concerns, declining disposal capacity, legislative mandates, economic considerations, and conservation efforts have influenced policies on the recycling of various waste materials and by-products. Waste materials and by-products are generally classified into four broad categories based on their source: agricultural, domestic, industrial, and mineral. Roughly 4,200,000,000 Mg (4.6 billion tons) of non-hazardous solid waste materials are produced annually in the United States (Collins and Ciesielski, 1994). Domestic and industrial wastes constitute almost 544,000,000 Mg (600 million tons) of this total. State agencies, research agencies, and manufacturers are paying increased attention to wastes such as scrap tires, glass, and paper. Of particular interest are the 20,700,000,000 kg (22.8 million tons) of plastic waste generated each year, of which 5,900,000,000 kg (6.5 million tons) constitutes packaging wastes (Strybos, 1993). While plastics constitute only 7 percent of the solid waste stream by weight, they comprise approximately 12 to 20 percent of the volume (Bloomquist, et al., 1993).

While the volume of wastes continues to grow, approval of facilities for waste processing and disposal is becoming more difficult to obtain due to public concerns and increasingly restrictive environmental regulations. As a result, the cost of waste handling and disposal continues to escalate, and a greater percentage of resources is being devoted to recycling and waste management techniques. In addition, many manufacturers are now attempting to recycle and market plastics and other materials for a variety of widespread applications, including various roadside safety appurtenances and work-zone traffic control devices. The number and cost of these devices installed and replaced annually within Texas and the rest of the nation are significant, and the potential exists for effecting a measurable and positive impact on environmental problems in a cost-effective manner.

Clearly, the movement toward increased utilization of recycled materials in highway safety is national in scope. However, the level of practice and knowledge of waste material recycling and use in roadside applications varies from state to state. Highway department personnel at all levels need to be aware of the various types of waste materials that can be recycled, applications for which they can be used, experiences of other agencies with these

products, and their suitability based on technical, economic, and environmental considerations. Investigations are needed to determine basic properties of existing recycled materials and products, comparability with the desired properties, and the practicality of their application in terms of safety, availability, cost, durability, etc.

OBJECTIVES

In response to these needs and the increased focus and interest in the use of recycled materials such as plastics, rubbers, paper, glass, etc., the Texas Department of Transportation (TxDOT) sponsored research study 0-1458 entitled "Recycled Materials in Roadside Safety Devices." The purpose of this study is to investigate and explore the use of recycled materials in roadside safety applications with the goal of implementing products (either existing or newly developed) which meet established safety criteria. More specifically, the objectives of this research effort are as follows:

- Identify existing or commercially available roadside safety products manufactured in part or in whole from recycled materials and evaluate their suitability for implementation;
- Determine fundamental properties of selected recycled materials and products considered candidates for use in roadside safety systems or components therein;
- Evaluate the compliance of selected recycled materials and products with nationally recognized safety performance standards;
- Develop recommended performance standards and specifications for acceptable designs; and
- Conceptualize new roadside safety system designs using recycled materials and recommend the most promising designs for further study.

SCOPE AND RESEARCH APPROACH

This report summarizes the first phase of a three-phase research program. In Phase I, researchers obtained information regarding existing products manufactured in part or in whole from recycled materials through an extensive literature review and survey of research organizations, government/state agencies, professional and trade societies, and manufacturers. Emphasis was placed on those materials and products having application in the roadside safety

area. Roadside safety features of interest include, but are not limited to, guardrail support posts and rail-to-post offset blocks; sign blanks and their supports; energy absorbing elements in crash cushions, end terminals, and truck mounted attenuators; delineator posts; mailbox supports; and work zone traffic control devices such as drums, cones, and barricades.

The Phase I information was categorized into two distinct areas: (1) commercially available roadside safety products and traffic control devices having the potential for immediate implementation, and (2) other products and materials not specifically designed for use in roadside safety devices but having potential use in such applications.

For those products lacking the desired data to make a conclusive decision regarding their suitability for implementation, Phase II of this study will involve further characterization and evaluation through laboratory and dynamic testing. When possible, researchers will compare the properties of these materials and products to the desired characteristics or existing specifications for the applications under consideration.

Phase III of the study will consist of full-scale crash testing of selected products to validate laboratory results and verify their crashworthiness. The project team will then prepare performance specifications for those applications for which suitable alternatives have been identified.

II. SURVEY OF RECYCLED MATERIALS AND PRODUCTS

Two primary methods provided information regarding existing recycled products: a computerized literature search, and personal contacts with various research organizations, government/state agencies, professional and trade societies, and manufacturers. Researchers emphasized references and contacts which were believed to have relevance to the roadside safety area. The objective of this survey of information was to identify existing commercially available products suitable for immediate implementation by TxDOT, and to develop a database of product information which could be used to explore the feasibility of using recycled materials in the development of new, innovative roadside safety applications or as alternates to more conventional safety features.

LITERATURE SEARCH

Initial efforts to identify information pertaining to the use of recycled materials in roadside safety applications consisted of an in-depth computerized literature search. The purpose of this review was to identify reports, publications, journal articles, ongoing research studies, and other information that addresses the use of recycled materials in highway safety products, including material composition, physical and mechanical properties, performance, durability, cost, and availability.

Researchers performed on-line electronic bibliographic searches of relevant databases using Dialog Information Services and Orbit Search Service. The databases searched included: Transportation Research Information Service (TRIS), National Technical Information Service (NTIS), Compendex Plus (computerized version of the Engineering Index), Wilson Periodical Index, RAPRA (a rubber, plastics, adhesives, and polymeric composites materials index), Plastics Recycling Database (a service maintained by the Center for Plastics Recycling Research at Rutgers University), and the Society for Automotive Engineers Global Mobility Database. Numerous additional technical publications, reports, and articles identified as references from the computerized search were reviewed. In addition, numerous journals and periodicals, such as *Modern Plastics*, *Plastics Technology*, *Materials Performance*, and *Plastics Engineering*, were reviewed to supplement the search.

Initially, the search focused specifically on the use of recycled materials in roadside safety applications. During the initial literature survey, only a few citations were uncovered which reflects the relative infancy of the industry and the lack of research funding in this area. The scope of the literature search was then expanded to obtain more general information regarding a variety of recycled materials, including their properties, fabrication processes, and existing and potential applications.

This search yielded over 2,400 citations. Using titles and abstracts, researchers selected and obtained the most relevant of these for review. By far, the bulk of the references were obtained from TRIS. The subject matter ranged from collection strategies, separation techniques, economic analyses, mixing and processing procedures, mechanical properties, fabrication methods, to new product applications. Much of what is reported relates to basic materials research in which the mechanical and chemical aspects of different resin compositions are presented. Little applied research dealing with a material's suitability for specific end-use applications is available in the literature. A brief summary of some of the more relevant references is given below.

Roadside Safety Applications

Several research and transportation agencies have recently undertaken studies involving the use of recycled materials in roadside safety devices. The Ontario Ministry of Transportation sponsored a study to determine the technical and economic viability of using waste plastics and scrap rubber for non-structural highway products (Mota, et al., 1993). Information was gathered from a variety of sources via a computer literature survey, a mail survey, and telephone interviews. The study concluded that waste plastics based on the four major commodity resins (polyethylene PE, polypropylene PP, polystyrene, PS, and polyvinyl chloride PVC) would be suitable for certain non-structural highway products such as delineators, snow fencing, fence posts, and picnic tables and benches. The study also recognized the potential for use of recycled materials in other applications such as guardrail posts and offset blocks, noise barriers, access hatch collars and risers, and culverts.

Principal advantages or benefits associated with the use of recycled plastics and rubber/plastics blends are reported to be (Mota, et al., 1993):

- Excellent durability (long service life expectancy in outdoor environment),

- Maintenance-free service,
- Good balance of mechanical properties,
- Good fastening characteristics,
- Dimensional stability,
- No splitting, splintering, or cracking, and
- Can be sawed, drilled, and routed as with wood products.

Reported disadvantages of using plastics and rubber/plastics blends include:

- Relatively poor modulus (i.e., greater deflections under service loads),
- Poor creep performance, and
- Cost (compared to wood or steel).

As a follow-up to this study, the Ontario Ministry of Transportation sponsored a two-phase research program to develop specifications for plastic lumber for use in highway applications. From a review of existing wood product performance and data available for plastic lumber, draft specifications were created (Redpath, 1993). The applications examined were those in which wood products are currently being used, such as sign posts, guardrail posts and offset blocks, delineator posts, fence posts, sign blanks, survey stakes, noise barriers, and landscaping ties. The physical and mechanical properties, test procedures, design, and performance requirements for existing wood products provided the technical framework for the specifications. Literature reviews and surveys provided data on material properties of plastic lumber.

Phase II of this research study will include testing of several different plastic lumber products currently available from commercial manufacturers. The testing program includes laboratory evaluation of the material and monitoring of full-scale prototypes installed along the highway. Six commercially available products have been selected for the test program. The products consist of different material compositions and shapes including:

- Plastics and wood fiber mixture,
- Plastics and glass fiber mixture,
- Commingled plastics,
- 100 percent high density polyethylene (HDPE), and
- Solid and hollow shapes.

The first stage of this Phase II effort has been completed (Boyd, 1994), and test results are being used to modify the draft specifications proposed in Phase I.

A paper by Smith and Ramer (1992) discusses ongoing research sponsored by the Florida Department of Transportation which investigates the feasibility of utilizing recycled plastic wastes for fence line posts and guardrail posts as mandated by a 1988 state law. Testing focused on the acquisition of properties and characteristics considered essential for the applications being investigated. The paper presents data on flexural strength, tensile strength, insect resistance, soil microorganism resistance, water absorption, fire resistance, and exposure resistance. It was noted that large diameter posts showed major variations in composition and properties. Some possessed large voids which reduced the mechanical strength of the sample. Exposure tests indicated that warpage was a concern for posts with small cross sections.

Based on test results of recycled lumber from five manufacturers, a tentative fence post specification is proposed. Other applications reported as being under investigation include sign substrates, delineator posts, rebar support chairs, and guardrail offset blocks.

Other research conducted jointly by Florida DOT and the University of Florida discusses mechanical properties of commingled post materials (Florida DOT, 1992). The feasibility of optimizing post design by engineering the properties of the outer shell and inner core is explored. The outer shell or skin region of the post is recognized as having the greatest influence on flexural properties. Alternative materials may be used in the core region to absorb energy and improve the impact performance of the post. Dynamic tests indicate that the mechanical properties of the post skin show no significant orientation effects. Application of this technology may be useful in applications such as guardrail posts and sign supports.

An ongoing research project sponsored by the Federal Highway Administration (FHWA) is investigating the use of recycled materials for highway noise barriers, guardrail posts and offset blocks, and right-of-way fence posts (SwRI, 1993a). Several design concepts for noise barriers using recycled plastic lumber and recycled rubber have been proposed. Another aspect of the study concerns evaluating the feasibility of replacing standard wood guardrail posts and offset blocks with products manufactured from recycled materials. A W-beam guardrail system comprised of 100 percent recycled guardrail posts and offset blocks

successfully contained and redirected a 2,043-kg (4,500-lb) test vehicle impacting the installation at a nominal 96.6 km/h (60 mph) and 25 degrees. However, it was noted that the maximum dynamic rail deflection was significantly greater than that observed in standard strong post guardrail systems. Thus, while the results indicate that TimbrexTM (a product manufactured from recycled plastic and sawdust) functions satisfactorily as an offset block, it is not an acceptable substitute for standard wood and steel guardrail posts in strong-post guardrail systems (Strybos, 1993). Dynamic pendulum tests of five other recycled posts obtained from commercial manufacturers indicated that they possessed insufficient fracture energy to serve as a substitute for standard wood and steel guardrail posts.

In related work, the Federal Highway Administration has conducted several full-scale crash tests of guardrail systems containing components made in whole or in part from recycled materials. During this testing, conducted at the Federal Outdoor Impact Laboratory (FOIL) facility, the recycled plastic guardrail posts fractured at energy levels far below those of standard wood and steel posts, indicating that they should not be substituted for conventional posts in strong-post guardrail systems.

A study sponsored by the Michigan Department of Transportation evaluated the dynamic properties of selected posts made from recycled plastics using full-scale pendulum tests (SwRI, 1993b). Results were compared with standard wood and steel guardrail posts. The study concluded that no posts manufactured solely from recycled plastic are currently available which would serve as a satisfactory replacement for conventional wood and steel posts.

In recent years, various manufacturers have contracted with TTI to test a number of different roadside safety devices comprised of recycled materials. One such study involved the testing of guardrail posts and offset blocks (Bligh, 1991a; Bligh, 1991b). The prototype guardrail posts consisted of an outer shell manufactured from post-consumer plastics and an inner core comprised of wood or thin-wall steel pipe. The plastic used in the outer shell consisted of LDPE, HDPE, PET, ABS, PP, and miscellaneous mixed scrap. The offset blocks were comprised entirely of the commingled plastic mixture.

Static laboratory compressive tests indicated that the commingled plastic block should be suitable as an alternate in standard guardrail systems. In-situ static load tests and dynamic pendulum tests showed that the composite guardrail posts were unsatisfactory as substitutes

for conventional wood and steel posts. However, recommendations were made for improving the performance of the guardrail posts, and a second generation post was found to be an acceptable alternative for use in standard strong-post W-beam guardrail systems (Bligh, et al., 1992).

In another study, sign supports manufactured from 100 percent post consumer polyethylenes were crash tested (Alberson, 1993). The posts fractured readily under dynamic loading as required for proper impact performance but were susceptible to excessive deflections when subjected to static loads applied at sign mounting height. Large deformations caused by differential thermal expansion in the support were also observed during the evaluation process.

In a ongoing study sponsored by TxDOT, TTI researchers are evaluating the crashworthiness of various work zone traffic control devices such as plastic drums, sign panels, temporary sign supports, and barricades. Of particular interest to the current study is the feasibility of using recycled plastic materials in the construction of barricades. A Type III barricade, comprised of commercially available, lightweight, hollow recycled plastic supports and cross members supported on standard wooden skids, was successfully crash tested for both frontal and end-on impact conditions. The support was assembled using wood screws in a manner similar to that used in the construction of standard wood barricades. In the same study, a Type III barricade assembled from a commercially available recycled plastic lumber product was determined to be unacceptable during full-scale crash testing due to intrusion into the occupant compartment of the test vehicle. The failure, which was similar to that observed with a standard Type III wood barricade, was attributed to the density of the recycled material and its tendency to fracture upon impact.

A report by the Oregon Department of Transportation relates their field experience with recycled plastics in highway construction and maintenance. The report includes material descriptions, installation locations, economic considerations, and environmental concerns. Products of interest which were evaluated include snow poles, sign supports, fence posts, and sound walls. The fence posts are reported to be working as intended. However, a tendency for the sign supports to warp and bow has been observed and the overall experience was rated as marginal. The sound wall materials are also reported to have a tendency to bow, but the

problems are considered to be manageable with the additional back support. Guardrail offset blocks are in the early stages of evaluation and testing.

General Information on Recycled Materials and Products

As indicated above, relatively few studies have specifically addressed the application of recycled materials in roadside safety appurtenances. Fewer have reported success in this area. This can likely be attributed to two factors: (1) lack of understanding of the engineering requirements (safety, strength, and durability) of the application being investigated, and (2) lack of understanding of material properties and behavior. Many of the references identified from the literature search deal with basic material research and do not specifically address roadside safety applications. These references provide information regarding the physical and mechanical properties of various recycled materials and how these properties are affected by the addition of various fillers and reinforcements. While not directly applicable to the present study, these references nonetheless provide valuable insight into the behavior of recycled materials. Such information is critical if acceptable alternatives are to be found for many of the demanding applications in the roadside safety area. While the articles obtained in this area are too numerous to cite individually, a review of some selected references is provided below to offer the reader an indication of the type of information available.

Salas, et al. (1990a) investigated the effect of reinforcing additives on the properties of post consumer plastic waste boards. This study demonstrated that it is possible to obtain significant improvements of some properties through the addition of certain additives. Additives studied include glass fiber, glass fiber-reinforced polypropylene pellets, and polypropylene, calcium carbonate, and mica. In some cases the improvements obtained in mechanical properties make the recycled boards nearly competitive with lumber with respect to flexural and compressive strength properties.

A report by Phillips, et al. (1989) describes physical and mechanical property test procedures used in characterizing product samples taken from post-consumer commingled plastic wastes. Specific test procedures discussed include: specific gravity compression, stress-strain, flexural load displacement, and flexural pre-test methods. Modifications to existing standard ASTM methods are reported to enable measurement of properties of molded heterogeneous commingled product samples. Representative data are included to illustrate test

method results and provide an indication of the degree of variability observed in properties and materials produced from similar commingled feedstocks.

Nosker, et al. (1991) reports the material properties of recycled plastic lumber composed of a mixture of commingled plastic and polystyrene (PS). Strength and stiffness are reported as a function of the percentage of PS. The compressive modulus ranges from 800 MPa at 0 percent PS up to 1,500 MPa at 50 percent PS. The flexural modulus also increases, ranging from 17 MPa at 0 percent PS to 22 MPa at 50 percent PS.

Chtourou, et al. (1991) investigated the behavior of recycled plastics composed of a blend of polypropylene (PP) and polyethylene (PE) combined with wood fibers. The specimens were fabricated through injection molding and compression molding. The mechanical tests showed that the strength and stiffness of the recycled plastic specimens increased linearly with the percentage of wood fibers. Also, the strength and stiffness of the recycled thermoplastic blends decreased with exposure to moisture.

In a paper by Selke, et al. (1989), five additives were studied to determine their effect on the tensile and impact strength of a recycled plastic composed of a mixture of HDPE and aspen hardwood fibers. In each case, the recycled plastic was composed of 5 percent additive, 30 percent wood fiber, and 65 percent HDPE by weight. While the results were quite variable, the addition of fibers with or without additives generally decreased the stiffness, increased the tensile strength, and decreased the impact strength relative to plain HDPE. Appendix A presents a bibliography containing these and other references considered relevant to the study.

In summary, while mechanical properties are available for various recycled plastic blends and commingled products, the wide variation in chemical compositions, processing techniques, and admixtures precludes the development of a standard set of material specifications for a given application. Therefore, it becomes necessary to develop performance standards for a given application based on a series of standard test procedures.

SOLICITATION OF INFORMATION ON AVAILABLE RECYCLED MATERIALS

Many references obtained from the literature search made reference to other research agencies, professional/trade organizations, manufacturers, and state agencies involved in recycling efforts. In turn, information gathered from these contacts led to increasing sources

of information. To date, approximately 250 contacts have been made. These contacts can be grouped into one of four general categories: (1) research agencies, (2) professional/trade societies, (3) manufacturers, and (4) state and federal agencies. Appendix B presents a complete list of contacts, along with an indication of those responding. The contact listings, which are subdivided into the categories mentioned above, include a contact person, address, and phone number when available. Generally speaking, there appears to be a growing public awareness of the problem of limited landfill capacities and the need for recycling initiatives, and enthusiasm among those interviewed was high regarding possible contributions to the problem's solution.

As suggested by the relatively small number of completed projects and large number of organizations in early phases of new research, this research area is still in its infancy. Table 1 lists research-oriented agencies and contact individuals responding thus far to inquiries concerning this study.

TABLE 1. Research-Oriented Agencies Responding to Study

| Contact Name | Research Agency Name | State/Prov. |
|-----------------------|--|-------------|
| Serji Amirkhanian | Clemson University | SC |
| David Hon | Clemson University | SC |
| Richard Ramer | Florida DOT/Univ. of Florida | FL |
| A. (Coom) Coomarasamy | Ministry of Transportation | Ontario |
| Robert Diraddo | Nat. Research Council of Canada | Ontario |
| Mary Haughney | Rensselaer Polytechnic Inst. | NY |
| Tom Nosker | Rutgers Univ. - Ctr. for Plastics Res. | NJ |
| John Strybos | Southwest Research Institute | TX |
| Charles McDevitt | Turner-Fairbank Hwy. Research Ctr. | VA |
| Michael Fix | Twin Cities Army Ammunition Plnt. | MN |
| Robert Malloy | Univ. of Mass. at Lowell | MA |
| Richard Lampo | US Army Constr. Eng. Res. Labs | IL |
| Craig Clemons | USDA Forest Service | WI |
| Frank Woeste | Virginia Polytechnic Inst. & State Univ. | VA |

As this table indicates, universities comprise most of the contacts made among those conducting research in this area. Many of these universities and institutions are working in cooperation with one or more state agencies. Additional responses from other individuals and organizations involved in the research of recycled materials are expected as the project progresses.

The American Society for Testing Materials (ASTM) is in the process of reviewing and revising standards for test methods of recycled plastic lumber. The fact that test methodologies and protocols are still evolving is further evidence of the lack of development in this field. For the last three years, the Quality Construction Task Force of the American Association of State Highway and Transportation Officials' (AASHTO) Subcommittee on Construction has surveyed the states requesting information on their current and past use of recycled materials. The majority of recycled materials are being used in pavements and embankment beautification. However, several states have indicated recycled material use in roadside safety features and traffic control devices. Appendix C presents a summary of the information contained in this report and relevant to the current study.

Multiple trade organizations are also involved in the recycled materials arena and many contacts were made as a result of information they provided regarding their members, affiliates, associates, and others. Following is a partial list of those contacted:

- American Plastics Council,
- Society of Plastics Industry,
- Plastic Lumber Association, and
- Society of Plastics Engineers.

These contacts will be summarized later in this report.

The commercial sector has repeatedly shown its willingness to cooperate with researchers and to provide specimens and test data when available. TTI researchers contacted some 200 manufacturers and asked them to provide information on their products. The requested information included physical and mechanical properties, percent recycled content, waste stream, cost, test results, and existing or potential applications. To date, over sixty responses have been received. Although not all of the respondents provided all of the information requested, most responses included literature brochures, small samples, laboratory test data, and price lists.

Several state transportation agencies, such as Florida and Michigan, have programs with research universities/organizations to determine the feasibility of the use of recycled materials in roadside safety devices. Florida has conducted perhaps the most comprehensive research on the subject to date. Through research conducted internally and in cooperation with the University of Florida, Florida DOT has investigated applications of recycled products such as fence posts, delineators, rebar support chairs, guardrail posts and offset blocks, and sign panels. North Carolina has installed several plastic sign supports for evaluation concerning long-term exposure to the elements.

All 50 Departments of Transportation and Puerto Rico were contacted regarding their use of recycled materials in roadside safety devices. To date, we have received 35 responses to our requests. According to the states responding, delineators from recycled products are the most widely used devices. The upright portions of the delineators are all made from recycled plastics. Bases for temporary delineators consist of recycled tires and recycled plastics. Recycled plastic lumber usage in barricades is also gaining momentum. Preliminary testimonies from several sources, including a TTI study sponsored by TxDOT, show desirable characteristics for plastic lumber barricades when subjected to vehicular impacts. North Carolina, however, has reported problems with durability, specifically, the loosening of fasteners and construction joints. Recycled plastic sign supports are being field tested in North Carolina, South Carolina, Nevada, and other states. Iowa has completed a study utilizing 102 mm × 102 mm (4" × 4") recycled plastic sign supports and found them to be unacceptable due to excessive deflections and temperature susceptibility. Below is a summary of comments obtained from the states agencies which responded to the request for information:

AL - They do not currently use recycled products in roadside safety devices, but have received information from Trafcon Windbreakers (delineators) and Timbrex.

CA - They do not use recycled products in roadside safety devices.

CT - They do not currently use recycled products in roadside safety devices. In previous years, they have used plastic sign blanks, but the blanks became very brittle during cold

weather and shattered easily from flying snow and ice. Traffic barricades made of 100 percent recycled HDPE were tried on an interstate construction project. Their light weight and inability to be anchored resulted in excessive blowdowns. Connecticut DOT does not perform tests on materials, but relies on manufacturers' information, certified test reports, and other states' experiences when evaluating products. There is a field study under way of thermoplastic sign blanks manufactured by International Plastics, Inc. Also, Trex offset blocks have been approved for use in Connecticut. Connecticut has been contacted by vendors representing the Lifeguard channelizer and the Gripper Plastic Delineator Post. The Gripper uses recycled tires and is manufactured by Plastic Safety Systems, Inc. Vendors from Plastic Piling and Greenline have also contacted Connecticut regarding their plastic/steel fender piling and delineator posts, respectively. They have also been approached by SABI regarding recycled aluminum stock. Visi-Barrier and Visi-Curb, made from recycled resin by Transpo Industries, have been rejected for use.

DC - The Federal Outdoor Impact Laboratory (FOIL) facility in McClean, Virginia, has crash tested guardrail posts constructed of commingled recycled plastic. Desirable results were not achieved.

FL - The Florida DOT is seeking the possible use of recycled plastics in highway applications such as: guardrail posts, interstate and highway fence posts, sign supports, barricade sign substrates, rebar support chairs, etc. Tests conducted include: flexural strength, tensile and compressive strength, water absorption, and fire susceptibility. Long-term exposure tests of recycled products are also being conducted.

GA - They do not currently use recycled products in roadside safety devices but the following are under evaluation: Trex, Amoco Posts for fencing or highway markers, and the Guardian Safety Barrier by Safety Barrier Systems.

HI - They do not use recycled products in roadside safety devices.

ID - They have had established sign blank specifications since April 1990. They have been contacted by Greenline regarding their delineators, International Plastics regarding their signage products, and Dura Post regarding their delineators, signing, and fence posts. However, none of these products are in use yet. They have also tested recycled aluminum sign blanks.

IL - Contractors with Illinois DOT use "Lifeguard Channelizer" and "SafetyCade" barricades. Manufacturers are using scrap fiberglass angles to construct Type I and Type II barricade frames. These barricades work well in low speed urban applications but are too light to function on high speed or rural highways.

IN - Indiana DOT replied that "it is likely that some products now used by Indiana DOT in roadside safety devices contain recycled materials of which we are not aware." They are considering guardrail offset blocks by Trex and tire chips for use as fill in barrel type crash attenuators.

IA - They do not currently use recycled plastics in roadside safety devices, but have experimented with sign blanks and posts. The products failed because of bending and cracking due to inconsistent quality. Iowa has also experimented with fiberglass and polycarbonate plastic sign blanks. These were also judged to be unsatisfactory. Furthermore, combination plastic and sawdust sign posts were evaluated and failed due to wind loads.

KY - They do not use recycled products in roadside safety devices.

MA - At present, Massachusetts is not aware of use of recycled materials in roadside safety devices within their state.

MD - They evaluated Safety Rings as ballast around traffic cones and recommended their acceptance for use around traffic cones and on a limited basis on Type III barricades. They also recommended further testing by the manufacturer. Safety Rings are more resistant to

movement than sandbags, but this may result in more damage to the vehicle. They are also aware of approval of Timbrex (Trex) by FHWA.

MI - They are currently evaluating Trex offset blocks for guardrails. In 1990 they began field testing recycled plastic posts manufactured by Turfgrass, Inc., in a guardrail installation. After several years the posts appeared not to meet *NCHRP Report 230* crash test criteria. A new work plan was devised to leave the posts in the ground for long term exposure/performance evaluation through 1995. They have tested Enviro recycled plastic mile marker posts and fenceposts made by Superwood. Evaluation showed the following: post heads shattered when being driven into the ground, posts tended to warp or lean when exposed to sun, and posts were brittle, flimsy, and hard to install. Perma Poly sign supports, manufactured by N.E.W., were tested but rejected for use based on a cost comparison. Loper Corp. produces recycled rubber products for use as posts and signs. Evaluation revealed the fence posts did not have sufficient structural integrity and they were recommended for intermediate post installation only.

MN - Minnesota has used HDPE delineator posts made by Gopher Sign Corp. and 100 percent recycled plastic road signs made by Recycled Plastic, Inc. Timbrex spacer blocks have been approved for use but have not been used.

MO - Missouri has experimented only with recycled plastic posts. Other "recycled" items in use come from refurbished virgin material such as sign blanks and guardrail. Tire beads are used for traffic barrel weights. Although the department has limited experience with these products, they are looking forward to the possibilities they offer. To encourage use of recycled materials, the word "virgin" has been removed from the specifications for plastic products.

MS - They do not use recycled products in roadside safety devices.

NC - They tested Type III barricades and found them to be flimsy, requiring frequent maintenance. Also components were not positively fastened at joints, so the assembly would

come apart when it was picked up to be moved. Sun and wind caused members to become misshapen and warped. NC thought the barricades needed a more rigid panel, positive anchorage, and joint connections to be viable.

NE - They are currently using flexible delineator posts by Carsonite and Timbrex (Trex) guardrail post blocks.

NH - New Hampshire has been contacted by DJH Developments, an Australian firm involved in the manufacture of recycled rubber delineator posts. Timbrex guardrail offset blocks are included on their "Approved Products List."

NJ - They do not use recycled products in roadside safety devices.

NM - They do not use recycled products in roadside safety devices but have been bombarded by vendors.

NV - They do not use recycled products in roadside safety devices but use other products containing recycled materials. They have product literature only on those products evaluated through a formal product evaluation process. They have been informed of current developments from Analogics Consulting regarding barrier rails. Nevada has reviewed and approved Plastic Safety System's drum channelizer. They have reviewed and rejected recycled aluminum sign blanks by SABI due to quality concerns. Some Greenline flexible delineators have been approved and others are under review. Envirowood plastic lumber does not meet specifications for sign posts. Nevada has also reviewed and approved Trex offset blocks.

NY - They use: Durapost tubular markers, Flexstake flexible delineators, Timbrex guardrail spacer blocks, and SABI sign panels.

OH - They did not specify many recycled products directly, but many are currently being used because they meet the performance requirements of standard materials. Products they

have found to compete favorably with virgin materials include: plastic barrels, delineators, aluminum signs, tire rubber ballasts, and most steel products. Recycled products that are not as competitive include: plastic posts, spacer blocks, and some rebar support chairs.

OR - Oregon has used recycled plastic sign and fence posts, snow poles, and sound barrier walls on an experimental basis to evaluate their field performance. Their experience with sign posts has been marginal. Posts tended to bow and could be easily worked loose from the ground. They are in the process of testing TREX offset guardrail blocks.

PA - They use the LifeGard Channelizer. They have approved tubular markers from Bent, Carson, Carsonite, Century Plastics, Flexstake, PA Ind. for Blind and Handicapped, Safe-Hit, and Unipar. Pennsylvania has approved flexible post delineators from Carsonite, Flexstake, Greenline, PA Ind. for Blind and Handicapped, and Safe-Hit. They have also approved nonmetallic drums from American Safety Service, Best Barricade, FIBCO, Kelch, Lakeside Plastics, Plastic Safety Systems, Protection Services, Radiator Specialty, Service and Materials Co., Trafix Devices, and Work Area Protection.

RI - They do not use recycled products in roadside safety devices.

SD - They do not use recycled products in roadside safety devices.

TN - They use truck tire sidewalls as ballasting collars for flexible drums used for traffic delineation. Tennessee has reviewed Superwood's Enviro recycled plastic product line.

UT - They do not use recycled products in roadside safety devices.

VA - Trex guardrail offset blocks, made by Mobil, are approved for use in this state.

WA - Their "New Products Committee" has received requests from vendors concerning products that contain recycled materials. They have found that there is little or no scientific evaluation of the products regarding physical properties or crash testing.

WV - They do not use recycled products in roadside safety devices.

III. POTENTIAL APPLICATIONS OF RECYCLED MATERIALS IN ROADSIDE SAFETY

Before draft specifications for the use of recycled materials in highway safety applications can be prepared, an understanding of existing test procedures and design requirements is necessary. First and foremost among design concerns for most safety features is impact performance. Generally speaking, roadside safety appurtenances and work-zone traffic control devices are used to shield or delineate hazards along the roadside or in work-zone areas in which construction, rehabilitation, or maintenance is being performed. Although these features are intended to protect motorists and maintenance crews, the features themselves also constitute hazards and, therefore, must be demonstrated to be crashworthy.

NCHRP Report 350 contains procedures for evaluating the safety performance of highway safety features (Ross, et al., 1993). The features covered by these procedures include longitudinal barriers (such as bridge rails, guardrails, and terminals), crash cushions, breakaway or yielding sign supports, and work zone traffic control devices. These procedures are directed at evaluating the safety performance of roadside features through vehicle crash testing and in-service evaluation. For vehicle crash testing, specific impact conditions are presented for vehicle mass, speed, approach angle, and point of impact. Individual tests are designed to evaluate one or more of the principal performance factors: structural adequacy, occupant risk, and post-impact trajectory of the vehicle.

It should be understood that the development of a safety feature is often a long and difficult process. From conception to implementation, a feature generally evolves through three phases: (1) research and development, (2) experimental, and (3) operational. During the research and development phase, the design matures through structural analyses and developmental testing of components and prototypes to a point where it is subjected to a set of full-scale crash tests. If the results of the tests satisfy the established evaluation criteria, it is placed in the experimental phase. During this phase it is installed on a limited basis for the purpose of closely monitoring the in-service performance of the feature. If its in-service performance (which encompasses installation, maintenance, accident history, and repair) is judged to be satisfactory, the feature may then be placed in the operational phase during which widespread implementation is achieved.

In addition to impact safety requirements, other factors such as structural adequacy for anticipated in-service loads and durability for the anticipated life of the feature must be considered. The relative importance of each of these factors varies with the application.

A review of some of the design requirements for some common highway safety applications under consideration for use of recycled materials is given below. As mentioned previously, a thorough understanding of these requirements is one of the two important factors in achieving a successful design; the other is comprehensive knowledge of the material's properties and behavior over the anticipated range of field conditions.

GUARDRAIL POSTS

Longitudinal traffic barriers may be designed for any one of six test levels as defined in *NCHRP Report 350*. In general, the lower test levels are applicable for evaluating features to be used on lower service level roadways while the higher test levels are applicable for evaluating features to be used on higher service level roadways or at locations that require a special, high-performance barrier. The basic level to which most existing hardware is designed is equivalent to test level 3 (TL-3). The safety requirements imposed by the impact conditions associated with this test level govern the strength of the barrier and its components.

The most widely used guardrail system across Texas and the nation is the strong post W-beam guardrail. Variations of this design have been successfully tested and used in service by a majority of state transportation departments for many years. In Texas, two alternative designs of the strong-post W-beam guardrail system are available for use. They differ only by the type of guardrail post and offset block utilized. The most common system consists of a 178-mm (7-in.) diameter round wood post embedded 965 mm (38 in.) below ground. The other design incorporates a W6x9 steel post embedded 1.12 m (44 in.) below ground. It should also be noted that the wood post design used by most other states consists of a 152 mm x 203 mm (6 in. x 8 in.) rectangular post and block with a standard embedment depth of 1.12 m (44 in.).

For the basic test level, TL-3, *NCHRP Report 350* recommends two tests for the evaluation of a guardrail system: test 3-10 and test 3-11. Test 3-10 involves an 820-kg (1,806-lb) passenger vehicle impacting the barrier at a nominal speed and angle of 100 km/h (62 mph) and 20 degrees. The purpose of this small car test is to evaluate occupant impact

severity. Test 3-11 consists of a 2,000-kg (4,404-lb), 3/4-ton pickup truck impacting the barrier at 100 km/h (62 mph) and 25 degrees. This test is intended to evaluate the strength of the barrier in containing and redirecting the pickup truck. Vehicular stability and post-impact trajectory are evaluation criteria for both tests.

Currently, there are no performance specifications for determining the structural adequacy of guardrail posts. The strength requirements are implicitly defined within the safety requirements outlined above. However, when designing a suitable guardrail post, one must first consider the intended function of the post given the desired behavior of the barrier system in which it will be used. For example, numerous references have been made to a strong-post guardrail system which, as one might expect, is in contrast to a weak-post guardrail system. In a strong-post system, much of the impacting vehicle's lateral kinetic energy is dissipated through rotation of the posts in the surrounding soil. Thus, the guardrail posts employed in such a system must have a structural capacity sufficiently greater than that of the surrounding soil such that the soil fails prior to the post yielding or fracturing. Should a post fail prematurely during an impact, its load carrying capacity and energy absorbing capability are lost. As a consequence, the dynamic deflection of the rail will increase and an undesirable event such as vehicular pocketing and rupture of the rail may result.

In a weak-post guardrail system, the guardrail posts are intended to do little more than support the rail element until it is engaged by the impacting vehicle. The posts are designed to yield or fracture readily in the path of the vehicle, and the vehicle is redirected almost entirely through tension developed in the rail or beam bending. Thus, by design, the guardrail posts in a weak-post system are substantially weaker than those in a strong-post system.

Due to the prohibitive cost of full-scale crash testing, developmental static and pendulum tests are often used to investigate the suitability of guardrail posts prior to conducting compliance testing. The results of these tests can be compared to similar baseline tests conducted on conventional wood and steel guardrail posts. If a candidate guardrail post possesses sufficient strength to yield or fail the soil when tested in an in-situ condition, it would be a likely candidate for use in a strong-post guardrail system. Should the post fracture or yield at its base without failing the soil, it could be considered for use in a weak-post guardrail system.

In addition to safety and strength requirements, durability should also be considered. Existing wood guardrail posts are pressure treated with cromated copper arsenate (CCA) or some other approved preservative. Steel guardrail posts are galvanized with a zinc coating to prevent deterioration and prolong service life. Although estimates vary with environmental conditions, the life expectancy of a guardrail post should be designed to be about 15 to 20 years.

GUARDRAIL POST OFFSET BLOCKS

In the steel-post guardrail system discussed above, a W6x9 steel shape similar to that used for the post is also used as a spacer block to offset the rail element from the face of the guardrail post. The purpose of the spacer block is to reduce vehicle interaction or snagging on the guardrail post during an impact so that the impacting vehicle can be smoothly redirected without imparting excessive decelerations to the occupants. The W6x9 shape used in the steel-post guardrail system provides an offset distance of approximately 152 mm (6 in.).

In contrast to the steel-post system, no offset block is used within the round wood post guardrail option. In the round wood post design, an offset block is unnecessary to achieve acceptable impact performance. This is attributed to the geometry of the round post reducing the severity of snagging. However, it should be noted that this behavior is based on an evaluation of the barrier under *NCHRP Report 230* (Michie, 1981), which is the predecessor of *NCHRP Report 350*. Since the test conditions contained in *NCHRP Report 350* are generally considered to be more demanding than those in *Report 230*, it is uncertain whether the omission of an offset block will continue to be acceptable in the standard guardrail system. The standard wood post guardrail system, widely used across the rest of the country, incorporates a 152 mm x 203 mm (6 in. x 8 in.) wood blockout which provides an offset distance of 203 mm (8 in.).

Currently there are no performance specifications or laboratory test procedures recommended for the evaluation of guardrail offset blocks. The minimum strength requirements are as dictated by the safety requirements. Because the offset block is a component of a guardrail system, it must be evaluated in conjunction with the rest of the

system. Thus, the safety requirements for offset blocks consist of the same test matrix and evaluation procedures described in the previous section for the guardrail posts.

In terms of durability, the conventional wood and steel offset blocks are treated or coated like the guardrail posts. Therefore, a similar life expectancy (i.e. 15 to 20 years) should be required.

SIGN SUPPORTS

Small sign supports being used within Texas can be categorized into one of four types: (1) fiberglass reinforced plastic (FRP), (2) thin-wall steel tubing, (3) U-post or flanged channel, and (4) standard schedule 40 steel pipe. The number and type of supports selected for use at a given site is a function of sign area and user preference.

In terms of structural requirements, all small sign supports are designed for loading conditions in accordance with AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*. The loading conditions for roadside sign supports are dominated by the required wind load, but also include dead load of the sign and support, and an ice load where applicable.

Since roadside sign structures are considered to have a relatively short life expectancy, the wind loading is based on a 10-year mean recurrence interval. For the state of Texas, isotach maps based on the 10-year recurrence interval indicate a design wind speed of 96.6 km/h (60 mph), which results in a reference wind pressure of 575 Pa (12 psf). The minimum mounting height to the bottom of the sign blank is currently specified to be 2.1 m (7 ft). Using this basic design data along with the area of the sign blank, the supports are designed to satisfy a combined stress ratio which proportions the axial, bending, and shear stresses.

In addition to the structural requirements, small sign supports are designed as breakaway structures to limit damage and injury during impact. The principal of a breakaway support is that a fracture or slip plane is provided near ground level to allow the support to disengage from its foundation. The standard pipe supports utilized by TxDOT typically incorporate either a pipe collar coupling, which permits fracture of the pipe on a plane through the threaded portion, or a slip base, which allows relative motion of the two base plates when the impact load exceeds the clamping force provided by the fasteners. Other

supports, such as the FRP, thin-wall steel tube, and flange channel systems, are designed to yield or fracture at or near the ground line.

The safety evaluation of breakaway support structures consists of two tests with an 820-kg passenger car: a low-speed test and a high-speed test. The low speed test, which is conducted at 35 km/h (22 mph), is generally intended to evaluate the breakaway, fracture, or yielding mechanism of the support. The high-speed test, which is conducted at 100 km/h (62 mph), is intended to evaluate vehicle stability and test article trajectory. Occupant risk factors and occupant compartment intrusion are a concern in both tests.

Other test methods, such as bogie vehicle tests or gravitational pendulum tests, are sometimes used to evaluate the safety performance of breakaway sign supports in lieu of full-scale crash testing. When a calibrated crushable nose assembly is used in conjunction with these alternate test procedures, the results are considered satisfactory for verifying proper activation of the breakaway mechanism and computing occupant risk factors such as occupant impact velocity and ridedown accelerations. However, a major limitation associated with these surrogate test vehicles is the lack of a compliant roof structure. Thus, it is not possible to assess the integrity of the roof or the potential for occupant compartment intrusion. If this type of behavior is a concern, full-scale testing is recommended.

Durability of small sign supports is generally not a major concern due to the relatively short life expectancy of these structures. The thin-wall steel tubing, flange channel, and pipe supports are generally coated or painted to inhibit corrosion and prolong the life of the support. Although the life expectancy may vary with the type of support, a period of 15 to 20 years should be adequate for this application.

SIGN BLANKS

Sign panels installed on small roadside supports in Texas are typically comprised of either aluminum sheeting or an exterior grade plywood. Sign blanks are required to resist the same loading conditions as the supports to which they are attached. This includes the dead load of the sign, an ice load, and a reference wind pressure of 575 Pa (12 psf) (based on a design wind speed of 96.6 km/h (60 mph). Depending on the area and aspect ratio of the sign blank, wind bracing may be necessary to obtain the desired structural capacity.

Although there are no specific safety evaluation criteria for the evaluation of sign blanks, they are typically evaluated in conjunction with testing of the sign support system. It should be noted that the trajectory of a support after impact is largely dependent on the size and weight of the sign blank. Generally speaking, the more massive a sign blank, the greater the potential for occupant compartment intrusion.

Although the application of sign blanks appears to be suitable for the implementation of recycled materials, they are given only cursory treatment in this study. An ongoing study sponsored by TxDOT is specifically addressing the use of recycled materials for sign substrates. The results of this study should be available in the fall of 1995. Consequently, the resources available under this project were focused on other roadside safety applications which would not otherwise receive attention.

WORK ZONE TRAFFIC CONTROL DEVICES

Work zone traffic control devices include plastic drums, barricades, cones, chevron panels and their supports, and delineator posts. These devices are used either alone or in combination to delineate hazards or channelize traffic.

As with breakaway support structures, two tests are recommended for the safety evaluation of work zone traffic control devices: a low-speed test and a high speed test. The low speed test is generally intended to evaluate the breakaway, fracture, or yielding mechanism of the device, whereas the high-speed test is intended to evaluate vehicle stability and test article trajectory. Occupant risk and occupant compartment intrusion are a concern in both tests.

For devices having a relatively small mass such as plastic drums and lightweight barricades, the high-speed test is considered to be critical and the low-speed test may be omitted. Other devices, such as traffic cones and delineator posts, have been demonstrated to pose little safety hazard to errant vehicles. For these devices, full-scale crash tests are typically not warranted and the design requirements are typically based on durability considerations.

EXISTING SPECIFICATIONS

Although the use of recycled materials in roadside safety devices is still very much a developing field of study, several of the more progressive states in this area have adopted, or are in the process of drafting, specifications addressing the use of recovered materials in various roadside safety applications of interest to this study. These specifications can be used to form the basic framework for reviewing and revising TxDOT standards to permit inclusion of recycled alternatives to conventional products. A brief overview of some of these existing specifications is given below. Additionally, Appendix D presents specifications currently proposed or adopted by various state agencies, including California, Connecticut, Florida, Illinois, North Carolina, New Hampshire, and Maine.

Mota, et al. (1993) have prepared draft specifications for the Ontario Ministry of Transportation for the use of plastic lumber in highway applications. The draft specifications provide minimum physical and mechanical properties for plastic lumber which are set such that the in-service performance should, in most cases, be similar to that of existing wood products. Applications which were addressed include sign supports, guardrail posts and offset blocks, sign blanks, fence posts, and delineator posts.

The limiting values provided in these specifications are preliminary in nature and are not based on full-scale testing. In Phase II of the project, laboratory testing of commercially available plastic lumber products and monitoring of full-scale field installations is being conducted. The results will be used to revise the draft specifications.

The Florida Department of Transportation (FDOT) has had considerable laboratory and field experience with evaluating recycled plastic products. The knowledge gained from these research programs has led to the development of standard test methods for recycled plastic fence posts and draft specifications for the use of recycled materials in various applications, including fence posts, flexible delineator post, guardrail offset blocks, and rebar support chairs. The specifications contain material requirements, including a minimum percent recycled content, as well as requirements pertaining to various physical and mechanical properties. In ongoing research, the field performance of several commercially available products are being evaluated and the draft specifications will be modified based on the results.

Other states are also active in the specification and use of recycled materials in roadside safety applications. North Carolina has developed specifications for guardrail offset

blocks, barricades, flexible delineator posts, and fence posts. California has specifications for plastic barricades. New Hampshire permits the use of recycled plastic guardrail offset blocks. Maine specification 652.02 was amended to include "All barricades, cones, drums, and construction signs may be constructed from new or recycled plastic" (Bloomquist, et al., 1993). The state of Illinois permits the use of plastics in various work zone traffic control devices such as barricades, drums, cones, and delineators. While the use of recycled plastics is not specified directly, it is not excluded by the specifications.

Over the last several years, the state of Connecticut has restructured its specifications to include the use of environmentally acceptable waste products. However, they recognize that while certain specifications can be readily formulated for items of little or no critical significance, assistance is needed in developing appropriate specifications for items with critical significance, such as safety devices and appurtenances.

TEST STANDARDS AND PROCEDURES

In order to be able to properly assess whether or not a product satisfies a particular specification, standard test procedures and methodologies must be established to provide uniform evaluation criteria. The American Society for Testing Materials (ASTM) is very active in writing standards for the testing of recycled materials and products. ASTM committee D-20, "Plastics," has two subcommittees currently addressing these issues: Subcommittee D-20.20, "Plastics Products," and Subcommittee D-20.95, "Recycled Plastics." Each of these subcommittees is further divided into sections and task groups. For example, Section D-20.20.01, "Manufactured Plastic Lumber and Shapes," has separate task groups addressing terminology, test methods, and performance and specifications. The ongoing work being conducted by these groups will establish national standards and test methodologies for the evaluation of recycled plastic products.

Others have also made progress in this area. As discussed in the literature review, research at Rutgers University has led to the development of various physical and mechanical property test procedures recommended for use in characterizing product samples taken from post-consumer commingled plastic wastes. Specific test procedures discussed include: specific gravity compression, stress-strain, flexural load displacement, and flexural pre-test methods.

Modifications to existing standard ASTM methods are reported to enable measurement of properties of molded heterogeneous commingled product samples.

State agencies are also playing an important role in the development of appropriate test standards. For example, Florida DOT has developed a test method for the evaluation of recycled plastic fence posts. This method describes four test protocols for properties considered crucial for the successful performance and durability of recycled products used in this application. The tests include: warpage resistance, water absorption, insect resistance, and flammability.

This information will be extremely useful for determining suitable test methods and protocols for determining the physical and mechanical properties of candidate recycled materials and products. It will also provide a framework for the development of performance specifications in subsequent phases of the study.

LEGISLATIVE AND REGULATORY CONSIDERATIONS

Increased public awareness regarding the growing volumes of waste materials and the declining number of landfills has begun to be reflected in a number of legislative initiatives which target various aspects of the problem. These federal and state laws and regulations encourage, or in some cases mandate, the recycling and reuse of various components of the solid municipal waste stream. Future legislation, in the form of requirements regarding percent of recycled content and acceptable waste stream or material types, may ultimately affect some or all of the roadside safety applications being investigated under this study.

Federal Legislation

The Resource Conservation and Recovery Act (RCRA) of 1976 was probably the first statute to call attention to the seriousness of the solid waste disposal problem and the need to develop alternative solutions to handling solid waste (Collins and Ciesielski, 1994). Section 6002 of the RCRA authorizes the establishment of guidelines for governmental procurement of items containing the highest practical percentage of recovered or recycled materials consistent with maintaining satisfactory levels of product quality, performance, and competitiveness. In addition, procuring agencies must review and revise specifications to

require the use of recovered and recycled materials to the maximum extent practical without compromising the intended end use of the product.

A provision in the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 requires the use of crumb rubber from scrap tires in asphalt paving mixes. The first applicable minimum utilization requirement of asphalt tonnage containing recycled rubber will be 10 percent in 1995. In addition, a proposed amendment before Congress would modify crumb rubber use under ISTEA to include all civil engineering uses in highway construction, not just hot-mix asphalt (Collins, et al., 1994).

In 1991, President Bush signed an Executive Order requiring that all federal agencies use recycled products whenever possible. The main objectives of this Executive Order were as follows (Collins, et al., 1994):

- To require that all federal agencies promote cost-effective waste reduction and recycling of reusable wastes generated by the federal government,
- To develop policy options and procurement practices to promote waste reduction and recycling within the federal government, and
- To encourage market demand for items produced using recovered materials by implementing federal procurement preference programs favoring such items.

Although these pieces of legislation do not directly pertain to the use of recycled materials in roadside safety applications, they demonstrate the progressive attitude that pervades regarding the use of recycled materials. Other legislation is currently being considered that will mandate the use of a certain percentage of recycled content in barricades. Similar requirements on other roadside safety devices will be forthcoming as it becomes more technologically and economically feasible to do so, and state highway agencies must be in position to respond effectively and efficiently to such mandates.

State Legislation

According to a synthesis of highway practice on recycling and use of waste materials and by-products in highway construction, approximately 50 percent of all states have now adopted legislation aimed at recycling selected components of the solid waste stream (Collins, et al., 1994). In a number of instances, state law or regulations mandate the use of certain waste materials in highway construction applications.

In 1988, the Florida Legislature passed a comprehensive solid waste management bill which directed the Florida Department of Transportation (FDOT) to expand its use of recovered waste materials in highway programs (Smith and Ramer, 1992). The legislation directed FDOT to initiate research and conduct demonstration projects to determine the feasibility of using various solid wastes in construction projects. Included in the list of waste byproducts and applications directly addressed by the legislation were recycled mixed plastic materials for guardrail posts and fence posts. If found to be feasible, FDOT was directed to develop appropriate specifications for and require the utilization of such products.

According to a study by the National Solid Wastes Management Association (NSWMA, 1990), 42 states have passed laws to stimulate recycling markets by encouraging state agencies to purchase products with recycled content. More than half of these states allow their agencies to pay from 5 to 10 percent more for products with recycled content.

Florida Statute 287.045 sets forth such requirements for the procurement of products and materials with recycled content in the State of Florida. In addition to allowing up to a 10 percent price preference to responsive bidders who have certified their products contain a certain minimum percentage of postconsumer recovered material, this statute permits an additional 5 percent price preference for those products and materials comprised of recycled materials recovered in the state. As part of the procurement process, the statute also permits the consideration of life-cycle cost when evaluating bids. In this manner, the expected service life of the product can be compared to the cost of the product.

As mentioned above, many other states have similar legislative requirements and procurement incentives. As public awareness of waste management problems and the benefits derived from recovering and reusing waste materials continues to grow, other states will follow suit. By sponsoring and advancing research in this area, TxDOT will be poised with the necessary information to address specific questions and concerns that will arise during this process.

IV. CHARACTERIZATION OF EXISTING RECYCLED MATERIALS

As mentioned previously, it is essential to have a basic understanding of a material's properties and behavior over the expected range of service conditions if suitable applications are to be identified. Toward this goal, this chapter outlines some general characteristics and properties of available recycled materials which may be suitable for implementation in roadside safety applications.

TYPES OF MATERIALS

Recycled materials, as the name implies, are by-products that result from several sources. Sources for recycled products are considered to come from two waste streams: post-industrial and post-consumer. Given the opportunity, most manufacturers prefer to manufacture products from post-industrial waste streams, as they provide the most homogeneous/predictable product. A typical post-industrial waste product may consist of tailings or rejected parts from a single processing line; therefore, the resulting purity level is high and the quality and properties of the resulting product are more reliable.

Conversely, a typical post-consumer waste stream contains a mixture of different materials. This is particularly true in the area of plastics. Because of this fact, a great deal of research has been devoted to developing methods for sorting and cleaning post-consumer plastics. The benefit of using these sorting procedures is that it helps provide more uniform and consistent recycled materials. Recycled products made from 100 percent plastic (such as HDPE) have properties very close to those of virgin plastic. However, the sorting process is relatively expensive and can drive up the cost of the end products.

For this reason, some manufacturers have opted to use the mixed waste stream directly, without knowledge of the exact percentage of each type of plastic waste present in the end product. Although this method makes it easier and cheaper to recycle, the physical and mechanical properties of the end product can vary significantly due to the presence of impurities and differences in material composition.

Materials available for recycling can be categorized into the classifications listed below.

- I. Plastics
 - A. High Density Polyethylene (HDPE) - milk and detergent bottles
 - B. Low Density Polyethylene (LDPE) - bags, film, or wrapping
 - C. Polyethylene Terephthalate (PET) - 2 liter soft drink bottles
 - D. Polypropylene (PP) - ketchup containers, luggage, and battery casings
 - E. Polyvinyl Chloride (PVC) - cooking oil bottles, blister pack, siding, pipes
 - F. Polystyrene (PS) - egg cartons, plates, cups, and plastic utensils
- II. Fiberglass
- III. Rubber
- IV. Wood Fiber
 - A. Wood scraps
 - B. Paper products
- V. Glass
- VI. Aluminum
- VII. Steel
- VIII. Combustion by-products
 - A. Fly ash
 - B. Cinders
 - C. Slag

Manufacturers of recycled roadside safety products typically report a recycled content ranging from 35 to 100 percent by weight. To meet the requirements of various end uses, most plastics generally contain different additives. The process of mixing additives with the base polymer is referred to as "compounding." The main classes of the various additives commonly used in the manufacture of plastic products are listed below (Kennepohl, 1992).

- Lubricants
- Stabilizers
- Plasticizers
- Fillers
- Impact modifiers
- Reinforcing agents
- Fire retardants
- Colorants

Occasionally, virgin material is required as a binder for the recycled material.

Plastics are often blended or reinforced with other materials to obtain desired physical or mechanical properties. A low cost method of enhancing the strength properties of plastic

lumber products is to add wood fibers as a reinforcing filler. Although more expensive, plastics reinforced with glass fibers provide a higher level of strength which may be required for some structural applications. Rubber/polyolefin blends have generated considerable interest because of the potential for utilizing recycled rubber. The key to its application lies in understanding the effect of the addition of rubber on the properties of the end product. Generally speaking, the addition of rubber degrades the mechanical properties of the recycled plastic product. However, if the rubber is used as an impact modifier, the properties of the product may be improved.

Use of recycled glass appears to be limited to pavement projects. The reflective qualities of glass augment roadside visibility and, as a result, enhance driver safety. Recycled glass paint beads have been used in several states with good results. The recycling of metals has been ongoing for several years. Several states have experimented with recycled steel guardrail and guardrail posts. Sometimes maintenance crews will straighten, repair, and reuse damaged steel shapes. Recycled aluminum has been used in the manufacture of sign panels, and some states are evaluating their field performance.

Mining and combustion by-products (fly ash, slag, cinders, tailings, etc.) have been used extensively in paving surfaces, subbase stabilization, and concrete fillers. Possibilities exist for use of these materials in roadside safety applications in which concrete is the preferred material, such as bridge rails and median barriers.

PHYSICAL PROPERTIES

The relative density of commercially available plastic lumber products typically varies from about 0.7 to 0.96, making them 1.5 to 2 times heavier than wood. Susceptibility to moisture for 100 percent recycled plastics and plastic-rubber blends tends to be small. However, blends containing wood and paper products tend to have higher rates of water absorption. Studies have shown that the strength of these products decreases with increasing moisture content (Mota, et al., 1993). In addition, since wood fibers expand with moisture content, the entire product will tend to expand. Various additives can be used to reduce moisture uptake.

Unlike wood, plastics are not susceptible to insect infestation. However, mixtures of wood and plastics may be susceptible to termite or carpenter ant attack, and this should be considered for applications in which the recycled materials are in contact with the ground.

Most manufacturers have reported little or no chemical leaching from their products. Additionally, many products have been used in marine environments and claim no degradation due to salt exposure. However, consideration of the effects of salt exposure should be given to products in which steel is used as a reinforcement material.

Because the coefficient of thermal expansion of plastic products can be up to 12 times greater than wood or steel, they will expand and contract to a much greater extent for a given change in temperature (Mota, et al., 1993). This relatively large thermal expansion and contraction should be considered in the design of connections and construction details. Where plastics are bonded to steel or wood in a composite fashion, the difference in expansion between the two materials could lead to cracking of the plastic or delamination at the interface. Cyclic temperature tests are therefore recommended on composite products to evaluate the potential for deterioration.

Plastics are much more prone to creep than conventional wood and steel materials. Creep is defined as a progressive deformation of a material over time while subjected to a constant stress. Thermoplastics are particularly susceptible to creep, with greater creep occurring at higher temperatures (Mota, et al., 1993). This can result in performance problems with sign supports and sign blanks. Under in-service dead loads and wind loads, sign supports may experience permanent sag, and sign blanks may wallow out around fasteners. These problems can be minimized by using reinforcing materials such as glass fibers to strengthen the product.

The susceptibility of plastic products to fatigue has not been investigated and more information is needed before an assessment can be made. Sign supports will probably be the most susceptible application to fatigue since wind gusts and sign flutter can result in a large number of load cycles.

MECHANICAL PROPERTIES

Mechanical properties can vary significantly from one recycled plastic product to the next due to differences in materials composition and the presence of impurities, contaminants,

or voids. Additionally, properties will vary as a function of the size and shape of the product. For example, studies have shown that there is an inverse relationship between size and strength (Mota, et al., 1993). That is, larger specimens will fail at lower stresses than smaller members. It has also been shown that, under tensile loading, the ultimate strength of a product varies as a function of the geometry of the cross section.

It has also been reported that "the ultimate strength of plastic lumber in bending (modulus of rupture), compression and tension appears to be comparable to No. 1 grade timber products. However, plastic lumber has a much lower flexural modulus of elasticity (stiffness) than wood" (Mota, et al., 1993). For example, a blend of polypropylene and newsprint was reported to have a flexural modulus of elasticity of 4800 MPa, which was considered to be high among recycled plastic products. However, this value is only about 65 percent of the stiffness of No. 1 grade Jack Pine. Therefore, although the ultimate strength of the recycled plastic products may be close to that of wood, the plastic products are generally not as stiff and, as a result, will tend to experience greater deflections for a given service load. Some vendors recognize this problem and are beginning to reinforce their supports with steel or glass fibers.

Generally speaking, a decrease in temperature will result in a gain in strength of recycled plastics. However, in like fashion, an increase in temperature will generally decrease mechanical properties such as compressive strength, bending strength, and modulus of elasticity.

FEASIBILITY FOR USE IN VARIOUS ROADSIDE SAFETY APPLICATIONS

The materials which appear most suitable for use in roadside safety applications include recycled plastics, fiberglass, rubber, wood fibers, either alone or in various combinations. From a strength standpoint, it appears to be practical to design these products to match the properties of wood. Consequently, recycled material can conceivably be applied to various applications in which wood is currently used. Wood is used extensively in applications such as guardrail posts and offset blocks, sign supports, sign blanks, and barricades, all of which deserve further investigation. Other potential applications include flexible delineator posts, channelizing drums, and traffic cones.

Legislative mandates aside, the economic viability of using recycled materials in roadside safety applications rests with life-cycle cost analyses. If an increased life expectancy over conventional material alternatives can be demonstrated, recycled materials could be marketed on a much more competitive level. Additionally, as the demand for these products increases, high-volume production lines should reduce manufacturing costs and result in a more competitive price structure.

Past problems with recycled materials have perhaps left some negative impressions on the users of these products which must be overcome. Ultraviolet resistance seems to be one area where manufacturers have made significant improvement. Manufacturers are recognizing creep and flexural problems and reinforcing products to minimize the weaknesses inherent in most plastics. Construction methods and connection details are also being modified to account for factors such as differential thermal expansion of plastics relative to wood or steel.

On a more positive note, as consumer awareness and participation in recycling programs continues to increase, the quality and purity of the post-consumer waste stream will improve. These improved waste streams should result in improved consistency and uniformity in the end products.

V. EXISTING AND COMMERCIALY AVAILABLE ROADSIDE SAFETY PRODUCTS

PRODUCTS BY APPLICATION TYPE

As information was collected on existing, commercially available products, seven general application areas emerged. These are: barricades, bollards, delineators (including flexible posts, drums, and traffic cones), guardrail offset blocks, guardrail posts, sign blanks, and sign supports. Pricing information provided by respondents of the survey was very limited, but most manufacturers generally claim competitive costs with conventional materials when the life expectancy of the product is considered. Given below are brief summaries of the information obtained from the literature search and surveys, divided by application type. Summary tables identifying specific products by application type are presented later in this report.

Barricades

Twelve barricade manufacturers were identified. Principal material types in descending order of composition are: polyethylene (PE), polyvinylchloride (PVC), polypropylene (PP), and polyethylene terephthalate (PET). Of these barricades, several have been crash tested and two have been field tested by a state agency. Under a separate contract with TxDOT, TTI researchers have crash tested two Type III barricades comprised of recycled plastics. The first design utilized hollow-core sections for the vertical support members and horizontal panels. Wood was used to construct the supporting skids. If a state desired a barricade composed entirely of recycled material, the supporting skids could be replaced with commercially available recycled plastic lumber. The results of the hollow section barricade test were deemed successful. The barricade evaluated in the second test was constructed entirely of solid HDPE recycled members. Upon impact, the recycled plastic lumber fractured into several large pieces, one of which penetrated the windshield of the test vehicle. The results of this test were deemed unsuccessful due to the observed occupant compartment intrusion.

All of the commercially available products were 100 percent recycled material with the exception of Bear-A-Cade. Bear-A-Cade consisted of 50 percent recycled material and

50 percent virgin material. Additionally, Bear-A-Cade has been crash tested and has gained field experience in the state of California. Several of the barricade manufacturers, including Protection Services, Inc., Recycled Plastics Ind., WLI Ind., and Flasher Flare South East, Inc., have reported field experience in different states.

Waste stream sources included post-consumer, post-industrial, or a combination of the two. There are also numerous recycled plastic lumber manufacturers who have products that show promise for use in barricade applications.

Bollards/Protective Posts

Four companies identified bollards or protective posts. The first company apparently originally developed its product for use as marine pilings and provides steel reinforcement in the core. However, the waste stream and recycled content for this product were not mentioned. The second company indicated 100 percent post-consumer, high-density polyethylene (HDPE); the third simply identified "plastics." The last company uses a combination of post-consumer and post-industrial plastics including, but not limited to: ABS, Acetal, EVA, HDPE, LDPE, LLDPE, Nylon, PET, Polyester or LCP, PP, and PS. The first product is awaiting approval by the State of California and the second product has been ASTM tested.

Delineators

A large response from manufacturers was received in the category of delineators. As used in this report, the category of delineators includes flexible posts, construction zone barrels or drums, and traffic cones. These devices were categorized together because they all serve to delineate or channelize traffic. For clarity, the summary table presented in the following section has been further subdivided into these distinct areas. Most of these devices serve as temporary features in work zones, but others such as flexible delineator posts may serve in both a permanent and temporary capacity.

Recycled content of these devices varied from 35 to 100 percent, and waste streams were indicated to be both post-consumer and post-industrial. Polycarbonates, PEs, "thermoplastics," and rubber tires were used in various components of these features. Recycled rubber tires were used in the base units of the portable/temporary delineation

devices. Recycled plastics were used in portions of the devices where impacts were anticipated. One post, made entirely of recycled rubber, was developed and is being used extensively in Australia.

Several of the products have been subjected to full-scale crash testing, static laboratory testing, and field evaluation. Based on these results, various states' agencies have approved several. Greenline manufacturers have taken the initiative to establish a buy-back program for its customers in which the company picks up any used or damaged products, recycles them, and issues a credit on future purchases.

Work Area Protection Corp. has PVC traffic cones that are currently being used in several states.

Guardrail Offset Blocks

Five manufacturers specifically identified guardrail offset blocks. All five cited their waste streams as post-industrial, post-consumer, or a combination of the two. The first manufacturer, Collins & Aikman, was motivated by a need to dispose of excess carpet fiber scraps. Their blockout has been successfully crash tested at the Southwest Research Institute (SwRI). The second company uses a 50-50 combination of wood fiber and polyethylene. This product has been successfully crash tested and has received a national letter of approval from the Federal Highway Administration (FHWA). Furthermore, it has gained field experience in MD, NE, NV, NY, and PA.

With the exception of Hwycor's fiberglass blockout, the remainder of the companies use recycled polyethylenes in combination with various other recycled plastics. Although these products will likely meet or exceed all requirements for guardrail offset blocks, the available information is limited to lab testing. Further evaluation is therefore recommended before these products are implemented.

Guardrail Posts

In conversations, many manufacturers have expressed a desire to produce guardrail posts; however, only two have been identified in the literature as having passed the required crash tests. The first is manufactured by the same company that has received approval from Federal Highway Administration on their guardrail offset block. As with their offset block,

the guardrail post is composed of a 50-50 mixture of wood fibers and polyethylene. This guardrail post has been field tested in Maryland and elsewhere. However, it should be noted that the maximum dynamic rail deflection observed during crash testing was approximately twice that of a standard strong post system. Therefore, although a guardrail system comprised entirely of these posts constitutes an acceptable design, the post is not a suitable substitute for conventional steel and wood guardrail posts in strong-post guardrail applications.

Testing conducted by TTI showed satisfactory impact performance for a guardrail post currently being marketed by the Recycled Tech Inc. This post, which is considered to be an acceptable substitute for standard wood and steel posts in strong-post guardrail systems, consists of an outer HDPE shell reinforced with a hollow thin-wall steel tube. There was no distress evident in the posts as a result of the full-scale impact. However, differential thermal expansion within the composite section caused cracking of the plastic end caps. Although not a safety concern, the issue of durability needs to be addressed.

In addition to the two products described above, various manufacturers, i.e., Amour Hydro Press, Inc., Jamarico, Inc., and Plastic Pilings, Inc., have provided samples that appear to have potential for use as guardrail posts. Additional flexural strength has been achieved in these products through the addition of fibers or steel reinforcement. However, further testing and evaluation is necessary before any of these other products can be implemented as a guardrail post.

Sign Blanks

Six different manufacturers identified six different types of materials for use in sign blanks. The first manufacturer uses 80 percent PET mixed with 20 percent glass fiber from the post-consumer waste stream. These sign blanks were ASTM tested and have been approved for experimental use in Pennsylvania. Due to the fact that field testing has not been completed, the size of the sign blanks will be limited due to concerns about warpage.

The second company utilized polycarbonates and fiberized signs from the post-consumer waste stream. This design has been field tested in Ohio and Connecticut with mixed reviews. The third sign blank is manufactured from 100 percent recycled aluminum. Several states have conducted laboratory and field testing with Nevada expressing some concerns regarding the consistency and quality of the material.

The fourth sign blank for which information was provided contains 40 to 75 percent HDPE and has been ASTM tested. The fifth sign is made from 100 percent commingled HDPE, LDPE, PP, PS, and PET. It has also undergone lab testing. The remaining company provided only limited information on their product.

As indicated earlier in this report, the application of sign blanks will not be emphasized in this study. An independent, ongoing study also sponsored by TxDOT is specifically addressing the use of recycled materials for sign substrates. The results of this study should be available in the fall of 1995. Consequently, the resources available under this project will be focused on other roadside safety applications. It should be noted, however, that the information on sign blanks gathered in this study has been shared with the other research team, and the researchers will continue to work collaboratively on these efforts.

Sign Supports

Eighteen companies identified products for use as small sign supports. Four of the products were manufactured from 100 percent recycled HDPE, six were from 100 percent commingled plastics, and one was comprised of a recycled HDPE, LDPE and PP shell around a steel core. The remaining three were composed of a variety of different materials. One product consisted of various plastics including, but not limited to: ABS, Acetal, EVA, HDPE, LDPE, LLDPE, Nylon, PET, Polyester or LCP, PP, and PS. Another was made of HDPE, screener waste fiberglass, and other miscellaneous materials. Two manufacturers cited the use of both recycled tires and plastics in their sign supports. Another two manufacturers responded to our request for information but, at this time, are not using any recycled materials. However, both of these companies have products into which recycled materials can be incorporated and which have either been approved or show promise for use as sign supports. The last support post consists of wood fiber and polyethylene in a 50-50 mix.

Waste streams identified were post-consumer, post-industrial, and a combination of the two. One post comprised entirely of HDPE has been ASTM tested, and another was installed in Wisconsin for two years as part of a field evaluation program. One commingled post was rejected by Nevada and another by Michigan.

A third sign support made from commingled material has been crash tested by TTI and has received approval from FHWA in terms of demonstrated crashworthiness; however,

there is some concern about load capacity of the post and its susceptibility to temperature variations. Static load tests were conducted and excessive deflections were observed in every test. The crash testing program consisted of tests on both a light colored polyethylene mixture and a black mixture. Before the tests were run, warping of approximately 152 mm (6 in.) was noted in the black 3 m (10 ft) sign support. Warping or bowing of the light colored support post was not as pronounced. There was a noticeable difference in surface temperatures of the shaded side versus the side facing the sun. Field testing of the product, which consists of ABS, Acetal, etc., is currently being conducted in Oregon.

PRIORITIZATION SCHEME

Several driving factors were used in the evaluation and prioritization of existing products. Fulfillment of safety requirements, which typically includes some level of full-scale crash testing, was considered to be of primary importance. The next most important factor considered in the prioritization of these products was field experience reported by state agencies. The field evaluations provide an indication of the functionality and durability of the product under service conditions. For those products for which crash testing is not critical, a satisfactory field evaluation may be sufficient grounds for experimental implementation.

The next factor considered in the evaluation scheme is the availability of mechanical properties from laboratory testing. Although such information is insufficient for final evaluation of the product, the potential use of the product can be evaluated by comparing the reported material properties with known requirements (safety, structural, and durability) for the given application. Other factors such as percent recycled content and type of waste stream were also considered. However, a review of product information revealed that these factors did not provide a meaningful grouping since most of the products were comprised of 100 percent recycled material from the post-consumer waste stream.

The information presented in the following table is a compilation of information obtained on existing, commercially available roadside safety features manufactured in part or in whole from recycled materials. For ease of reference, the products are grouped by application type. Applications summarized in the table include barricades, bollards and

protective posts, delineators (including traffic cones, channelizing drums, and flexible posts), guardrail offset blocks, guardrail posts, sign blanks, and sign supports.

As one refers to this table, any product with a prioritization rating of "1" is considered suitable for implementation based on safety considerations. Anything with a rating of "2" has, at a minimum, some field experience with a state or federal agency. Depending on the results of an engineering evaluation, some of these products of a less critical nature (e.g., delineator posts, traffic cones, etc.) could possibly be implemented immediately on an experimental basis. Other products in this rating category which are more critical in nature (e.g. barricades, sign supports) may require crash testing in order to satisfy safety requirements before they can be implemented. A rating of "3" indicates product evaluation has been limited to laboratory testing only. Because performance specifications based on physical and mechanical properties of a material do not yet exist for most of these applications, none of these products are recommended for implementation without further testing and engineering evaluation. Products identified in the literature for which very limited information was provided were given a rating of "4." Some of these products may be suitable for implementation but without additional information, an appropriate evaluation cannot be made at this time.

SUMMARY BY APPLICATION TYPE

For all existing recycled roadside safety products identified in the literature search, information obtained from vendors was sorted and summarized by application type. Blank spaces in the table indicate that information was not provided. A prioritization rating is presented in the first column of the table for each product based on the evaluation scheme described above. Appendix E presents selected physical and mechanical properties reported for each of the products. The presentation of the material properties is grouped by application type following the same order as the summary table below.

TABLE 2. PRODUCT PRIORITIZATION

| Ranking | Manufacturer | Product Name | Product Description | | | | Product Testing | | |
|-------------------|--------------------------------|----------------------|---------------------|--------------------|-----------------------------------|---------------------|--|-----------------|--------------------|
| | | | Material Type | Recycled Content % | Waste Stream | Fabrication Process | Lab/Crash Testing | Approval Status | Field Experience |
| Barricades | | | | | | | | | |
| 1 | Bear-a-Cade | | HDPE, virgin | 50%/50% | Post-consumer | Molded | Crash | | CA |
| 1 | Recycled Plastic Products, Inc | Plasti-Rail | HDPE | | Post-consumer and Post-industrial | Extruded | Crash | | |
| 2 | Flasher Flare South East, Inc | | HDPE | 100% | Post-consumer and Post-industrial | Molded | | | FL, OH, IN, TN, TX |
| 2 | Protection Services, Inc | Type III | PP, PVC | 100% | | | | | NC |
| 2 | Recycled Plastics, Ind | Recyclemaid | HDPE | 100% | Post-consumer | Extruded | Lab | | WI |
| 2 | WLI Industries | SafetyCade | HDPE | 96% | Post-consumer | Molded | ASTM 1505, 790, 638 | | IL |
| 3 | Aldan Lane Co. | | PE | 100% | Post-industrial | | Lab | | |
| 3 | Eaglebrook | Durawood | HDPE | 100% | Post-consumer | | ASTM D792, D695, D638, D790, D732-90, D696 | | |
| 4 | Distribution Inc. | Enviro-Cade | HDPE | 100% | Post-consumer | Molded | | | |
| 4 | International Plastics Corp | Type III, Plasticade | HDPE | 100% | Post-consumer | Molded | | | |

TABLE 2. PRODUCT PRIORITIZATION (Continued)

| Ranking | Manufacturer | Product Name | Product Description | | | | Product Testing | | |
|----------------------------------|--------------------------------|------------------|----------------------------------|--------------------|-----------------------------------|---------------------|--|-------------------------------|------------------|
| | | | Material Type | Recycled Content % | Waste Stream | Fabrication Process | Lab/Crash Testing | Approval Status | Field Experience |
| 4 | N.E.W. Plastics Corp | Perma-Poly | HDPE | 100% | Post-consumer | Extruded | ASTM D792, D695, D790, D785 | | |
| 4 | Utility Plastic Recycling, Inc | | HDPE, PET, PVC, PP | 100% | Post-consumer and Post-industrial | Molded | | | NY |
| 4 | Tipper Tie | | PE | 100% | Post-consumer and Post-industrial | | Crash | | |
| Bollards/Protective Posts | | | | | | | | | |
| 2 | Plastic Pilings, Inc | | HDPE, LDPE, PP shell, steel core | | | | | Pending CA | |
| 3 | Eaglebrook | Durawood | HDPE | 100% | Post-consumer | | ASTM D792, D695, D638, D790, D732-90, D696 | | |
| 4 | Recycled Plastics Man | | Plastics | 100% | | | | | |
| 4 | Refuse/Enviro Sys, Inc | Hammer's Plastic | ABS, Acetal, EVA, DPE, etc. | 23% pc and 75% pi | Post-consumer and Post-industrial | | | | |
| Defineators - Cones | | | | | | | | | |
| 2 | Work Area Protection Corp. | | PVC | 8% pc and 50% pi | Post-consumer and Post-industrial | Molded | Lab | Contracts with several states | |

TABLE 2. PRODUCT PRIORITIZATION (Continued)

| Ranking | Manufacturer | Product Name | Product Description | | | | Product Testing | | |
|----------------------------|--------------------------------|-------------------------|---|------------------------|-----------------------------------|---------------------|--|---|-----------------------|
| | | | Material Type | Recycled Content % | Waste Stream | Fabrication Process | Lab/Crash Testing | Approval Status | Field Experience |
| 4 | International Plastics | Plasticade | HDPE | 100% | Post-consumer | Molded | | | |
| 4 | Amazing Recycled Products, Inc | | PVC | some | | | | CO DOT rejected | Some cities, counties |
| 4 | Utility Plastic Recycling, Inc | | HDPE, PET, PVC, PP | 100% | Post-consumer and Post-industrial | Molded | | | |
| Delineators - Drums | | | | | | | | | |
| 1 | Plastic Safety Sys | Lifeguard Channelizer | Drum: LDPE, HDPE, Base: Rubber tires | > 70% Ballast and Body | Post-consumer | | ASTM D638, D1505, D792, D882, D790 Crash tested | Approved | 24 States |
| Delineators - Posts | | | | | | | | | |
| 1 | Carsonite | Carsonite Survivor Post | Post: Recycled thermoplastic Anchor: Steel | up to 75% Total | Post-consumer | | Crash | | MI, NE |
| 1 | Davidson Plastics Co (DAPCO) | Flexi-Guide | Engineered, recycled thermoplastic | > 50% | Post-consumer | Extruded | Crash | Failed | MI |
| | | | Engineered, recycled thermoplastic | > 50% | Post-consumer | Extruded | | Approved in AR, CA, CO, NV, SC, WY, pending in TX | |

TABLE 2. PRODUCT PRIORITIZATION (Continued)

| Ranking | Manufacturer | Product Name | Product Description | | | | Product Testing | | |
|---------|--------------------|---|--------------------------------------|------------------------|---------------------|--|------------------------------------|--------------------------------------|-----------------------------|
| | | | Material Type | Recycled Content % | Waste Stream | Fabrication Process | Lab/Crash Testing | Approval Status | Field Experience |
| 1 | FlexStake, Inc | Flexible and Type III Bridge Marker, One-Piece, Two-Piece, Bi-Directional Channelization, Surface Mounted | Polycarbonate | 35%-65% | Post-consumer | Extruded | | Approved for use in 85-95% of states | NC, Asia, Europe, Australia |
| | | HD 400 (unhinged), now called HD 300 | Polycarbonate | 35%-65% | Post-consumer | Extruded | | App'd for use in 85-95% of states | NY, IL, WV |
| | | HD 600 (ground mounted) | Polycarbonate | 35%-65% | Post-consumer | Extruded | Crash | Passed | MI |
| | | Polyflex | HDPE | 40% - 75% | Post-consumer | Extruded | ASTM | | |
| 1 | Plastic Safety Sys | The Gripper | Drum: LDPE, HDPE, Base: Rubber tires | > 70% Ballast and Body | Post-consumer | | ASTM D638, D1505, D792, D882, D790 | | |
| 1 | Greenline | One Piece | Engineered, recycled thermoplastic | > 70% Total | > 51% Post-consumer | Post meets req. of ASTM D-5033-90, Sections 3.1.7 and 3.1.18 | Approved TX | TX | |
| | | Surface Mount | | | | | Pending TX | | |
| 2 | | Two Piece Highway, Guardrail Mount | | | | | Some app'd, others pending | | NV |

TABLE 2. PRODUCT PRIORITIZATION (Continued)

| Ranking | Manufacturer | Product Name | Product Description | | | | Product Testing | | |
|--------------------------------|-----------------------------|------------------------------|--|------------------------|-----------------------------------|--------------------------------|-------------------|-----------------|--------------------|
| | | | Material Type | Recycled Content % | Waste Stream | Fabrication Process | Lab/Crash Testing | Approval Status | Field Experience |
| 2 | Keneco, Inc | | Tires | 100% | Post-consumer | Cut out, vulcanized, and baked | Lab, Crash | | Australia |
| 3 | Aldan Lane Co | | PE | 100% | Post-industrial | | | | |
| 4 | Scientific Developments Inc | Portable Traffic Delineators | Posts: recycled plastics, Bases: recycled scrap tire rubber | Post: 50%, Bases: 100% | Post-consumer | | | | |
| Guardrail Offset Blocks | | | | | | | | | |
| 1 | Collins & Aikman | ER ³ | Vinyl, nylon | | Post-consumer and Post-industrial | | Lab, Crash | Passed | |
| 1 | Mobil | Trex | Wood Fiber & Polyethylene | 50%/50% | Post-industrial | | Crash | FHWA | MD, NE, NV, NY, PA |
| 1 | Recycled Technology, Inc | Guardrail | Polyethylene | | | | Lab, Crash | | |
| 3 | Envirocrete 2000, Inc | | Scrap tires, recycled ground glass & cement, recycled HDPE and/or PVC for sleeve | 75%/25% | Post-consumer | | Lab | | |
| 3 | Envirowood | | HDPE, PET, PP, PVC | 100% | Post-consumer and Post-industrial | | Lab (Strength) | | |

TABLE 2. PRODUCT PRIORITIZATION (Continued)

| Ranking | Manufacturer | Product Name | Product Description | | | | Product Testing | | |
|------------------------|--------------------------------|---------------------|--|--------------------|--|----------------------------------|-------------------|---------------------|------------------|
| | | | Material Type | Recycled Content % | Waste Stream | Fabrication Process | Lab/Crash Testing | Approval Status | Field Experience |
| 3 | Jomarico, Inc (div of RPL) | Trimax | HDPE, screener waste fiberglass, misc | 75%/20%/ 5% | Post-consumer and Post- industrial | | Lab | | |
| 3 | Plastic Lumber Company, Inc | | Commingled thermoplastics HDPE, LDPE, PP, PS, PET | 100% | Post-consumer | | ASTM | | |
| 4 | Hwycom, Inc | Fiberglass | | 0% | | | | | |
| Guardrail Posts | | | | | | | | | |
| 1 | Mobil | Trex | Wood Fiber & Polyethylene | 50%/50% | Post-industrial | | Crash | FHWA | MD |
| 1 | Recycled Technology, Inc | Plastic Post | Polyethylene & steel core | | | | Lab, Crash | | |
| 3 | Xymax | | Ground wheat straw/scrap plastic | 60%/40% | Post-consumer and Post- industrial | Extruded but can be molded | Lab | ASTM D143, D1761 | |
| 3 | Amour Hydro Press, Inc | Amour Fiber Core | Cured waste fiberglass, resins, & other by-products | 85% | Post-industrial | | Lab | | |
| 3 | Envirocrete 2000, Inc | | Scrap tires, recycled glass and cement, recycled HDPE and/or PVC for sleeve | 75%/25% | Post-consumer | | Lab | | |

TABLE 2. PRODUCT PRIORITIZATION (Continued)

| Ranking | Manufacturer | Product Name | Product Description | | | | Product Testing | | |
|--------------------|-------------------------------|---------------------------|--|--------------------|-----------------------------------|---------------------|----------------------------------|-----------------|--------------------|
| | | | Material Type | Recycled Content % | Waste Stream | Fabrication Process | Lab/Crash Testing | Approval Status | Field Experience |
| 3 | Jomarico, Inc (div of RPL) | Trimax | HDPE, screener waste fiberglass, misc | 75%/20%/5% | Post-consumer and Post-industrial | | Lab | | |
| 3 | Plastic Pilings, Inc | | HDPE, LDPE, PP shell, steel core | | | | | | |
| 4 | Gibson Recycling | | Recycled tire rubber and recycled plastics | | | | | | |
| 4 | Hwycom, Inc. | Fiberglass Guardrail Post | | 0% | | | | | |
| Sign Blanks | | | | | | | | | |
| 2 | Composite Technologies | PFM Blanks | PET, glass fiber | 80%/20% | Post-consumer | Molded | Lab, ASTM D638, D790, D695, D696 | Passed | PA |
| 2 | International Plastics | DuraPlate | Polycarbonates and fiberized signs | 100% | Post-consumer | | | | OH, CT, KY, GA, PA |
| 2 | SABI | 3004-H38 | Aluminum | 100% | Post-consumer | | | Failed | NV |
| | | | Aluminum | 100% | Post-consumer | | | | NY |
| | | 3016-H38 | Aluminum | 100% | Post-consumer | | Lab | | ID |
| 3 | Flexstake, Inc | Polyflex | HDPE | 40% - 75% | Post-consumer | Extruded | ASTM | | |

TABLE 2. PRODUCT PRIORITIZATION (Continued)

| Ranking | Manufacturer | Product Name | Product Description | | | | Product Testing | | |
|----------------------|-----------------------------|-----------------------|---|--------------------|-----------------|---------------------|---|-----------------|-------------------------|
| | | | Material Type | Recycled Content % | Waste Stream | Fabrication Process | Lab/Crash Testing | Approval Status | Field Experience |
| 3 | Plastic Lumber Company, Inc | Simple Signs | Commingled thermoplastics HDPE, LDPE, PP, PS, PET | 100% | Post-consumer | | ASTM | | |
| 4 | Aldan Lane Co | | PE | 100% | Post-industrial | | | | |
| Sign Supports | | | | | | | | | |
| 1 ¹ | Lancaster Composite | Composite Post 40 | | | | | Crash tested SwRI | Passed | |
| 1 ² | REPP Ind | | Polyethylene | | Post-consumer | Extruded | Crash & static bending tests ³ | FHWA-impact | NC |
| 2 ⁴ | Hwycom | Fiberglass | | 0% | | | | | |
| 2 | MetroPlastics | DuraPost/ DuraBord | HDPE | 100% | Post-consumer | Extruded | Lab | | OR State U (Idaho file) |
| 2 | N.E.W. Plastics Corp | Perma-Poly | HDPE | 100% | Post-consumer | Extruded | Installation, ASTM D792, D695, D790, D785 | | WI |

¹ Successfully crash tested, no recycled content at this time.

² Insufficient structural capacity.

³ Successful crash test, static load, excessive deflection

⁴ Approved by TxDOT, no current recycled content.

TABLE 2. PRODUCT PRIORITIZATION (Continued)

| Ranking | Manufacturer | Product Name | Product Description | | | | Product Testing | | |
|---------|------------------------------|------------------|---|---------------------------------------|-----------------------------------|---------------------|-------------------|-----------------|------------------|
| | | | Material Type | Recycled Content % | Waste Stream | Fabrication Process | Lab/Crash Testing | Approval Status | Field Experience |
| 2 | Refuse/Enviro Sys, Inc | Hammer's Plastic | ABS, Acetal, EVA, DPE, etc. | 23% Post-consumer and 75% Post-indust | Post-consumer and Post-industrial | | Installation | | OR |
| 3 | Aeolian | | HDPE | 100% | Post-consumer and Post-industrial | Extruded | | | |
| 3 | Eaglebrook | Durawood | HDPE | 100% | Post-consumer | | ASTM | | |
| 3 | Environmental Recycling, Inc | | Commingled plastics | 100% | | | | | |
| 3 | Envirocrete 2000, Inc | | Scrap tires, recycled glass and cement, recycled HDPE and/or PVC for sleeve | 75%/25% | Post-consumer | | Lab | | |
| 3 | Envirowood | | HDPE, PET, PP, PVC | 100% | Post-consumer and Post-industrial | | | Rejected | NV |
| 3 | Jomarico, Inc (div of RPL) | Trimax | HDPE, screener waste fiberglass, misc | 75%/20%/5% | Post-consumer and Post-industrial | | | | |
| 3 | Mobil | TREX | Wood Fiber & Polyethylene | 50%/50% | Post-consumer and Post-industrial | | | | |

TABLE 2. PRODUCT PRIORITIZATION (Continued)

| Ranking | Manufacturer | Product Name | Product Description | | | | Product Testing | | |
|---------|-----------------------------|--------------|--|--------------------|-----------------------------------|---------------------|-------------------|-----------------|------------------|
| | | | Material Type | Recycled Content % | Waste Stream | Fabrication Process | Lab/Crash Testing | Approval Status | Field Experience |
| 3 | Plastic Lumber Company, Inc | Simple Signs | Commingled thermoplastics HDPE, LDPE, PP, PS, PET | 100% | Post-consumer | | ASTM | | |
| 3 | Superwood | (2x4) | PE, PP | 100% | | | Installation | Failed | MI |
| 4 | Gibson Recycling | | Recycled tire rubber and recycled plastics | | | | | | |
| 4 | Plastic Pilings, Inc | | HDPE, LDPE, PP shell, steel core | | | | | | |
| 4 | Recycled Plastic Products | Plasti-Post | HDPE | 100% | Post-consumer and Post-industrial | | | | |

RECOMMENDATIONS FOR IMPLEMENTATION

Before products can be placed on the roadside, their safety performance should be evaluated. For most roadside safety features of interest to this study, this safety evaluation involves some level of full-scale crash testing. At the very least, an engineering evaluation should be made to determine if a product meets desired structural and durability requirements. Transportation agencies should also monitor field performance of products installed on an experimental basis to evaluate any long-term exposure problems such as creep or warpage. Products that do not currently meet these criteria cannot be recommended for implementation. Such a decision is not necessarily indicative of whether or not the product is suitable for implementation, it simply means that further testing and evaluation is required before a determination can be made. For example, although mechanical properties obtained from laboratory tests can provide sufficient information to evaluate the structural adequacy of a product, these tests may not be sufficient for evaluating the dynamic impact performance or crashworthiness of the feature.

The structural requirements placed on delineator devices such as posts, drums, and cones are typically not very demanding. Hence, these materials tend to be lightweight, which makes it much easier to meet the required impact criteria. In fact, for most of these devices, durability requirements are of greater concern than the safety requirements. As the structural requirements imposed on a product increase, the consequences of an impact with the device also tend to increase. Thus, for applications such as sign supports in which the post must be designed to withstand considerable wind loads, the proper functioning of the breakaway mechanism becomes more critical.

Listed below are products from the preceding table which are considered suitable for implementation. A brief discussion of these selected products is given to provide more information than could be contained in the table. It should be noted that the evaluation contained herein was based on information that manufacturers and state agencies provided for the researchers and is not based on any independent testing or monitoring of field installations under this project.

The evaluation was based primarily on the ability of the product to meet nationally recognized safety standards, on field experience reported by other agencies, and to a lesser extent on any physical and mechanical properties that were reported. The basic premise is

that those products which have demonstrated their crashworthiness can be safely installed and monitored on an experimental basis. Monitoring of the field performance is recommended to evaluate long-term exposure to in-service conditions which is difficult to discern from laboratory test results. Factors such as cost, availability, ease of handling, and special equipment have not been directly addressed due to lack of information in these areas.

The list of existing, commercially available roadside safety devices manufactured in part or in whole from recycled materials and considered suitable for experimental implementation is as follows:

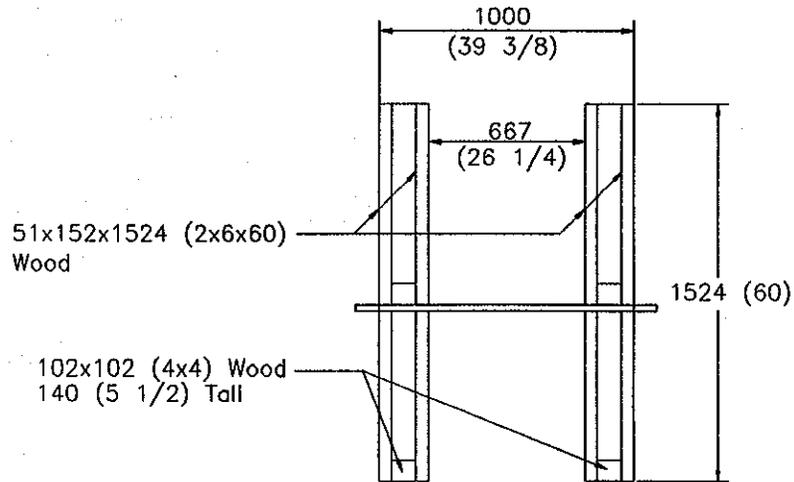
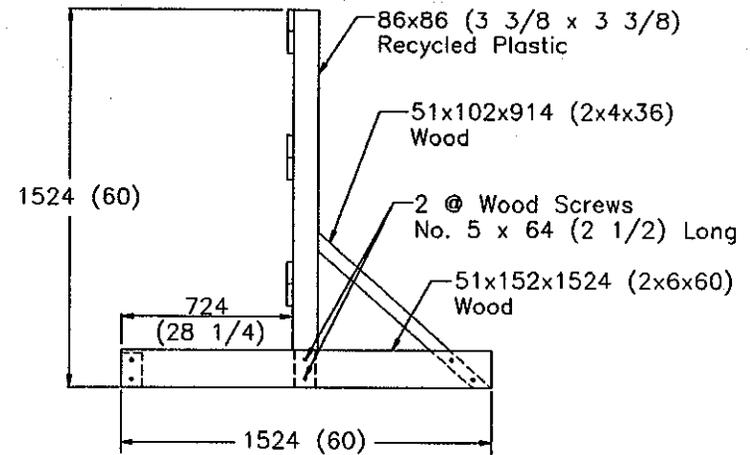
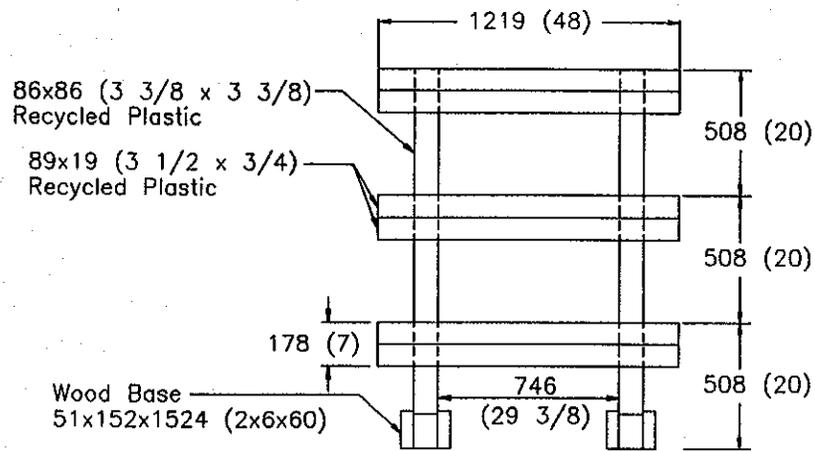
Barricades

- **Bear-A-Cade**

Bear-A-Cade provided specifications from the state of California on plastic barricades, a copy of which is included in Appendix D. Their product has met the specifications and is approved for use in that state. The barricade must be an A-frame design with a minimum of two horizontal cross-members on each side. Bear-A-Cade manufactures barricades with both a 100 percent virgin high-impact plastic content and a 50/50 virgin/post-consumer content. A recycled credit is offered on all broken panels.

- **Recycled Plastic Products**

Components manufactured by Recycled Plastic Products were used to construct a Type III barricade. All above ground level members were recycled plastic while the supporting skids were fabricated from dimensional lumber. When crash tested, the barricade performed better than the standard wood barricade system. During a test with a wood barricade, large fragments of the system broke off and penetrated the occupant compartment of the vehicle. The recycled plastic barricade, which was comprised of lightweight hollow core members, remained intact throughout the impact sequence and came to rest adjacent to the vehicle. Figure 1 shows details of the tested installation.



Type III Barrier -- Recycled Plastic Upright with Wood Bases

Total Weight of Barricade: 80 lb

Weight of Upper Portion: 23 lb

FIGURE 1. Type III Recycled Plastic Barricade

Bollards

- Plastic Pilings, Inc.

Plastic Pilings, Inc. has various cross sections available that are suitable for use as bollards or protective posts. Their pilings are currently being used in California as mooring piles in marine applications and are reported to be performing well. Some of their products contain steel reinforcement that provides additional structural integrity. Corrosion or deterioration of the steel reinforcement is not a factor due to the fact that the recycled plastic completely encases and protects the steel.

Delineators - Traffic Cones

- Work Area Protection has indicated contracts in 15 states.

Delineators - Channelizing Drums

- Plastic Safety Systems, Inc.

The upper structure of the Lifeguard Channelizer is comprised of both low-density and high-density polyethylenes. Recycled tires are used as ballast around the base of the drum. Total recycled content is in excess of 70 percent and the drums have been placed on the approved/qualified list in 24 states. Additionally, full-scale crash tests have been conducted in Pennsylvania, Minnesota, North Carolina, Missouri, New Jersey, and New Mexico with good results.

Delineators - Flexible Posts

- Carsonite

Michigan and Nebraska have indicated field testing of the Carsonite Survivor Post. Responses to our requests for additional information have not been received. However, due to the minimal safety concerns imposed by these devices, it should be suitable for field installation and monitoring.

- Davidson Plastics Co. (DAPCO)

DAPCO has received approval from Arkansas, California, Colorado, Nevada, South Carolina, and Wyoming, and is currently awaiting approval from the state

of Texas. Their Flexi-Guide delineators are comprised of over 50 percent recycled thermoplastics. Their product line includes: flexible highway delineator posts, temporary overlay markers, raised pavement markers, and guardrail post reflectors, all of which should be suitable for implementation.

- Flexstake

Flexstake has experience in many states with several different products. Their surface mounted delineator has been field tested in North Carolina, Asia, Europe, and Australia. Driven, soil mounted stakes have been used in New York and Michigan. A video tape provided with the literature demonstrates full-scale impacts involving vehicles ranging from passenger cars to semi-trucks with good performance.

- Plastic Safety Systems

The Gripper is a surface mounted temporary delineator post. The base is constructed of 100 percent recycled tire tread.

- Greenline

Greenline offers one-piece driven delineators, two-piece surface mounted delineators, and guardrail mounted delineators. Their total recycled content is greater than 70 percent and they have received partial approval of their product line from Nevada DOT. As mentioned earlier, Greenline has initiated a buy-back program, which may be an added incentive to potential customers.

- Kennco, Inc.

Kennco has in-ground and surface mounted delineator posts constructed from 100 percent recycled tire tread. Their product has been used extensively in Australia. Full-scale crash testing, accelerated weather testing, and numerous strength tests have been conducted with good results.

Guardrail Offset Blocks

- Collins & Aikman

The results of full-scale crash testing performed on a guardrail offset block being marketed by Collins & Aikman were presented informally at the 74th annual meeting of the Transportation Research Board in Washington, D.C., in January

1995. The performance of the product was judged to be satisfactory, and approval was being sought from the Federal Highway Administration for use as an alternate to standard wood offset blocks. The product is partially composed of carpet fiber scraps. Attempts at acquiring additional information have been unsuccessful to date.

- Mobil Oil Corporation

Crash testing has been successfully performed on the Trex guardrail offset block, which is a product of Mobil Oil Corporation. This product was previously known as Timbrex, and before that as Rivenite. Approval has been received from FHWA, and they have field experience in various states including Maryland, Nebraska, Nevada, New York, and Pennsylvania. Although TxDOT does not currently use offset in conjunction with its round wood posts, the Trex offset block has also been approved for use in steel post guardrail systems which are also used in Texas.

- Recycled Technology, Inc.

Crash testing was conducted in 1992 on recycled guardrail offset block comprised of HDPE and manufactured by Ryerson Plastics. Subsequent to the testing, exclusive rights to the product transferred to Recycled Technology, Inc. These blockouts were tested in conjunction with guardrail posts in a strength test to *NCHRP Report 230* standards. There was no distress observed in any of the guardrail offset blocks as a result of the testing.

Guardrail Posts

- Mobil

When subjected to full-scale crash testing, a W-beam guardrail system comprised of Trex guardrail posts and offset blocks successfully contained and redirected the test vehicle and met all evaluation criteria. However, it was noted that the maximum dynamic displacement measured for the test was approximately twice the deflection of a standard G4(2W) or G4(1S) strong-post guardrail system. Therefore, although the Trex guardrail post has received FHWA approval, it should not be used as a substitute for conventional wood and steel guardrail posts

in strong-post guardrail systems. The Trex guardrail system would be suitable at sites where the increased dynamic deflection can be accommodated.

- Recycled Technology, Inc.

Full-scale crash testing conducted by TTI demonstrated that a composite recycled guardrail post, originally manufactured by Ryerson Plastics, exhibited acceptable impact performance. This post, which is considered to be an acceptable substitute for conventional wood and steel posts in strong-post guardrail systems, consists of an outer HDPE shell reinforced with a hollow thin-wall steel tube. No distress of the plastic shell was observed as a result of the full-scale impact. However, differential thermal expansion within the composite section caused cracking of the plastic end cap located at the top of the post. Although not a safety concern, the issue of durability needs to be addressed.

Subsequent to the testing program, exclusive rights to the product transferred to Recycled Technology, Inc. The researchers have been unable to determine if FHWA approval for the post has been obtained or whether it has gained any field experience.

Sign Blanks

- Composite Technologies

Composite Technologies sign blanks have received approval and are used in a limited capacity in Pennsylvania. There were some concerns about warping of larger sized panels and further evaluation is ongoing.

- International Plastics

To our knowledge, DuraPlate has not been crash tested; however, it has been approved in Kentucky, Georgia, and Pennsylvania. International Plastics has initiated a buy-back program to retrieve and recycle the sign blanks when their functional life has expired.

- Signs and Blanks, Inc. (SABI)

SABI sign blanks are manufactured from 100 percent post-consumer aluminum. Apparently, satisfactory results have been obtained in New York and Idaho, but Nevada rejected them because of "quality concerns."

Sign Supports

- **REPP Industries**

TTI crash tested REPP Industries' recycled plastic sign support in 1993. From a safety standpoint, the supports were deemed acceptable, but deflections due to wind loads and thermal expansion probably limit their usefulness in field applications. If the supports are stiffened to mitigate these problems, retesting will be required.

VI. SUITABILITY OF OTHER RECYCLED MATERIALS FOR ROADSIDE SAFETY DEVICES

OTHER EXISTING PRODUCTS AND THEIR CURRENT APPLICATIONS

As indicated in the previous section, technology associated with recycled materials has advanced to a point at which their properties can be tailored to a variety of widespread applications, including various roadside safety features. However, as indicated in the **RECOMMENDATIONS FOR IMPLEMENTATION** section of the previous chapter, only a relatively few products are currently available which satisfy all of the safety, structural, and durability requirements. Consequently, further research in this area is needed for several reasons.

First, there is a need for competition in the market place. For some applications, the number of acceptable products may be as few as one or two, and some of these are proprietary in nature. If more products can be brought to the market place, it would foster competition and hopefully result in reduced consumer costs. Secondly, this field is still in its infancy, and a large amount of research is still presently being devoted to the development of improved materials and processes. Use of these new materials may offer improved products in terms of strength, crashworthiness or long-term durability, and continued research is necessary to evaluate these new products and determine their usefulness. In addition, use of products with improved physical and mechanical properties may enable more cost effective solutions to be developed for applications for which use of existing materials is considered impractical. For instance, economical alternatives for some of the more demanding applications such as guardrail posts and sign supports have yet to be achieved, and this need should be addressed. Conversely, there may already be some existing recycled materials and products which were developed and applied to other applications which could offer immediate solutions to some of the problems being addressed in the area of roadside safety.

Candidates for future evaluation include those products given a rating of three or four in the table of existing products presented in Chapter 5. At present, the researchers felt that information provided for these products was insufficient to complete an evaluation. Because these products are already geared toward roadside safety applications, only a modest amount of additional investigation may be required to bring some of them to the implementation

stage. Other candidates for this effort include existing materials and products which were developed for other uses, but which appear to have potential in roadside safety applications. Some of the many plastic lumber products which have been identified from the literature search and survey might satisfy this criteria.

A further discussion of other materials and products and their properties is given below, followed by specific recommendations for future work by type of application.

Material Types

The largest number of manufacturers responding to the study survey reported producing recycled plastic products or at least partially recycled plastic products. The largest waste stream in the plastic category is high and low density polyethylenes, which emanate from milk and detergent bottles, bags, film, and wrapping. Polypropylenes were also used in many of the products for which information was provided. Additionally, PVC, PET, PS, and resins reinforced with fiberglass were also noted. Waste streams of wood products are being commingled with plastic and molded into nominal lumber shapes.

Most of the manufacturers are trying to position their products to compete with similarly dimensioned wood products for applications such as fence posts, landscape timbers, picnic tables, etc. However, some are already applying their materials to specific roadside safety applications. For instance, recycled vinyl is reportedly being used in traffic cones, and recycled polyethylenes are being used in drums, delineators, and sign blanks. Polycarbonates are also being used in delineator posts and sign blanks.

Recycled tires are currently being used in several fashions:

- Ground and remolded into various shapes,
- Ground and commingled with recycled plastics, then molded into various shapes,
- Sections of the tire, sidewall or tread, separated for use as ballast for temporary work zone devices, and
- Sections of tread, attached back to back and covered with a plastic sleeve for use as a delineator post.

Aluminum and steel have been recycled extensively and, thus, are almost never considered when one looks to utilize recycled materials. Entire steel mills are devoted to melting scrap iron and manufacturing new standard shapes. If desired, steel components

manufactured from these production lines could be given preferential consideration over similar virgin products. Likewise, recycled aluminum products should be given serious consideration, provided they can meet required quality standards.

Other recycled products such as glass, paper, fly ash, concrete, and asphalt have applications in highway construction, but not necessarily in roadside safety devices. One possible exception is the potential use of fly ash as an additive in precast or cast-in-place concrete bridge rails and median barriers. Some of these materials may also have use as an additive or filler in plastic or rubber blends to enhance mechanical or physical properties of the end product.

Available Sizes

Based on the information received, materials are either molded into specific shapes for applications such as cones, barrels, delineators, barricades, and sign blanks, or they are molded or extruded into simple circular or rectangular shapes. Since a large portion of the samples received are referred to as plastic lumber, they naturally follow nominal lumber dimensions. These products may have application as single members, such as in sign supports, or in combination, such as in the construction of a barricade or other device currently fabricated from dimensional wood products. Cross uses for materials manufactured for specific applications will be much more limited.

Properties

Comparison of material properties should be driven by, but not limited to, past experience in roadside safety devices. For instance, it is likely that products used for guardrail posts and blockouts will have strength and stiffness properties consistent with their steel and wooden counterparts if a one-to-one substitution policy is desirable. In applications such as sign supports and bollards, close attention must be paid to stiffness and creep to assure long-term durability and performance. While delineators do not carry large loads, they should be designed to be durable and resilient when impacted. Furthermore, they should remain upright and visible before and after impact.

SUITABILITY FOR ROADSIDE SAFETY APPLICATIONS

As expressed earlier in the report, materials for use in roadside safety devices must serve a dual purpose. Structural adequacy and crashworthiness are the two primary design considerations. Therefore, as one begins to develop new devices or new uses for existing products, simple applications will be the most readily adapted.

Barricades

The potential for using other recycled materials in the construction of barricades is high. Barricades are constructed from components and thus lend themselves to fabrication from existing manufactured shapes such as nominal lumber sizes, tubular members, and flat panels. Many manufacturers produce plastic lumber from varying waste streams. Testing done by TTI suggests barricades constructed of components from different waste streams may be desirable. A possible combination might include: lightweight, hollow recycled plastic or recycled fiberglass members for use as uprights and panels, and denser recycled polyethylenes for use in the base units or skids. The literature review indicates that lightweight, hollow members are currently manufactured by at least two companies: Aeolian and Recycled Plastic Products, Inc. Dense, solid recycled polyethylene-based plastic lumber products are commercially available from many manufacturers.

Barriers

Traffic barriers have not been specifically targeted by manufacturers due to the difficulties in managing the extremely high levels of energy imparted by an impacting vehicle. Some states are using recycled rubber and plastics in retaining walls and sound barriers. If sufficient anchorage and/or weight is provided, these products could possibly function as median barriers.

Hwycom, Inc. indicated that they have a patent pending for an entire guardrail system composed of fiberglass components. At this juncture, virgin material is to be used. But even if recycled fiberglass is found to be unfeasible, there is some merit in the fact that such a fiberglass guardrail system will be completely recyclable. On a similar note, researchers at the University of Nebraska-Lincoln, Midwest Roadside Safety Facility are currently investigating the use of composite materials in guardrail systems. Although virgin, fiber-

reinforced resins are the focus of this investigation, the results of this work may possibly provide future opportunities for the integration of recycled material.

Bollards

Typically, bollards are placed as protective measures and are not used in high speed applications. Consequently, safety aspects of impacts are not of major concern and these posts are commonly installed in a rigid foundation. Existing products with high strength and stiffness are good candidates for use as bollards. Plastic Pilings, Timbrex, and Jomarico all have products that exhibit desirable qualities with respect to strength and stiffness and may be suitable candidates for this application.

Delineators

There are several types of delineators that would make good candidates for recycled material use. Structural requirements are not very demanding and many of the recycled materials currently on the market should have acceptable properties for this application. Manufacturers who are prepared to mold recycled materials into cones and traffic barrels should also be given serious consideration for future evaluation. It should be noted that many devices used in delineator type applications are sufficiently light so as not to cause safety concerns for vehicle impacts. Thus, the evaluation process for these products is greatly simplified over those for other more critical safety features.

“To purchase traffic cones made with recycled plastic, purchasers should have assurances that the cones can:

- (1) resume their shape after impact,
- (2) withstand rough treatment in all temperatures,
- (3) resist becoming projectiles when struck,
- (4) resist damage when run over by vehicles,
- (5) resist UV degradation, and
- (6) bond with reflective materials.” (American Plastics Council, 1994.)

One manufacturer has indicated a lack of consistency in their product due to changes of material in each run. Any products able to meet the above criteria should be considered

suitable for implementation and inclusion on the state's Approved Materials List. Others can be accepted on an experimental basis until field performance is verified.

Plastic traffic barrels will be judged by similar criteria. If overall dimensions and weights are equal to existing approved models, then barrels made of recycled materials should be suitable for implementation on an experimental basis.

The previous two applications, cones and barrels, are typically used in a temporary fashion. Delineator posts are generally used in a more permanent setting. As such, departments will want to verify structural adequacy. The current TxDOT specifications for delineator posts should be adequate for this evaluation.

Guardrail Offset Blocks

Products specified in the bollard section above should also have suitable characteristics for use as guardrail offset blocks. High strength and stiffness properties qualify them for consideration. The loading requirement for offset blocks is significantly different than those for guardrail posts and sign supports. During an impact, an offset block primarily experiences compressive and shear stresses, and is not subject to the high flexural stresses typically experienced by post-type applications. Since plastics tend to be relatively strong in compression, many existing materials should be capable of satisfying the requirements for this application.

Guardrail Posts

Specimens received from Amour Hydro Press, Inc., Jomarico, Inc., and Plastic Pilings, Inc. show promise for use in guardrail posts. Again, high strength and stiffness are apparent in these samples, which is necessary to withstand the large impact loads and flexural stress these posts are subjected to during an impact. Pendulum tests and static bending tests can be used to verify that these existing products have the potential for meeting full scale testing requirements. Other manufacturers having recycled products with properties matching those of wood posts are also suitable candidates for further investigation. Promising samples along this line have been received from Xymax.

Sign Supports

Field experience and lab test results are available from Metro Plastics, N.E.W. Plastics Corp., and Refuse/Enviro Systems, Inc. Additionally, many manufacturers are listed who produce recycled plastic lumber products that have been tested to varying degrees. Due to the potential problems of creep and warpage for these long, slender supports, products strengthened with glass fibers or other reinforcement material have the most potential for use in this application. Additionally, as with guardrail posts, existing products capable of matching the properties would also warrant consideration in this area.



VII. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Recently, environmental concerns, declining disposal capacity, legislative mandates, economic considerations, and conservation efforts have begun to influence policies on the recycling of various waste materials and by-products. While the volume of wastes continues to grow, approval of facilities for waste processing and disposal is becoming more difficult to obtain due to public concerns and increasingly restrictive environmental regulations. As a result, many manufacturers are now attempting to recycle and market plastics and other materials for a variety of widespread applications, including various roadside safety appurtenances and work-zone traffic control devices.

This report summarizes the first phase of a three-phase research program intended to evaluate the use of recycled materials in roadside safety devices. Researchers obtained information regarding existing products manufactured in part or in whole from recycled materials through an extensive computerized literature review and survey of research organizations, government/state agencies, professional and trade societies, and manufacturers. Roadside safety applications which were evaluated include: guardrail support posts and rail-to-post offset blocks, sign blanks and their supports, flexible delineator posts, and work zone traffic control devices such as channelizing drums, traffic cones, and barricades.

The information was summarized and categorized into two distinct areas: (1) commercially available roadside safety products and traffic control devices having the potential for immediate implementation, and (2) other products and materials not specifically designed for use in roadside safety devices but having potential use in such applications.

A prioritization scheme was developed to assist in the evaluation of existing products. Fulfillment of specified safety requirements was considered to be of primary importance. Relevant field experience reported by state agencies, and the availability of physical and mechanical properties from laboratory testing were also weighed heavily in the evaluation process. Factors such as cost, availability, and ease of handling were not directly considered due to lack of information in these areas. Based on this evaluation scheme, specific products considered suitable for immediate implementation were identified and categorized by application type.

RECOMMENDATIONS

Recommendations for commercially available, recycled roadside safety products considered suitable for immediate implementation are summarized below. The recommended devices are listed by manufacturer and product name, and are categorized by application type. A more detailed discussion of these selected products is presented in Chapter V. It should be noted that under Phase I, TTI researchers performed no independent testing or field evaluation of the selected products. Therefore, the recommendations contained herein are based on information found in the literature and provided to the researchers by manufacturers and state agencies.

The evaluation was based primarily on the ability of the product to meet nationally recognized safety standards, on field experience reported by other agencies, and on any physical and mechanical properties that were reported. The list of existing, commercially available roadside safety devices manufactured in part or in whole from recycled materials and considered suitable for experimental implementation follows.

Barricades

- Bear-A-Cade
- Recycled Plastic Products

Bollards

- Plastic Pilings, Inc.

Delineators - Traffic Cones

- Work Area Protection

Delineators - Channelizing Drums

- Plastic Safety Systems, Inc. - Lifeguard Channelizer

Delineators - Flexible Posts

- Carsonite - Survivor Post
- Davidson Plastics Co. (DAPCO) - Flexi-Guide

- Flexstake
- Plastic Safety Systems - The Gripper
- Greenline
- Kennco, Inc.

Guardrail Offset Blocks

- Mobil Oil Corporation - Trex
- Collins & Aikman
- Recycled Technology, Inc.

Guardrail Posts

- Mobil Oil Corporation - Trex
- Recycled Technology, Inc.

Sign Blanks

- Composite Technologies
- International Plastics - DuraPlate
- Signs and Blanks, Inc. (SABI)

For some of these devices, information regarding long-term performance and durability is lacking. It is therefore recommended that these products initially be implemented and monitored on an experimental basis. If in-service performance is judged to be satisfactory, the devices could then be upgraded to full operational status.

Factors such as cost, availability, and ease of handling should be considered in the final selection of products for applications in which more than one product is recommended. These factors were not considered in the initial evaluation due to lack of information in these areas.

Although suitable from the standpoint of safety performance, the products recommended for use as guardrail posts may not have immediate application in Texas. The deflections observed in tests of the Trex guardrail post were approximately twice those typically observed with standard strong-post guardrail systems. Therefore, it is not considered

to be a direct substitute for conventional wood and steel posts. However, the Trex post should be suitable for use at sites which can accommodate the additional dynamic deflection.

Unlike Trex, the other guardrail post is considered to be a satisfactory substitute for use in strong-post systems. However, problems associated with differential thermal expansion of the composite plastic/steel section have raised durability concerns which need to be addressed before it is used on a widespread basis.

Although several products are identified for use as sign blanks, it should be noted that there is an ongoing TxDOT study which is specifically investigating this application. Therefore, it may be advisable to review the recommendations from that study before implementing any of the products listed above.

Some products lacked the desired data from which to make a conclusive decision regarding suitability for implementation, and further evaluation of those showing the most promise should be conducted under Phase II. One notable area in which acceptable products are currently lacking is small sign supports. Although one product met all required safety criteria, problems with warpage were observed. Several other manufacturers currently have products which have undergone some laboratory testing and field evaluation. With further evaluation through dynamic pendulum testing some of these products may be found to be suitable for implementation. Specifically, products strengthened or reinforced with glass fibers or other materials have the most potential for use in this application.

Guardrail posts is another application which deserves further investigation. Products which will serve as direct substitutes for currently used wood and steel post options are still lacking. Specimens received from Amour Hydro Press, Inc., Jomarico, Inc., and Plastic Pilings, Inc. show promise for use in this area. In situ static load tests and dynamic pendulum tests should be able to verify the potential for one or more of these existing products to meet full-scale crash test requirements.

In addition, the potential exists for developing recycled alternatives for breakaway wood guardrail posts such as those used in the ET-2000 end terminal and short-radius guardrail treatments. The function of these "breakaway" posts is to fracture during end-on impacts in order to minimize the potential for vehicle ramping or vaulting. The posts are weakened in such a way as to maintain substantial lateral load capacity to aid in redirection

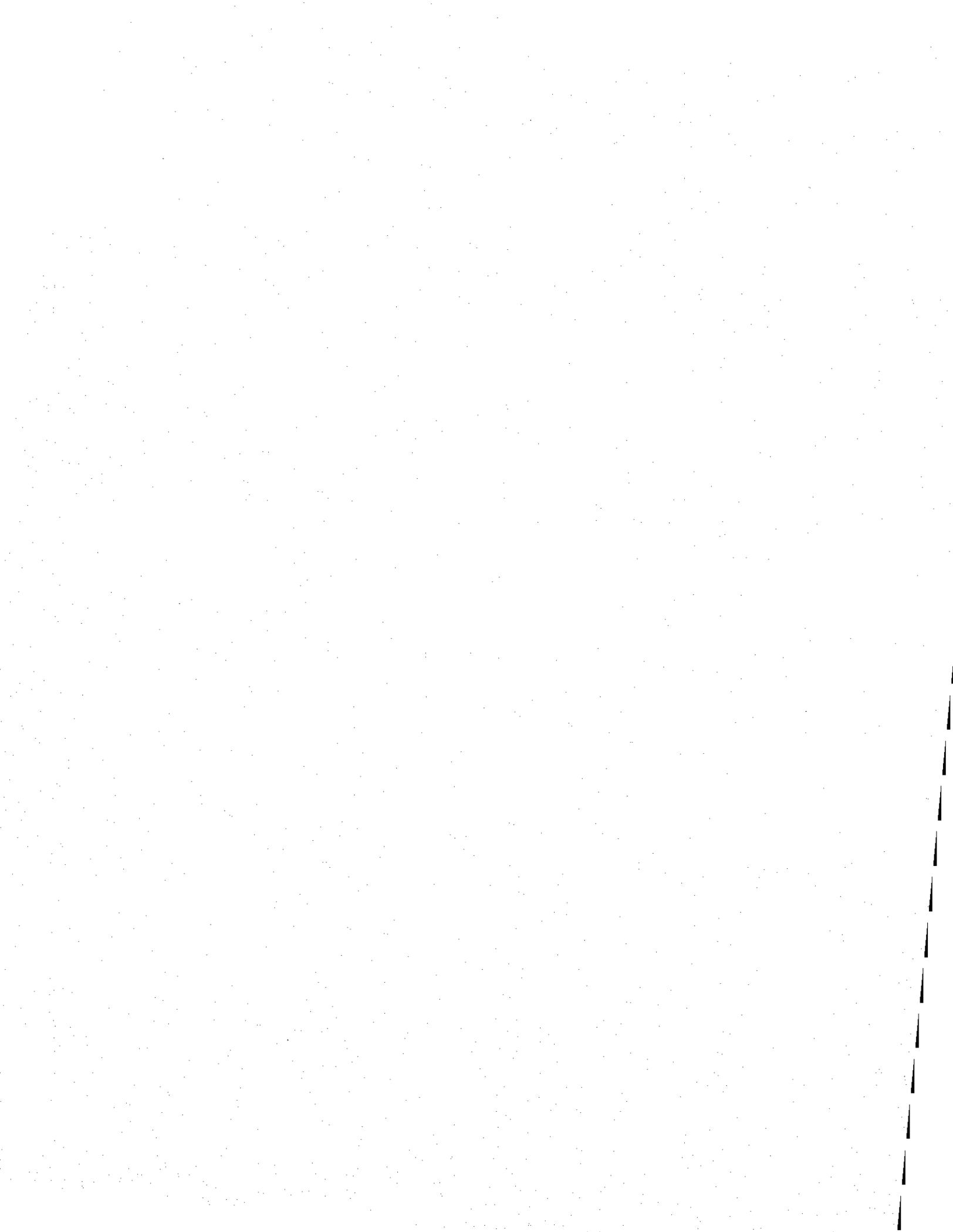
of the vehicle during oblique impacts into the side of the guardrail system. The properties of recycled plastics appear ideally suited for this application.

Further investigation of barricade alternatives is also recommended under Phase II. Previous testing done by TTI suggests the potential for constructing 100 percent recycled barricades from existing manufactured shapes in much the same fashion as wood barricades are currently fabricated. The preferred combination appears to involve the use of light weight, hollow members for the uprights and horizontal panels, and denser recycled lumber products for the base units or skids. Aeolian and Recycled Plastic Products, Inc. are two manufacturers that currently manufacture light weight plastic sections. Solid recycled polyethylene-based plastic lumber products are commercially available from many manufacturers.

Other applications such as mailbox supports also deserve attention. It is anticipated that materials suitable for use as small sign supports may also have application for mailbox supports.

Continued investigation of the use of other materials in roadside safety applications would also be beneficial. For example, very few accomplishments have been made in regard to the use of recycled rubber. Other plastic blends and reinforced materials may also be suitable for use in the roadside safety area. This project has generated a lot of interest among manufacturers and members of the research community, and several have indicated their interest in working with the project team on these issues. This collaboration may take the form of sharing expertise or providing prototypes of different mix designs for testing.

In summary, as public awareness of waste management problems and the potential benefits derived from recovering and reusing waste materials continues to grow, the need for acceptable alternatives to conventional products will also grow. The results of this research project and others like it will enable TxDOT and other state agencies to respond to these present and future needs.



APPENDIX A
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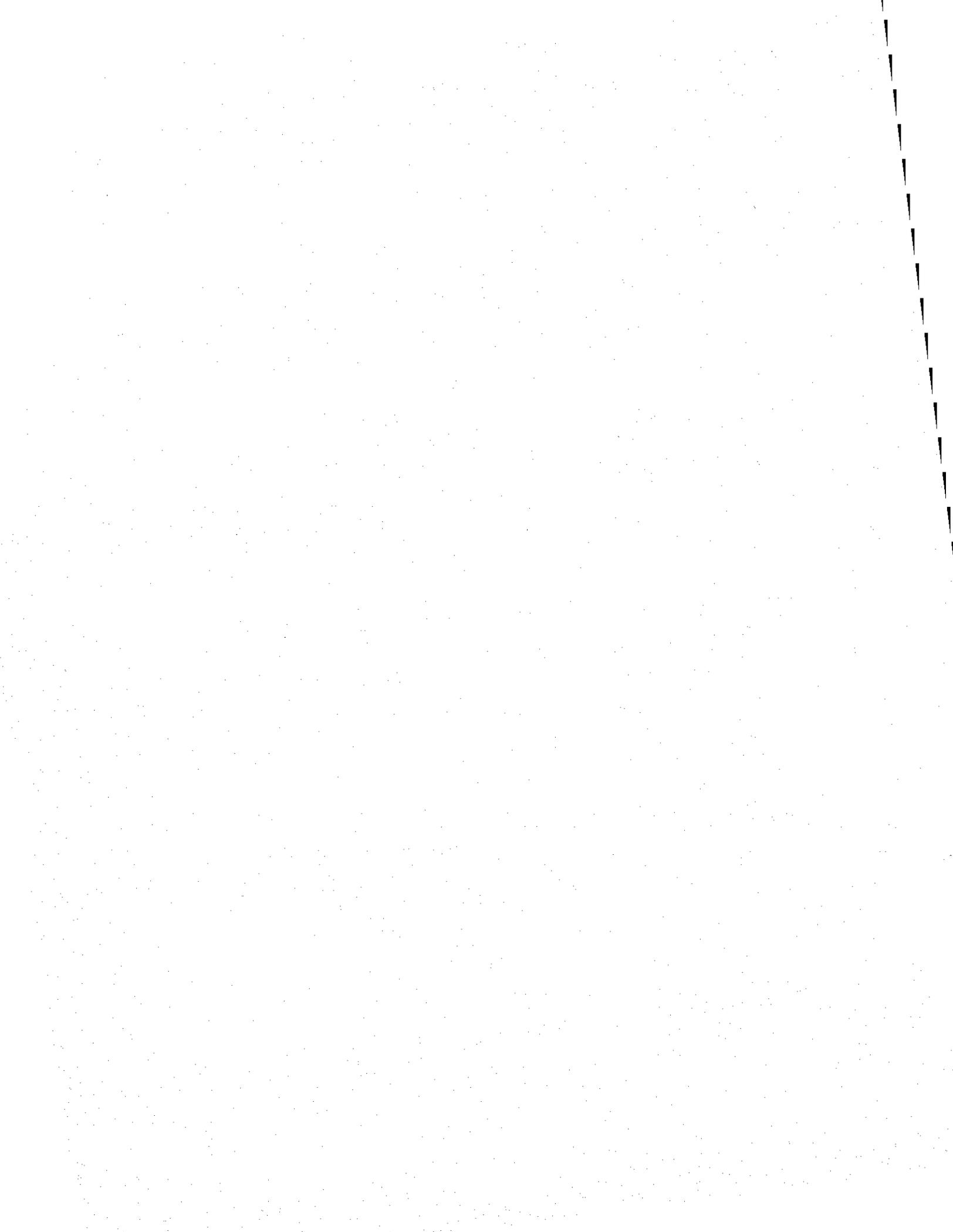
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APPENDIX C

**USE OF WASTE MATERIALS IN HIGHWAY
CONSTRUCTION**

USE OF WASTE MATERIALS IN HIGHWAY CONSTRUCTION ¹

| PRODUCT | STATE | RESULT | DATE | EXP ² | COMMENTS |
|---------------------------------|-------|-----------|------|------------------|--|
| Roadside Safety Features | | | | | |
| Coal Bottom Ash | TX | Good | | | For ice control |
| Forest By-Products | WI | Good | 1989 | | Wood chips-paper-coconut, erosion control hydro-mulches & blankets |
| Guardrail | AZ | Unknown | | L | Maintenance does some recycling |
| Guardrail | CA | Good | 1981 | E | Recycled guardrail used by maintenance & construction |
| Guardrail | MT | Good | 1980 | M | Straighten bent guardrail or sell as scrap |
| Guardrail | OK | Good | | | |
| Guardrail | VA | Excellent | | E | Guardrail reused for maintenance work |
| Guardrail | WI | Good | | | Restraighten and regalvanize some guardrail |
| Metal Structures | MD | Fair | 1980 | M | |
| Old Sign Faces | AZ | Unknown | | L | Maintenance does some recycling |
| Old Sign Faces | CA | Good | 1981 | L | Recycled sign structures used by construction & maintenance |
| Old Sign Faces | ID | Excellent | 1983 | M | |
| Old Sign Faces | MD | Good | 1987 | E | |
| Old Sign Faces | ME | Good | 1989 | | Refinish signs and reuse |
| Old Sign Faces | MO | Good | 1980 | E | |
| Old Sign Faces | MT | Good | 1980 | M | Rem old face or use back of slow or sell as scrap |

¹ Taken from Quality Construction Task Force AASHTO Subcommittee on Construction held August 8, 1994

² EXP=Experience Rating: E=Extensive M=Moderate L=Limited

USE OF WASTE MATERIALS IN HIGHWAY CONSTRUCTION¹ - Cont'd

| PRODUCT | STATE | RESULT | DATE | EXP ² | COMMENTS |
|----------------|-------|--------------|------|------------------|--|
| Old Sign Faces | VA | Good | | E | Not cost effective, not currently used |
| Old Sign Faces | WI | Excellent | 1980 | | Intc blak refill with new sheet dam blak rec alm pre |
| Plastic | DE | Not reported | | | Potential use of recyc plastic prop spec change to allow |
| Plastic | FL | Good | 1991 | E | Fence posts guardrail posts and blocks |
| Plastic | GA | Good | 1990 | L | Barricades and barrels |
| Plastic | GA | Unknown | | | |
| Plastic | IA | Unknown | 1992 | L | Experimental trial as sign blanks |
| Plastic | MA | Good | 1991 | L | Safety barrels |
| Plastic | MD | Unknown | | | |
| Plastic | MI | Poor | | L | Experimental guardrail posts |
| Plastic | MO | Unknown | | | |
| Plastic | NC | Fair | 1992 | L | Fences |
| Plastic | NC | Good | 1993 | L | Guardrail offset blocks |
| Plastic | NJ | Unknown | | | None used |
| Plastic | SC | Unknown | 1992 | L | Ongo sty to eval recy plast fen post for wv wir fen |
| Tires | CO | Good | | | |
| Tires | DE | Not reported | | | Substitute blockouts between metal costs & beams |
| Tires | MA | Good | 1992 | L | Stabilizer for cones and barrels |

C-4

¹ Taken from Quality Construction Task Force AASHTO Subcommittee on Construction held August 8, 1994

² EXP=Experience Rating: E=Extensive M=Moderate L=Limited

USE OF WASTE MATERIALS IN HIGHWAY CONSTRUCTION¹ - Cont'd

| PRODUCT | STATE | RESULT | DATE | EXP ² | COMMENTS |
|--------------------------------|-------|-----------|------|------------------|--|
| Tires | MD | Unknown | | | |
| Tires | MD | Unknown | 1993 | L | Tims used as ballast for drum and cones |
| Tires | MO | Unknown | | | |
| Tires | NC | Good | 1991 | L | Retaining wall |
| Tires | NJ | Unknown | | | Proposed uses |
| Traffic Control Devices | | | | | |
| Glass | MO | Unknown | | | |
| Glass | OR | Good | | | Used in manufact of glass beads for traffic paint |
| Glass | TX | Good | | | Used in producing glass beads |
| Glass | WY | Excellent | | E | Paint beads |
| Metal Structures | MD | Unknown | | | Are used if in good condition or sold to scrap |
| Old Sign Faces | LA | Good | | | Overly use when poss by dotd salv rail is use |
| Old Sign Faces | MD | Unknown | | | Used 70% or sold to a scrap dealer 30% und com bid |
| Old Sign Faces | OK | Good | | | Tubing from signs |
| Plastic | CA | Good | 1991 | L | Delineator and channelizer posts |
| Plastic | CT | Unknown | 1985 | L | Sign blanks |
| Plastic | FL | Good | 1992 | M | Delineator posts sign substrates |
| Plastic | GA | Good | 1990 | L | Barricades and barrels |

¹ Taken from Quality Construction Task Force AASHTO Subcommittee on Construction held August 8, 1994

² EXP=Experience Rating: E=Extensive M=Moderate L=Limited

USE OF WASTE MATERIALS IN HIGHWAY CONSTRUCTION¹ - Cont'd

| PRODUCT | STATE | RESULT | DATE | EXP ² | COMMENTS |
|----------------------|-------|---------|------|------------------|-------------------------------|
| Plastic | GA | Good | | | |
| Plastic | IA | Unknown | 1992 | L | Considered for sign posts |
| Plastic | IL | Good | | E | Barricades |
| Plastic | KS | Good | | | |
| Plastic | MA | Good | 1988 | L | Drums, cones |
| Plastic | MD | Unknown | | | |
| Plastic | ME | Unknown | 1993 | | Barrel (drums) |
| Plastic | MI | Unknown | | L | Experimental delineator posts |
| Plastic | MO | Unknown | | | |
| Plastic | NC | Poor | 1991 | L | Barricades |
| Plastic | NC | Fair | 1992 | L | Delineator posts |
| Plastic | NJ | Good | 1990 | E | Cones |
| Plastic | NY | Good | 1990 | M | |
| Plastic | TN | Unknown | 1990 | | Sign blanks |
| Plastic | TN | Unknown | | L | Delineator posts |
| Plastic | WY | Unknown | 1993 | L | Delineators |
| Tires | IL | Good | | L | For cone weights |
| Traffic Signal Heads | NC | Good | 1992 | L | Refurbished and reused |

¹ Taken from Quality Construction Task Force AASHTO Subcommittee on Construction held August 8, 1994

² EXP=Experience Rating: E=Extensive M=Moderate L=Limited

APPENDIX D

SPECIFICATIONS FROM STATES

California

September 1993

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF PROCUREMENT AND SERVICES
OFFICE OF MATERIEL OPERATIONS
1900 ROYAL OAKS DRIVE
SACRAMENTO, CA 95815
PH: (916) 322-2137

SPECIFICATIONS FOR
PLASTIC BARRICADES

9905-5012-9

I. SCOPE

This specification covers plastic barricades, designed for use on construction and maintenance projects.

The barricade is designed to incorporate reflective sheeting, warning lights, signs or other devices to maximize visibility and safety.

II. GENERAL

A. Materiel

The barricade shall be constructed from plastic materials that are resistant to impact, ultra violet light, ozone, hydrocarbons and shall resist stiffening with age.

All hinge bolts for barricades shall be bound with self locking devices.

B. Workmanship

The barricade shall exhibit good workmanship and shall be free of burns, discoloration, blow holes (other than holes required for molding which shall be plugged or sealed), contamination and other objectionable marks or defects which may affect appearance or serviceability.

C. Manufacturer's Quality Control

No later than ten days prior to fabrication of the barricade, the contractor shall submit a copy of the manufacturer's quality control program to the California Department of Transportation, Division of New Technology, Materials and Research Laboratory for review and approval. The quality control program shall include, but not necessarily be limited to the following items;

1. Basis for acceptance of incoming or raw materials.
2. The type, method and frequency of control testing.
3. The procedure and location for recording quality control data.
4. The procedure and location for conducting the final inspection.
5. Identification of the person responsible for quality control testing and their respective authority within the organization.

D. Marking

The lower cross-members of each barricade shall be marked with the "Caltrans" logo. The logo shall be black in color and a minimum of 2 inches high by 10 inches wide. Each barricade shall also be marked with the month and date of fabrication. All markings shall be die stamped, legibly stamped with permanent black ink or other approved methods. Such identification shall be nonreflective.

III. GENERAL REQUIREMENTS

A. Dimensions

The barricade shall be an A-frame design with a minimum of two horizontal cross-members on each side, one upper cross-member for reflective sheeting, and one lower cross-member located near the base of the legs, suitable for supporting a sand bag. The legs shall have no rigid stay bracing. If the legs are hollow, the contact point on the bottom of the legs shall be a minimum of 1/4-inch in thickness.

IV. Reflective Sheeting

Reflective sheeting shall be an engineer grade type approved by Caltrans with reflective intensity as specified in Section 12-3.06A of the Standard Specifications. The sheeting shall be applied with the stripes sloping downward from upper right to lower left on one side and from upper left to lower right on the other.

A minimum of 270 square inches of reflective sheeting shall be applied to the recessed area of the upper cross-member.

The reflective sheeting shall be permanently bonded to the barricade. The entire area of the orange and white shall be reflectorized with a material that has a smooth, sealed outer surface that will display the same approximate size, shape and color day and night. Bubbles, wrinkles or poor adherence will be cause for rejection.

V. Flasher Attachment

The uppermost portion of the barricade shall provide a means for attaching a 12 volt battery operated bi-directional barricade flashers as described in the Commodity Standard Specification No. 6230-600-0110-0. The flasher unit and related hardware shall be attached independently of the barricade hinge bolts. The flasher shall be secured in such a manner that will prevent the flasher from becoming dislodged from the barricade during impact testing.

VI. Shipment

The barricades shall fold flat and shall be shipped 50 per pallet, covered with black plastic sheeting and securely fastened to the pallet with strapping over the plastic.

VII. Prerequisite to Qualification

Before any manufacturer's barricade can be qualified for bidding, a certified test report shall be submitted. This report shall be completed by an independent testing laboratory which certifies that the barricade complies in all respects with the requirements covered in this specification.

VIII. Sampling and Acceptance

A. Sampling

Barricades may be sampled and tested, prior to shipment, by the California Department of Transportation, Division of New Technology, Materials and Research Laboratory. A sample shall consist of four randomly selected barricades for lot quantities up to and including 2000. For lots larger than 2000, an additional barricade shall be sampled for each additional 1000 barricades or fraction thereof. A resample will consist of twice as many units as originally sampled. Delivered barricades are also subject to inspection, sampling and testing for compliance with these specifications. Material not meeting specifications will be rejected. Discounts will be figured from the date of final release.

B. Acceptance

One hundred percent of the original sampling of each lot of barricades shall comply with all requirements. A resample of the lot will be allowed at the request of the contractor when at least 75 percent of the original sample complies with all requirements. Any resampling will be charged to the contractor at the current prevailing testing rate. Any failure in the resample will be cause for rejection of the entire lot or shipment and further sampling or testing will not be allowed. However, if all resamples pass, the lot may be accepted.

IX. PATENT INDEMNITY: The vendor shall hold the State of California, its officers, agents and employees, harmless from liability of any nature or kind, including costs and expenses, for infringement or use of any copyrighted or uncopyrighted composition, secret process, patented or unpatented invention, article or appliance furnished or used in connection with the contract or purchase order. Bidders may be required to furnish a bond or other indemnification to the State against any and all loss, damage, costs, expenses, claims and liability for patent or copyright infringement.

The upper cross-member shall have an area for reflective sheeting, 12 inches by 24 inches, recessed a minimum of 0.125 inches. The top of the reflective sheeting shall be a minimum of 36 inches above the ground, when the barricade legs are fully extended. When fully extended, the distance between the legs of opposing sides, measured at the bottom, shall be between 36 and 45 inches.

Both sides of the barricade shall provide for positive attachment of either aluminum, fiberglass reinforced plastic or disposable temporary signs, oriented in a diamond or horizontal rectangle position. The attachments shall accommodate diamond shaped signs 24"x 24" and 36"x 36" and horizontal rectangle signs between the sizes of 21"x 9" and 48"x 18".

Barricades shall be constructed with stacking lugs.

B. Color

Barricades shall be a color impregnated white. The yellowness index shall not exceed 12 when tested in accordance with ASTM Designation: D 1925 or E 313. The daylight 45 degree, 0 degree luminous directional reflectance be a minimum of 50 when tested in accordance with ASTM Designation E97.

C. Weight

The barricade weight shall be between twenty and twenty four pounds. If internal ballast is used, the ballast shall be comprised of a non-toxic, freeze-resistant, non-volatile yielding material. All ballast material shall be in the lower 1/4 of the barricade.

D. Physical Properties and Performance

1. Heat Resistance

The barricade shall be sufficiently rigid to resist wilting after conditioning a minimum of 2 hours at 140 degrees F., plus or minus 5 degrees F., in an environmentally controlled chamber. Testing shall be performed in the environmental chamber.

The conditioned barricade shall support a 20# weight, positioned at the midpoint of the upper cross members with the legs fully extended. The weight shall remain in place for a period of 15 minutes. The barricade shall not decrease in height more than 1/2 inch nor shall any leg vary from a straight line more than 1/4 inch.

2. Cold Resistance

The barricade shall be conditioned a minimum of 2 hours at -5 degrees F., plus or minus 3 degrees F., in an environmentally controlled chamber. Testing shall be performed in the environmental chamber.

- a. A steel ball weighing 2 pounds shall be dropped a distance of 5 feet through a virtually frictionless vertical guide to impact the front surface of the barricade. The surface of the barricade being struck shall be oriented in a horizontal position with the legs supported both ends. The leg shall be subjected to 5 impact tests concentrated near the midpoint. Fracturing, cracking, or splitting of the plastic shall constitute failure.

3. Colorfastness

The barricade materials shall be exposed for 1000 hours in Type A Xenon Arc Exposure Apparatus (ASTM G26), with no significant yellowing, darkening or loss of pliability.

4. Impact Resistance

The barricade shall be manufactured from impact resistant materials and designed to minimize damage to impacting vehicles, their occupants and also reduce the risk of injury to pedestrians and workers. The barricade shall maintain its integrity after 3 impacts at 35 MPH. by a conventional passenger vehicle.

E. Replacement Parts

Replacement parts shall be readily available from the manufacturer and easily installed with common hand tools.

Connecticut

Supply And Demand

The supply and demand of recyclable materials and recycled products is a primary factor that, at least for the present, renders legislation of their mandatory use by the DOT on a rigid quota or percentage basis completely unacceptable.

The current volatility of the supply and demand of recycled products and materials is governed primarily by the "fledgling" nature of the recycling industry itself. On the demand side, new uses and products, which either involve or contain recycled materials, are being developed and marketed virtually everyday. Moreover, the supply of recyclable materials is also being influenced everyday by legislation that excludes landfilling as an alternative.

Uncertainty over availability of a given recycled product can only result in increased bid prices. The thought of paying an egregious amount of money for a product that was previously landfilled, simply because the demand for it has been artificially stimulated, does not make much sense. In the transportation community, the time frame between design and actual construction is normally from 6 months to 3 years. The availability of a certain recycled material or product may change significantly over this period due to unforeseen market forces.

Performance

The performance, or so to speak, serviceability of a recycled material or product incorporated into a transportation project could exert an even greater influence on overall cost than supply and demand, even though it is often an intangible or unknown entity in the design stage. Many materials such as aluminum, steel, bituminous concrete and concrete have been recycled into highway structures for many years. Their performance under certain conditions has been well documented and designers would normally have few if any reservations concerning their use. Other recycled materials and products that have recently come on the market would, of course, have no track record of performance. Even though considered equivalent to the conventional material in terms of a certain set of tested physical and chemical properties, the recycled material may, for some unforeseen reason, cause the premature failure or collapse of the entity into which it has been incorporated. The lack of experience with new products or materials should be offset by their limited use in critical areas or moderate use in noncritical areas. Their heavy usage in either case would be inexpedient until such time as they have proven their worthiness.

Specifications

DOT construction and maintenance activities have been, are, and will be governed by a set of "Standard Specifications for Roads, Bridges and Incidental Construction," and "Supplemental Specifications" or by "Special Provisions" where new products or procedures are being incorporated into a job as specialty items.

As previously mentioned, DOT has over the past several years restructured its specifications to include the use of environmentally acceptable waste and waste products generated from the demolition of buildings and structures.

The ability of DOT to absorb other waste materials and recycled-content products that become available will depend to a large degree on the formulation of specifications governing their use. Certain specifications can be readily formulated for items of little or no criticality. For other recycled construction items that assume critical significance, such as safety devices or appurtenances, the DOT would not have the wherewithal to perform the highly sophisticated testing required, and would have to rely on other agencies, e.g., AASHTO, ASTM, OSHA, etc., to develop the appropriate specifications. The point at which the DOT could begin to utilize these critical items would of course depend on the delivery of these specifications.

Effect of Mandatory Use of Waste Materials on Existing Industry

As a frequently deemed necessary means of ensuring markets for waste products and materials, legislative bodies have recently explored the concept of their mandatory use in construction projects, usually as a certain percentage of some total quantity.

Reservations to this form of artificial stimulation of the demand for a product are raised not only by the using agency (in this case, the DOT), but also, and rightly so, by the industry that originally manufactured the virgin product being replaced or by the industry that might be in direct competition for the recycled material, whose use is being mandated elsewhere. An example of the latter would be a mandate that X percent of waste glass be placed in all DOT embankments constructed in the future. If the supply of this glass is insufficient to meet this rigid demand, the price of cullet would be driven up, adversely affecting those in the business of recycling the glass into its original form - a much higher level of use for the cullet.

Subsidies in the form of product or process mandates can, if not applied properly and with flexibility, create chaos within a broad sector of the industry that is being artificially prodded. Mandates could provide the appropriate stimulus if they could be readily adjusted to correspond with the availability or supply of the materials or products, whose use they are intended to stimulate.

Future Recyclability of Recycled Materials

Another consideration in approving the use of recycled products or materials deals more with the long-term than the short-term scenario. Here, the question arises: Does the addition of some recycled substance to an otherwise recyclable material in any way alter the recyclability of that material? For example, the addition of glass or rubber to bituminous pavement may render these heretofore recyclable materials extremely difficult to recycle or totally unrecyclable. There is little if any information on this aspect of recycling, especially the recycling of plastics that are produced with fillers such as wood fibers or sawdust.

Florida

B5360024

When called for
(Blocks - Recycled
Mat'l - No
options)

OFFSET BLOCKS - RECYCLED MATERIALS. () (REV 2-2-93)

SUBARTICLE 536-2.4 (Page 505). The text is deleted and the following substituted:

Offset blocks for this project shall be made from a minimum of 50% recycled plastic waste. Such plastic shall be accumulated from post consumer and industry waste from the State of Florida. The material for these blocks shall have a minimum specific gravity of 0.950. The minimum compressive strength of these blocks in the lateral dimension shall be 1600 psi. The maximum water absorption allowed over the theoretical lifetime of the block shall not exceed 10% by weight. The block attachment shall be by a single bolt. The size tolerance in the direction of the bolt hole shall not be more than $\pm 1/4$ inch. The blocks shall present a neat appearance and have plane surfaces with the exception that an indentation with lip as provided by the manufacturer will be required for the contact surface of blocks installed on steel posts. Unless otherwise noted on the plans, the blocks shall be 6 inches wide, 6 inches deep and 14 inches high for use with steel post and 6 inches wide, 8 inches deep and 14 inches high for use with timber post. Dimensional tolerances shall be $\pm 5/8$ inch in height, $\pm 3/8$ inch in width, and $\pm 3/8$ inch in depth.

The manufacturer shall certify that the material components of completed blocks are resistant to the Formosan termite and the fire ant with no more than 10% infestation expected to occur during the theoretical lifetime. The theoretical lifetime is considered to be at least 20 years.

FLEXIBLE DELINEATOR POST AND REFLECTIVE SHEETING -
GROUND AND SURFACE MOUNTED. () (REV ~~6-12-92~~)

10-1-93

ARTICLE 705-2 (Pages 613 and 614) is expanded as follows:

In addition to the requirements specified in Sections 993 and 994, flexible delineator posts with reflective sheeting will be required at certain locations as shown in the plans.

The flexible delineator post and reflective sheeting shall meet the following requirements:

I. Specific Requirements for Flexible Delineator Posts:

These Specifications define requirements for flexible plastic delineator posts which are designed for pavement and ground mounting.

A. Material: The material shall be made of at least 51% post consumer commingled recycled plastic from Florida which will withstand multiple impacts by full size vehicles and return to a functional delineator position. The material shall be UV (ultraviolet) stabilized and inert to all normal atmospheric elements.

B. Workmanship: The post shall exhibit good workmanship and shall be free of burns, discoloration, contamination, and other objectionable marks or defects which affect appearance or serviceability.

C. Marking: The top of the post on the side away from traffic shall be stamped showing the month and year of fabrication. The numerals shall be at least one-half inch in height and shall be either die stamped or legibly stamped with permanent ink.

D. Dimensions: The post shall have a minimum outside width of three inches and of sufficient length to provide an installed height of 48 inches above the pavement surface.

E. 1. Base Anchoring: The post shall be designed to facilitate a permanent installation which shall resist overturning, twisting and displacement by wind and impact forces. The post shall be designed for anchorage to the existing pavement. Installation shall be in accordance with the manufacturer's instructions.

2. Ground Anchoring: The post shall be designed to facilitate a permanent installation which shall resist overturning, twisting and displacement by wind and impact forces. The post shall be designed for anchorage in the ground. Installation shall be in accordance with the manufacturer's instructions.

F. Color: The post shall be opaque white. The yellowness index shall not exceed 12 when tested in accordance with ASTM D 1925 or ASTM E 313. The daylight 45 Degree, 0 Degree luminous directional reflectance shall be a minimum of 70 when tested in accordance with ASTM E 97.

G. Physical Properties and Performance:

1. Heat Resistance: The post shall be conditioned a minimum of two hours in an oven at approximately 140 Degrees Fahrenheit. The conditioned post shall be capable of straightening itself within 30 seconds when bent 180 Degrees at the midpoint or at the flexible joint for each of four bends. The test on each post shall be completed within two minutes of removal from the oven.

2. Colorfastness: The post shall be exposed for one (1) year near a south Florida seacoast with no significant yellowing or darkening..

3. Impact Resistance: The posts, installed according to manufacturer's recommendations, shall be capable of returning to a vertical position ± 5 Degrees and remain serviceable after receiving 15 vehicle impacts at 55 miles per hour at a 20 Degree angle in both directions. The ambient temperature must be no less than 40 Degrees Fahrenheit.

4. Durability: If a ground mounted post fails or is not serviceable within one (1) year of installation due to normal wear (exposure, vehicle impacts, etc.), the manufacturer shall replace and install at his cost. For surface mounted posts, a six (6) month durability is required.

5. Resistance to Herbicides: The posts shall be sprayed or coated with herbicide(s) currently being used by the Department. After a minimum of 48 hours and then thorough rinsing, the posts shall show no significant change in color, flexibility, or integrity.

II. Reflective Sheeting for Flexible Posts:

A. Description: The reflective sheeting shall be in accordance with Section 994 for Type III-A, III-B, or III-C. The reflective sheeting shall be from the Department's Qualified Products List (QPL) and shall be minimum of 36 square inches (3" x 12") in area applied at the top of the post.

B. Mounting: The reflective sheeting shall be mounted by pressure sensitive adhesive which has adequate strength to prevent loss or disbonding of the sheeting during the life of the post.

The reflective sheeting shall be free from scratches, abrasions, and other physical damage prior to mounting.

III. Material Tests and Certification: Before a manufacturer's post can be placed on the Qualified Products List, the manufacturer shall submit a certified test report and test data, developed by an approved testing laboratory attesting that their marker post complies in all respects with the requirements covered in this specification. Test data submitted by the manufacturer may be subject to verification by suitable tests conducted by the Department.

ARTICLE 705-4 (Page 614) is expanded by the following new pay item:

Item No. 705-71 - Delineator, (Flexible) - each.

RECYCLED PLASTIC FENCE POSTS. (REV 11-29-93)

PAGE 751. The following new Section is inserted after Section 971:

SECTION 972
RECYCLED PLASTIC FENCE POSTS

972-1 Description.

When called for, line posts shall be made from recycled plastic in accordance with these specifications.

The recycled plastic fence line posts shall be one of the products included on the Qualified Products List, current at the time of the products proposal for use. For initial approval, the producer shall furnish to the State Materials Engineer a certified test report from an approved independent test laboratory that shows the material meets all specifications herein. In addition, a one year exposure test in Florida will be required.

972-2 Definitions.

RECYCLED PLASTIC - Those plastics composed of post-consumer material or recovered industrial material only, or both, that may or may not have been subjected to additional processing steps designed to afford products such as or reprocessed or reconstituted plastics.

POST-CONSUMER MATERIALS - Those products generated by a business or consumer that have served their intended end use and that have since been separated or diverted from solid waste for the purpose of collection, recycling, and redistribution.

RECOVERED MATERIAL - Materials and by-products that have been recovered or diverted from solid waste, but not including those materials and by-products generated from, and commonly used within, an original manufacturing process.

972-3 Materials.

The materials used for this fencing shall consist of a minimum of 70 percent by weight of recycled plastic and shall be uniform in composition throughout the length of the post. The post shall contain no more than 20 percent voids over its length. The posts shall be brown, approximating tree bark, to blend with the surroundings and shall have no cracking, chipping, flaking, peeling or splintering in the final product. Only chemicals, including fillers and colorants, designed to inhibit photo degradation, biological/biochemical decomposition, insect infestation, or burning will be permitted to enhance durability.

972-4 Physical Requirements.

972-4.1 Minimum dimensions for line posts:

| | | |
|---------------|---|--|
| Length | - | Eight feet. |
| Cross-section | - | Round post 4.0-inch diameter Square post 4.0-inch by 4.0-inch minimum. |

972-4.2 Straightness:

The straightness of the post shall comply with 954-5 for timber fence posts.

972-4.3 Flexural Strength:

The post shall meet the requirements of the latest edition of the Southern Pine Inspection Bureau's Standard Grading Rules for Southern Pine Lumber for No. 2SR Stress Rated Grade Timber.

972-4.4 Surface Finish:

The post shall exhibit a homogeneous and smooth surface finish and be relatively free of indents or other surface imperfections.

972-5 Predicted Service Life.

In-service posts shall provide a minimum acceptable performance life of 35 years. Conditions to be considered in establishing the minimum acceptable performance life shall include, but are not limited to, the following:

- a. Insect infestations, especially by fire ants and termites causing a weight loss resulting in a loss in strength exceeding ten percent of its original strength.
- b. Rotting or erosion due to soil micro-organisms.
- c. Any cracks, breaks or stress cracks.
- d. Water uptake exceeding ten percent by weight of its original weight over its predicted lifetime.
- e. Non-flammability-retarded susceptibility to burning via appropriate additives.
- f. Straightness as noted in 972-4.2.

The test methods to comply with the above shall be in accordance with FM 5-557.

972-6 Sampling and Delivery.

Recycled plastic fence posts shall be delivered in wrapped bundles of no more than 25 posts. One additional post per thousand or a minimum of one per order shall be included in the order for Department testing.

972-7 Certification.

For recycled plastic fence posts, the manufacturer shall certify that such posts have been tested in accordance with this specification and found to meet the requirements. A certification shall be provided for each lot of a shipment. The manufacturer shall also certify the following:

- a. The source of the recycled plastic waste, including the state (FL, GA, etc.) from which the recycled plastic was obtained, and type of waste (consumer or industrial).
- b. The total percent of recycled plastic in the final product.

Any marked property variations from the original test values for a material or evidence of inadequate field performance of a material will be considered as sufficient proof to remove the material from the Department's Qualified Products Lists.

Florida Method of Test
for

RECYCLED PLASTIC FENCE POSTS

Designation: FM 5-557

1. SCOPE

1.1 This method describes four test protocols for properties considered crucial for the successful performance and durability of the material. The tests include:

- a. Warpage resistance
- b. Water absorption
- c. Insect resistance
- d. Burn susceptibility

2. EQUIPMENT

- 2.1 Balance capable of accuracy to 0.01g.
- 2.2 Vacuum drying oven.
- 2.3 Large drying oven (inside height greater than 813mm (32 in.) capable of achieving 150°C (300°F).
- 2.4 Oven post holder (Figure 1).
- 2.5 Warpage measurement fixture (Figure 2).
- 2.6 Inside-to-inside calipers and digital or other micrometer to measure accurately caliper distances.
- 2.7 Brass wire and engravable labels to identify individual discs.
- 2.8 4 L container and hot plate for boiling water.

3. PROCEDURE

- 3.1 Warpage Resistance: Cut two 813mm (32 in) long sections from two selected posts such that

the ends are perpendicular to the linear axis of the post. Mark the post at 51mm (2 in) intervals end to end. Drive one nail into each end of the post as close to the center as possible. This will provide the post support during warpage measurements. Place the post in the oven in the special holders (see Figure 1). The holder is a 102mm (4 in) square wood box attached to a 305mm (12 in) board. Wooden wedges are used to tightly hold the post vertically in place in the box during heating.

Heat to 130°C (266°F) for up to eight (8) hours or until warping occurs. Place the posts on the warpage test fixture via the v-notches (Figure 2). This device consists of a board 864mm (34 in) long to which are attached two vertical sides 203mm (8in) x 140mm (5.5 in) each containing a 25mm (1 in) v-shaped notch. After supporting the heated posts in the notches via the nails, take measurements every 51mm (2 in) along the post. Use an inside-to-inside caliper placed vertically to measure the distance between board and post. Measure the caliper distance via digital micrometer or other approved device. Convert measurements to percent warpage by the following:

$$\% \text{ Warpage} = \frac{\text{Initial Value} - \text{Final Value}}{\text{Initial Value}} \quad (100)$$

- 3.2 Water Absorption: Cut six post discs with a thickness between 3mm and 6mm (1/8 in to 1/4 in). Clean the disc edges of cuttings. Attach brass engraved labels to identify discs. Connect via wire. Dry samples at 105°C (221°F) to constant weight. Weigh all samples to 0.01g. Insert the samples in the boiling water and continue boiling for 600 minutes. Remove the samples and absorb excess surface moisture by patting on a towel. Reweigh samples.

Calculate water absorption:

$$\% \text{ absorption} = \frac{\text{weight boiling} - \text{weight dry}}{\text{weight dry}} \quad (100)$$

- 3.3 Insect Exposure: Cut six 6mm (0.24 in) thick discs of each post. Clean disc edges of cuttings. Attach brass engraved labels to identify each disc. Dry samples 24 hours in a vacuum oven at 105°C (221°F) to constant weight. Weigh every sample to 0.01g.

In initial tests, the vacuum-dried post discs were tested at the University of Florida Institute of Food and Agriculture Sciences (IFAS) Research and Education Center in Ft. Lauderdale, Florida. However, any recognized insect laboratory will be permitted (eg, USDA labs, Gulfport, MS., Gainesville, Fl.). The materials are then exposed for two (2) weeks to two species of termites, Eastern subterranean (*Reticulitermes flaviper*) and Formosan subterranean (*Captotezures formosanius*). Vacuum dry the exposed samples to constant weight and calculate the percent weight loss.

$$\% \text{ Weight Loss} = \frac{\text{Initial Weight} - \text{Final Weight}}{\text{Initial Weight}} \quad (100)$$

For fire ants, also use a two week exposure and follow the same protocol.

- 3.4 Flammability: Three line fence posts 102mm (4 in) diameter x 2440mm (8 ft) shall be embedded in soil in a row 2.4m (8 feet) but not more than 3.0m (10 feet) apart. If no dry grass is present around the posts, then 102mm (4 in) dry hay shall be placed around the posts and ignited. If grass is present, the grass shall be at least 102mm (4 in) high and shall burn when ignited. Manufacturers shall provide proof of the posts' reduced susceptibility to burning.

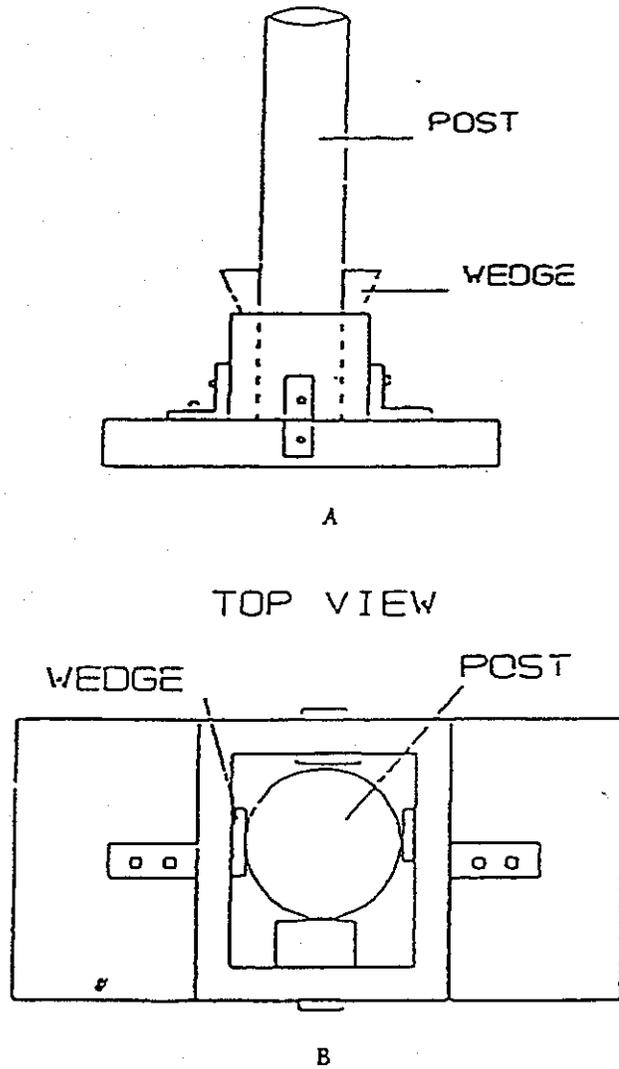


Figure 1: Diagram of stand used to ensure the vertical position of the posts during heat treatment

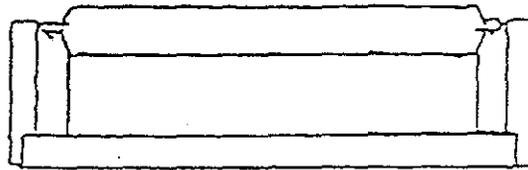
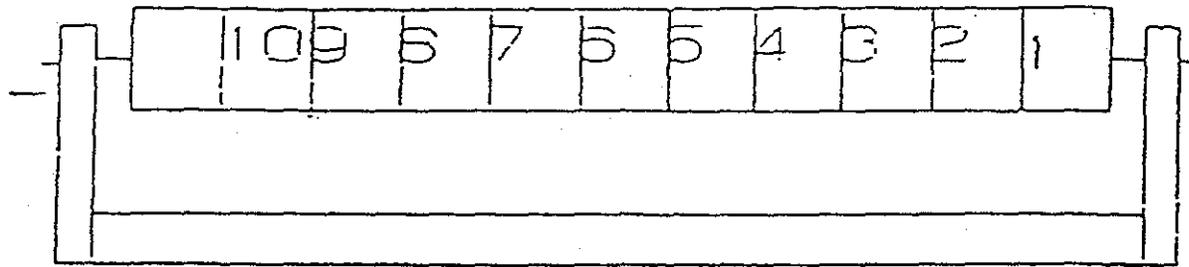


Figure 2 : Diagram of apparatus used to measure warpage with post in place.

Illinois

Quality Standard for Work Zone Traffic Control Devices

1990



Illinois Department
of Transportation
Bureau of Traffic

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ENGINEER OF OPERATIONS
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Quality Standard for
Work Zone Traffic Control Devices

1990

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Introduction

Traffic controls are a necessary part of highway work zones to warn motorists of hazards, advise them of the proper path through the zone, delineate areas where they may not operate, and to separate them from the workers. This is accomplished by the deployment of a system of devices. The success of this system depends on the quality of each device and its placement. Quality could be easily controlled by requiring all devices to be new at the time of a project's initial installation. This, however, would not be in the best interest of controlling costs and reducing waste. This standard does not apply to new devices, but should aid in the determination of the quality of used devices.

The normal temporary use of work zone traffic control devices subjects them to wear that does not occur to permanent devices. Much of this wear may be due to carelessness during the storage, shipping, relocating, and removal of devices which causes much of the deterioration in appearance. Whenever a high percentage of these worn and damaged devices appear on the same project, the general appearance of the work zone leaves much to be desired and could lead to a potential loss of motorist confidence and compliance.

This standard has been developed in an effort to offset the deterioration in appearance of work zones. A determination of quality should be made at several stages: while in storage, during preparation for delivery to the work zone, during initial set-up and periodically during the course of the work. Suppliers and contractors are encouraged to apply this standard prior to delivery of devices to the jobsite. Doing so will minimize Department involvement and reduce costs related to on-site replacement.

Quality Classifications and Requirements

The quality of the work zone devices in this standard has been divided into three categories, acceptable, marginal, and unacceptable.

At the time of the initial set-up or at the time of major stage changes, 100 percent of each type of device (cones, drums, barricades, vertical panels, or signs) shall be acceptable. Throughout the duration of the project, the percentage of acceptable devices may decrease to 75 percent, only as a result of damage and/or deterioration during the course of the work.

Acceptable Devices that meet the quality requirements herein for this classification and all other requirements such as design, size, color, weight, etc. in the plans and specifications, shall be determined to be acceptable for use on highway construction or contract maintenance projects.

Marginal Devices that meet the quality criteria for marginal as described herein may remain in the work zone until they reach 25 percent for that type of device or until it is determined that they have become unacceptable.

Unacceptable Devices in this category shall not be delivered to the jobsite. When found in the work zone, they shall be immediately removed and replaced.

The following photographs, together with the accompanying description, should be used as a guide to determine if the device is acceptable, marginal or unacceptable. A direct comparison of each device to this standard is not required for rejection of devices, however, this standard should be used to resolve disputes. One aid in avoiding potential disputes is to retain samples of devices in each category to supplement the photographs shown in the Evaluation Guides on Pages 5, 9, 12, and 15.

Application of This Standard

The application of this standard provides the means to meet the requirement of Article 107.14, Paragraph 8, of the Standard Specifications for Road and Bridge Construction which states:

Any traffic control device which has become ineffective due to damage or defacement shall be replaced by the Contractor. All traffic control devices shall be kept clean and neat appearing. The Engineer shall be sole judge as to the acceptability of placement and maintenance of all traffic control devices.

The inclusion of the following sample special provision within the contract will make the use of this standard mandatory.

SPECIAL PROVISION

QUALITY STANDARD FOR WORK ZONE DEVICES

Only signs, barricades, vertical panels, drums, and cones that meet the requirements of the Department's "Quality Standard for Work Zone Traffic Control Devices - 1990" shall be used on this project. Copies of this publication are available from the Engineer of Traffic for the contractor's use prior to the initial set-up. Work shall not begin until a determination has been made that the traffic control devices meet the quality required in this standard. Compliance with this requirement will be considered incidental to the contract and no extra compensation will be allowed.

Quality Standard for Signs

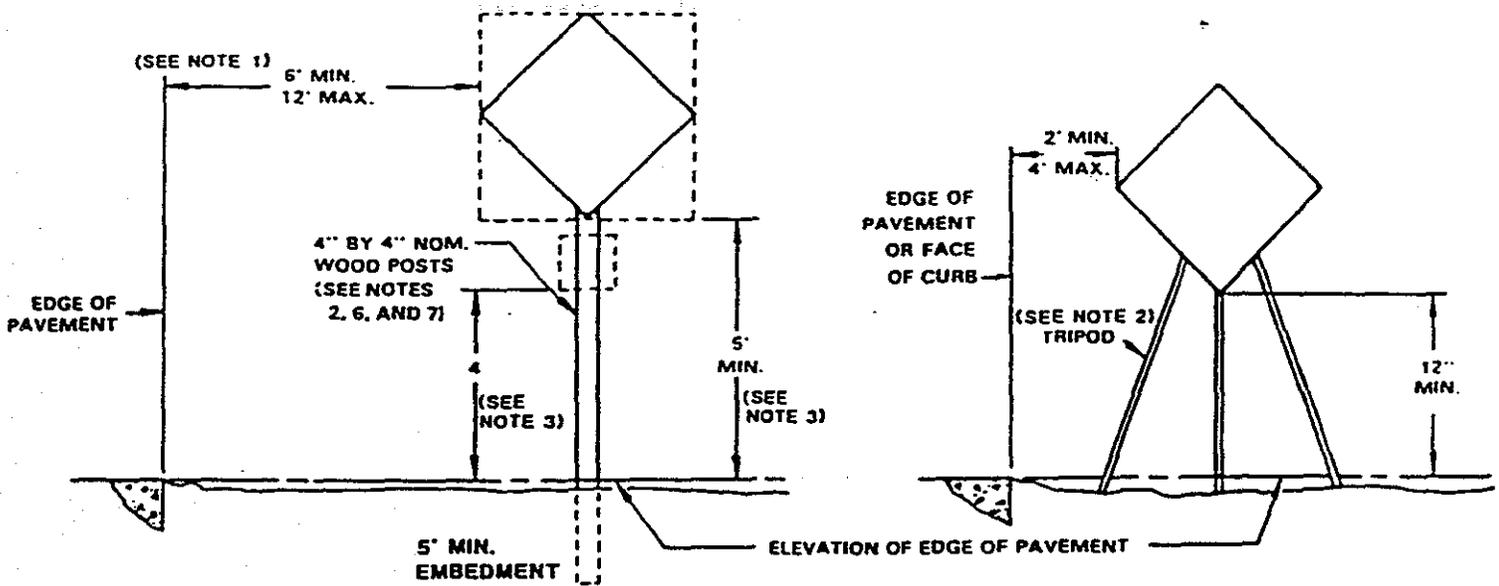
This standard applies to signs in all classifications: warning, regulatory and guide, that are furnished by a supplier, subcontractor, or contractor to be used for traffic control in work zones.

All standard signs shall conform to the requirements of the contract documents which provide the means (through the Manual on Uniform Traffic Control Devices and its supporting manuals) for a contractor or a supplier to furnish signs that are correct in size, shape, color and legend. Special signs, should they be required, are detailed in the plans. Article 718.17 of the Standard Specifications for Road and Bridge Construction provides the requirements for reflectorization. High intensity sheeting generally found on signs appears as a honeycomb pattern containing the silhouette of a worker.

For signs to be used in work zones all of the above must be met to the satisfaction of the Department. In addition, the following portions of Standards 2298 regarding sign erection shall be met. As illustrated, post mounted signs shall be plumb and signs on temporary supports shall be within 20° of a vertical position. Sign installation dimensions must be adhered to. Sign positioning at the work site should be determined based on site conditions. Usually the longitudinal dimensions should be increased if a design location proves to be unsuitable.

The Evaluation Guide on Page 5 is to be used to evaluate the quality of the sign face only. No mention is made of dents, bends or other deformations. If any sign is bent to the extent that its shape is nonstandard or a portion of the sign itself is missing, such as a plywood sign with a broken corner, the sign shall be determined unacceptable.

TYPICAL SIGN INSTALLATIONS



Excerpted from **STANDARD 2298-8**

1. 2 ft. minimum to face of curb.
2. Alternate designs and or materials may be permitted when authorized by the Engineer. All materials shall be substantial and durable.
3. Add 2 ft. if parking exists within 200 ft. in advance of the sign location or if pedestrian movement is likely to occur at any time during the project.
4. Signs on temporary supports shall be within 20° of a vertical position.
5. Weights of concrete, stone, or brick will not be allowed and all weights used to stabilize signs other than sandbags must be rigidly attached to the sign support as close to the ground as possible.
6. Two posts shall be used for signs greater than 16 sq. ft. in area or where the height between the sign and the ground exceeds 7 ft. Bracing no heavier than 2" x 4" wood may be used for added support. Any brace placed parallel to the road shall be sloped down toward approaching traffic.
7. If approved by the Engineer, skids may be used to support signs where posts are impractical. If used, they shall not exceed the structural design of Type III barricades and shall be no greater than 4 ft. in length.

EVALUATION GUIDE - WORK ZONE SIGNS

Acceptable - This is an example of an acceptable sign. It is not new. There are several abrasions on the surface but very little loss of lettering. There has been no touch-up of the lettering. This message is legible at a minimum distance of 400' during the day and 350' with low beam headlights at night.

Letter size for this message on a 48" x 48" sign is 7C.



Marginal - This is an example of a sign with marginal acceptability. Of the many surface abrasions throughout the sign face, many are within the individual letters of the message. The sign surface is free of any residue. Although some color fading is evident, the background color and reflectivity are still apparent at night. This message is legible at a minimum distance of 400' during the day and 300' with low beam headlights at night.



Unacceptable - This is an example of an unacceptable sign. Signs with asphalt splatter or cement slurry of an amount similar to the abrasions that are evident throughout the face of this sign are unacceptable. Some letters have a loss of more than 50 percent. There is noticeable color fading.



Quality Standard for Barricades and Vertical Panels

This standard applies to Type I, II and III barricades and vertical panels that are furnished by a supplier, subcontractor, or contractor for traffic control use in work zones.

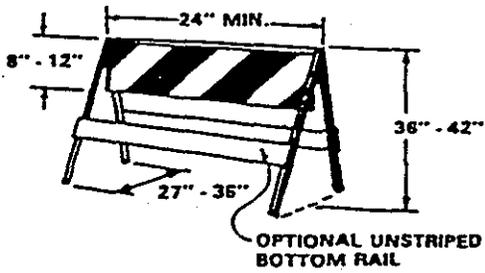
Barricade type and the placement of barricades and vertical panels are specified in the contract documents. Article 718.18 of the Standard Specifications for Road and Bridge Construction provides the requirements for reflectorization.

For barricades and vertical panels to be used in work zones, all of the above requirements shall be met to the satisfaction of the Department. In addition, the following portions of Standard 2299 regarding sizes, shapes, mounting heights, and structural design shall be met. Vertical panels shall be erected and maintained in a vertical position.

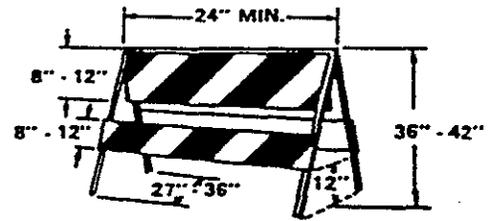
The Evaluation Guide on Page 9 is to be used to evaluate the quality of the reflectorized portion of barricades and vertical panels. In addition to this evaluation, barricade supports must also be evaluated. Any one or any combination of the following will cause a barricade to be unacceptable.

- o Deformation of the support assembly to the extent that the barricade panel is not parallel to the roadway surface.
- o Bent or twisted legs
- o Rusty metal parts
- o Unpainted wooden rails

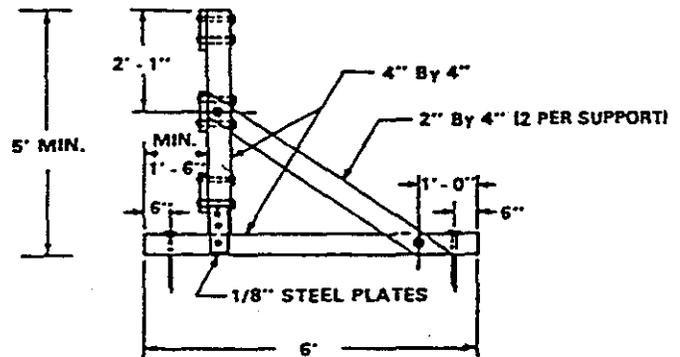
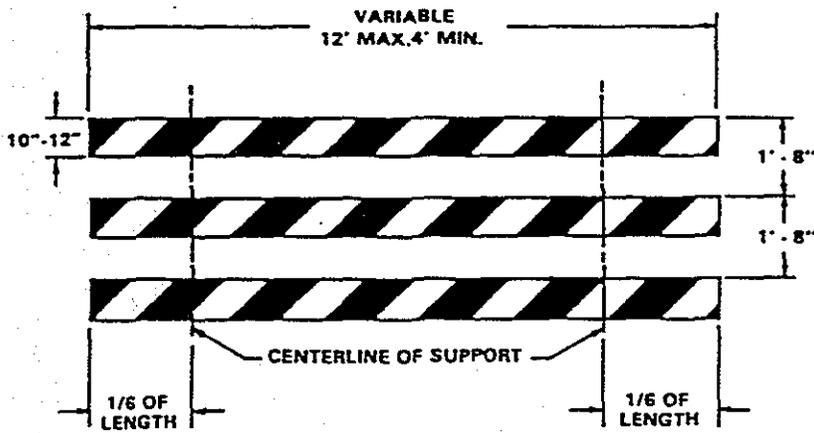
TYPE I BARRICADES



TYPE II BARRICADES

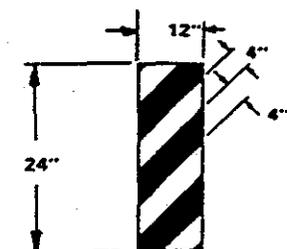


TYPE III BARRICADES

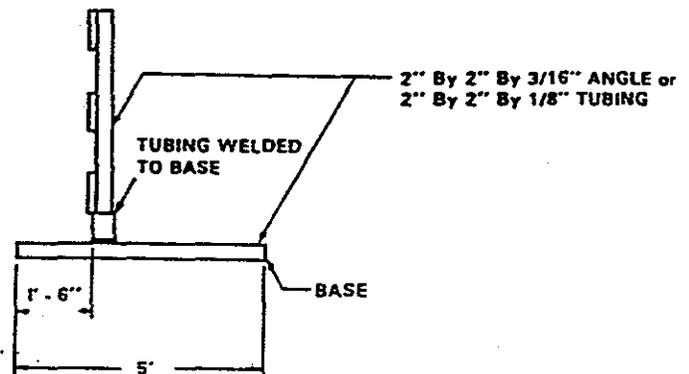


TYPICAL WOOD SUPPORT

VERTICAL PANELS



SEE NOTE 14 FOR SUPPORT OR MOUNTING REQUIREMENTS



D-40 TYPICAL STEEL SUPPORT

* GENERAL NOTES

1. Type I Barricades are intended for use on lower speed roads and shall not be used where normal speeds are greater than 40 MPH unless the reflective area of the upper rail is at least 288 square inches.
2. Type I and Type II Barricades shall not be intermixed within an individual string of barricades.
3. Type III Barricades are intended for road and lane closures and shall not be used for channelization or delineation.
4. All heights shown shall be measured above the pavement surface.
5. Unless otherwise noted, the reflective sheeting used for barricades, drums, and vertical panels shall meet the requirements of Article 718.17 and 718.18 of the Standard Specifications for Road and Bridge Construction.
6. All barricades and vertical panels shall have alternating reflectorized white and reflectorized orange stripes sloping downward at 45° toward the side on which traffic will pass. Barricade stripes shall be 6 inches in width on barricades 36 inches or greater in length and 4 inches in width on barricades less than 36 inches in length. Type I and Type II Barricades shall be striped on both sides. Type III Barricades shall be striped on both sides where traffic approaches from either direction. Vertical panels placed on the outside of curves shall be striped on both sides. The predominant color for other barricade components shall be white or silver, except that unpainted galvanized metal or aluminum components may be used.
8. Frames for Type I and Type II Barricades shall be designed so as to provide a stable support and should be constructed of light weight steel or aluminum angles or tubing, wood, plastic, or rubber and have no rigid stay bracing for "A" frame designs. As Type III Barricades are only used at closures, they may be constructed of heavier materials than Type I or Type II Barricades. However, they should not have any vertical or sloping supports heavier than 4-inch by 4-inch lumber, 2-inch by 2-inch by 1/8-inch steel tubing, or 2-inch by 2-inch by 3/16-inch steel angles.
9. Barricade rails shall be no heavier than 1-inch thick lumber or plywood except for the "sawhorse" design Type I Barricade which may have a rail no heavier than 2-inch thick lumber. Other light weight weather resistant materials such as plastic, fiberglass or sheet aluminum may be used. Barricade rails may be sloping or vertical. Nominal lumber dimensions may be used to satisfy wooden barricade component dimensions.
10. The name and phone number only of an agency, contractor, or supplier may be shown on the nonreflective surface of the face part of a barricade. Such identification shall be in one color and nonreflective with letters not to exceed 1-inch in height.
11. When used, warning lights on barricades, drums, or vertical panels shall be mounted above the top of the device to the side on which traffic will pass and shall not obscure any reflectorized portion of the device.
12. Weights of concrete, stone, or brick will not be allowed and all weights used to stabilize barricades other than sandbags must be rigidly attached to the legs of the barricades as close to the ground as possible. No sandbags will be allowed on the top rail of barricades. Sandbags may be placed on barricade legs, over striped bottom rails not facing traffic, over unstriped bottom rails, or suspended from the barricade rail or frame in such a manner so that the bulk of the sand is at least 18 inches below the top of the barricade. Drums may be weighted internally with just enough sand, water, or other material to provide stability.
14. Vertical panels may be either post mounted, frame supported or attached to the top of a barrier. Post mounted vertical panels shall be firmly attached to light weight wood or metal posts with the top a minimum height of 48 inches above the pavement surface. Frame supported vertical panels shall conform to General Notes 8, 9, 10 and 12 of this Standard and shall only be used where normal speeds are 40 MPH with the top a minimum height of 36 inches above the pavement surface. This device shall only be used as specified on the plans or as directed by the Engineer.

EVALUATION GUIDE - TYPE I, II, OR III
BARRICADE PANELS OR VERTICAL PANELS

Acceptable - This is an example of an acceptable panel. It is not new. There are several abrasions on the surface but very little loss of reflective sheeting. The orange is vivid and the stripes provide contrast which is clearly visible at a minimum distance of 700' with low beam headlights at night.



Marginal - This is an example of a panel with marginal acceptability. There are numerous surface abrasions throughout the panel surface. Some color fading is evident, however, it is free of large areas of residue or missing reflective material. The colors, stripes, and reflectivity are visible and discernible at a minimum distance of 700' with low beam headlights at night.



Unacceptable - This is an example of an unacceptable panel. The surface is marred over a high percentage of the panel area. There is noticeable loss of reflectivity and obvious color fading. Panels with asphalt splatter and/or cement slurry, or any combination of missing and covered reflective material similar in area to that shown here would also make a panel unacceptable.



Quality Standard for Drums

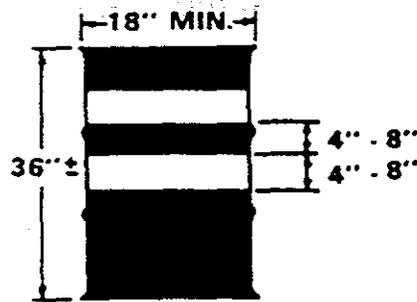
This standard applies to drums that are furnished by a supplier, subcontractor, or contractor for traffic control in work zones.

Drum placement is specified in the contract documents. Article 718.18 of the Standard Specifications for Road and Bridge Construction provides the requirements for reflectorization. High Intensity sheeting is required on drums with lights shown for lane closure tapers and runarounds on Standards 2316, 2317 and 2417. The High Intensity sheeting generally found on drums appears as a honeycomb pattern containing the silhouette of a worker.

Drums used in work zones shall meet the above requirements to the satisfaction of the Department. In addition, the following portion of Standard 2299 shall be met.

The Evaluation Guide on Page 12 is to be used to evaluate the general appearance of drums. In addition, drums that are dented severely enough to affect their overall dimensions or contain fractures that affect their stability or ability to retain the reflective sheeting are unacceptable.

DRUMS



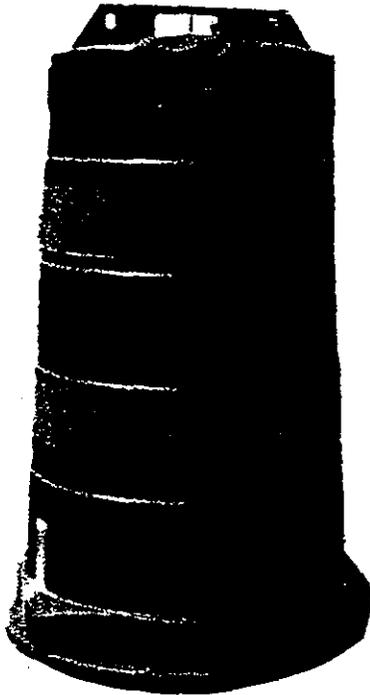
* GENERAL NOTES

4. All heights shown shall be measured above the pavement surface.
5. Unless otherwise noted, the reflective sheeting used for barricades, drums, and vertical panels shall meet the requirements of Article 718.17 and 718.18 of the Standard Specifications for Road and Bridge Construction.
7. Drums shall be non-metallic and have alternating reflectorized orange and reflectorized white horizontal, circumferential stripes 4 inches to 8 inches in width. There shall be at least two orange and at least two white stripes on each drum. If nonreflective spaces are left between the orange and white stripes, they shall be no more than 2 inches in width. All nonreflectorized portions of the drums shall be orange or white. Drums may be slightly conical in shape and may have one or more flat surfaces to minimize rolling when hit.
11. When used, warning lights on drums, shall be mounted above the top of the device to the side on which traffic will pass and shall not obscure any reflectorized portion of the device.
12. Weights of concrete, stone, or brick will not be allowed

. Drums may be weighted internally with just enough sand, water, or other material to provide stability.

* Excerpted from **STANDARD 2299-12** with appropriate deletions.

EVALUATION GUIDE - DRUMS

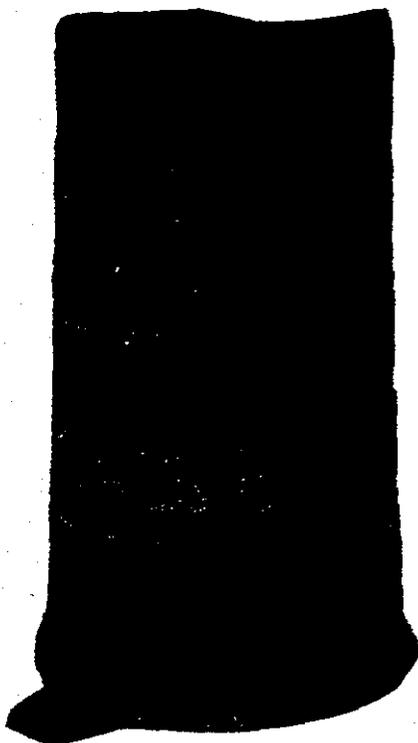


Acceptable - This is an example of an acceptable drum. It is not new. The sheeting has only minor tears and scratches. The dent shown does not seriously reduce the reflectivity.

Marginal - This is an example of a drum with marginal acceptability. The sheeting has numerous tears and scratches, however, it is free of large areas of residue or missing reflective material. The large dent shown reduces the effectiveness of the upper reflective band, however, the drum strength is not reduced.



Unacceptable - This is an example of an unacceptable drum. The large areas of missing reflective material or the fractured upper area makes this drum unacceptable. Drums with asphalt splatter and/or cement slurry, or any combination of missing and covered reflective material, similar in area to the missing reflective material would also make a drum unacceptable.



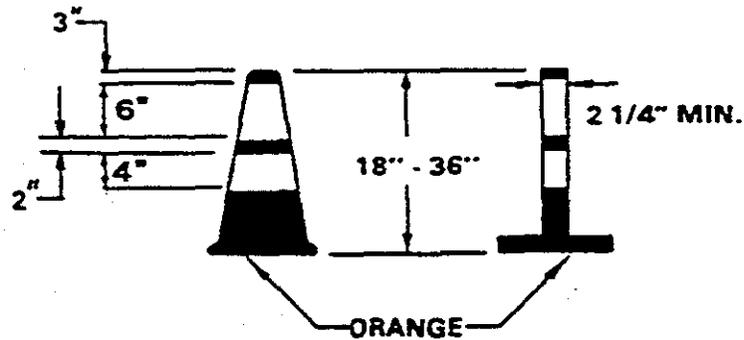
Quality Standard for Cones

This standard applies to cones of 18, 28, and 36-inch heights that are furnished by a supplier, subcontractor, or contractor for traffic control in work zones.

Cone placement and required minimum height is specified in the contract documents. Cones used in work zones shall be orange in color, a minimum height of 18 inches, and shall meet the requirements of the following portion of Standard 2299.

The Evaluation Guide on Page 15 is to be used to evaluate the general appearance of cones. In addition, cones that contain fractures that affect their stability or their ability to maintain their placement are unacceptable.

CONES



* GENERAL NOTES

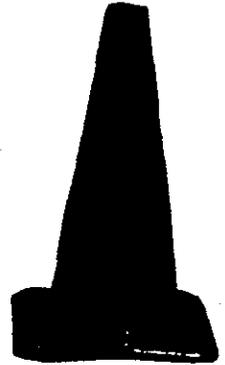
4. All heights shown shall be measured above the pavement surface.

13. Cones shall be constructed of durable material able to withstand abuse by vehicular traffic. Minimum weights shall be 4 pounds for 18 inch, 7 pounds for 28 inch, and 10 pounds for 36 inch cones with a minimum of 60 percent of the total weight in the base. On fully access-controlled facilities, cones shall be a minimum of 28 inches in height. Reflectorized cones shall only be used as specified on the plans or as approved by the Engineer. When used, reflectorized cones shall be a minimum 28 inches in height and shall have two reflective bands; one a minimum of six inches wide placed three inches from the top of the cone and the other a minimum of four inches placed two inches below the six inch band.

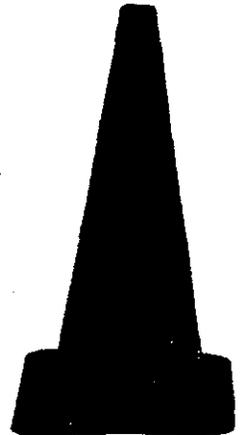
* Excerpted from STANDARD 2299-12

EVALUATION GUIDE - CONES

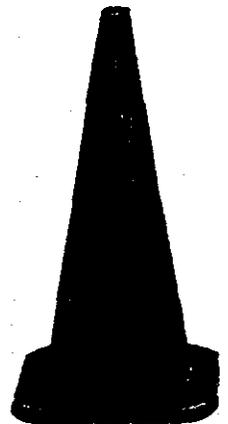
Acceptable - This is an example of an acceptable cone. Although it is not new, the surface is free of punctures and abrasions and the color is bright. The surface may be dirty, but will readily respond to washing.



Marginal - This is an example of a cone with marginal acceptability. The surface is dirty and may not be readily cleaned due to abrasion and discoloration.



Unacceptable - This is an example of an unacceptable cone. The punctures and the large area of staining make this an unlikely candidate for improvement. Large areas of asphalt splatter or cement slurry would also make a cone unacceptable.



State of Illinois
Department of Transportation

SPECIAL PROVISION
FOR
TEMPORARY TRAFFIC CONTROL DEVICES

Effective: February 1, 1995

Temporary traffic control devices shall be according to Section 901 of the Standard Specifications, Standard 2298, and the following:

ARROW BOARDS: Arrow boards shall be according to Article 784.04 of the Standard Specifications. On roads with speeds of 80 km/h (45 mph) and above, Type C units shall be used for all operations 24 hours or more in duration, and Type B units may be used for operations less than 24 hours in duration. Type A, B, or C units may be used for all operations on roads with speeds less than 80 km/h (45 mph). Arrow boards shall not be used to direct passing moves into lanes used by opposing traffic.

TYPICAL SIGN INSTALLATIONS: Alternate designs and or materials may be permitted when authorized by the Engineer. All materials shall be substantial and durable.

Signs on temporary supports shall be within 20 degrees of a vertical position. Heights of concrete, stone, or brick will not be allowed and all weights used to stabilize signs other than sandbags must be rigidly attached to the sign support as close to the ground as possible.

Post mounted signs shall be erected and maintained within 5 degrees of a vertical position. Two posts shall be used for signs greater than 1.5 m² (16 sq. ft.) in area or where the height between the sign and the ground exceeds 2.1 m (7 ft.). Bracing no heavier than 50 x 100 mm (2 x 4 in.) nominal dimensioned wood may be used for added support. Any brace placed parallel to the road shall be sloped down toward approaching traffic.

When approved by the Engineer, skids may be used to support signs where posts are impractical. They shall not exceed the structural design of Type III barricades and shall be no greater than 1.2 m (4 ft.) in length.

FLEXIBLE DELINEATORS: Flexible delineators shall be tubular in shape and designed to bend under repeated impacts and return to an upright position without damage to the impacting vehicle or the tubes. They shall be attached to the pavement with adhesive meeting the recommendations of the delineator manufacturer. The use of studs will not be permitted without the approval of the Engineer.

The tubes shall be orange in color and have 2 reflectorized orange and 2 reflectorized white bands meeting the requirements for signs in Article 784.06 of the Standard Specifications.

The tubes shall be readily removable from the bases to permit field replacement. All missing or severely damaged tubes shall be replaced prior to suspension of work each working day and once each nonworking day on a schedule approved by the Engineer.

TEMPORARY RUMBLE STRIPS: The rumble strip shall be black in color formed of high strength formed polycarbonate. The strip shall be of one-piece construction with 2 channels on the underside for flexibility and proper adhesive bondage. The channels shall be interconnected at four or more locations to permit the bonding material to flow from one channel to the other. There shall be at least 6 weep holes through one or both channels to the upper surface of the strip and at least 4 through the leading edge of the strip to prevent air voids between the strip and the bonding material.

The rumble strip shall be capable of supporting a load of 2700 kg (6000 lbs.). The load capacity shall be determined by placing a strip over the open end of a 25 mm (1 inch) high vertically-positioned hollow metal cylinder having an internal diameter of 75 mm (3 inches) and a wall thickness of 6 mm (1/4 inch). The load shall be applied slowly through a 25 mm (1 inch) diameter by 25 mm (1 inch) high metal rod centered on the top flat portion of the strip. No weep holes shall be in the compression area. Breakage or significant permanent deformation of the strip shall constitute failure. Other similar designs may be used with the approval of the Engineer.

The strips shall be placed snugly against one another and attached to the pavement with an adhesive meeting the recommendations of the rumble strip manufacturer.

CONSTRUCTION SPEED LIMIT SIGN: The sign assembly shall be trailer mounted, conforming to Article 784.05 of the Standard Specifications. All signs shall be reflectorized meeting the requirements of Article 784.06 of the Standard Specifications. The signs may be combined on a single panel.

The flashing lights for the construction speed limit signs shall feature monodirectional amber lenses with reflectors and shall be visible through a range of 120 degrees when viewed facing the sign. The light shall be either strobe, halogen or incandescent lamps, be visible for a minimum distance of 1.6 km (1 mile), and have a minimum flash rate of 40 per minute. A small flashing "on" indicator light shall be provided on the back of the sign visible for 150 m (500 ft.) to provide confirmation to workers the light is operating. The lights shall operate on either full battery power with solar panel charging (capable of maintaining a charged battery level) and 135 amp, 12 volt deep cycle battery(s) or a gasoline or diesel powered generator with a maximum fuel capacity of 95 L (25 gals).

BARRICADES, WING BARRICADES, DRUMS, CONES, VERTICAL PANELS & HIGH LEVEL WARNING DEVICES: Type I and IA Barricades are intended for use on lower speed roads and shall not be used where normal speeds are greater than 70 km/h (40 mph) unless the reflective area of the upper rail is at least 0.18 m² (288 sq. inches). Type I and Type II Barricades shall not be intermixed within an individual string of barricades. Type III Barricades are intended for road and lane closures and shall not be used for channelization or delineation.

The reflective sheeting used for barricades, wing barricades, drums, and vertical panels shall meet the requirements of Article 784.03 and 784.06 of the Standard Specifications. All barricades, wing barricades, and vertical panels shall have alternating reflectorized white and reflectorized orange strips sloping downward at 45 degrees toward the side on which traffic will pass. Barricade stripes shall be 150 mm (6 inches) in width on barricades 900 mm (36 inches) or greater in length and 100 mm (4 inches) in width on barricades less than 900 mm (36 inches) in length. Type I and Type II Barricades shall be striped on both sides. Wing and Type III Barricades shall be striped on both sides where traffic approaches from either direction. Vertical panels placed on the outside of curves shall be striped on both sides. The predominant color for other barricades components shall be white, orange, or silver, except that galvanized metal or aluminum components may be used.

Drums shall be nonmetallic and have alternating reflectorized orange and reflectorized white horizontal, circumferential stripes. There shall be at least 2 orange and at least 2 white stripes on each drum. If nonreflective spaces are left between the orange and white stripes, they shall be no more than 50 mm (2 inches) in width. All nonreflectorized portions of the drums shall be orange. Drums may be slightly conical in shape and may have one or more flat surfaces to minimize rolling when hit.

Frames for Type I or Type II Barricades shall be designed to provide a stable support and should be constructed of light weight steel or aluminum angles or tubing, wood, plastic, or rubber and have no rigid stay bracing for "A" frame designs. Type III Barricades may be constructed of heavier materials than Type I or Type II Barricades.

Barricade and wing barricade rails shall be no heavier than 25 mm (1 inch) thick lumber or plywood except for the sawhorse design Type IA Barricade which may have a rail no heavier than 50 mm (2 inches) thick lumber. Other light weight weather resistant materials such as plastic, fiberglass, or sheet aluminum may be used. The face of the barricade rails may be sloping or vertical. Nominal lumber dimensions may be used to satisfy wooden barricade component dimensions.

For wing barricades, the optional back bracing shown on the wood or metal barricade may be used provided it attaches to the upright no higher than 300 mm (12 inches) above the bottom and provided that if wood is used, the bracing shall be no heavier than 50 x 100 mm (2 x 4 inches) in size. Other light weight designs may be used with the approval of the Engineer.

Only the name and telephone number of the agency, contractor, or supplier shall be shown on the nonretroreflective surface of all channelizing devices. The letters and numbers shall be a nonretroreflective color and not over 50 mm (2 inches) in height.

The lights on wing barricades, barricades, drums, or vertical panels shall be mounted above the top of the device to the side on which traffic will pass and shall not obscure any reflectorized portion of the device.

Weights of concrete, stone, wood, or brick will not be allowed and all weights used to stabilize barricades other than sandbags must be rigidly attached to the legs of the barricades as close to the ground as possible. No sandbags will be allowed on the top rail of barricades. Sandbags may be placed on barricade legs, over striped bottom rails not facing traffic, over unstriped bottom rails, or suspended from the barricade rail or frame in such a manner so that the bulk of the sand is at least 450 mm (18 inches) below the top of the barricade. Drums may be weighted internally with no more than enough sand or water to provide stability, or by other ballast system designed by the drum manufacturer and approved by the Department.

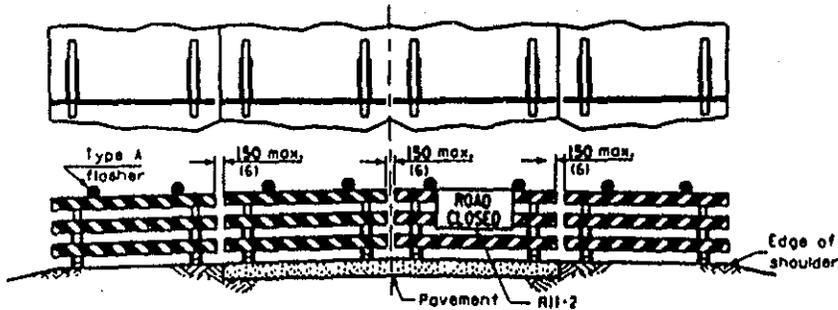
Cones shall be constructed of durable material able to withstand abuse by vehicular traffic. Minimum weights shall be 2 kg (4 lbs.) for 450 mm (18 inches), 3 kg (7 lbs.) for 700 mm (28 inches), and 5 kg (10 lbs.) for 900 mm (36 inches) cones with a minimum of 60 percent of the total weight in the base. Where posted speeds are greater than 70 km/h (40 mph) cones shall be a minimum of 700 mm (28 inches) in height. Reflectorized cones are not required for day light operations, and shall only be used as specified on the plans or as approved by the Engineer. When used, reflectorized cones shall have 2 white reflective bands

Vertical panels may be either post mounted, frame supported or attached to the top of a barrier. Post mounted vertical panels shall be firmly attached to light weight wood or metal posts with the top a minimum height of 1.2 m (4 ft.) above the pavement surface, or as approved by the Engineer. The frame and rail requirements for Type I and Type II barricades shall also apply to frame supported vertical panels. Frame supported vertical panels shall be used only where normal speeds are 70 km/h (40 mph) or less with the top of the panel a minimum of 900 mm (36 inches) above the pavement.

STOP AND SLOW PADDLE. The "STOP" face shall consist of white letters and border on a red reflectorized background. The "SLOW" face shall consist of black letters and border on an orange reflectorized background. All reflective faces shall be fabricated with sheeting meeting the requirement of Article 784.06 of the Standard Specifications. Areas outside sign borders shall be light blue or black. The portion of the staff within the sign face shall match the sign colors. All colors and letters shall meet applicable federal standards.

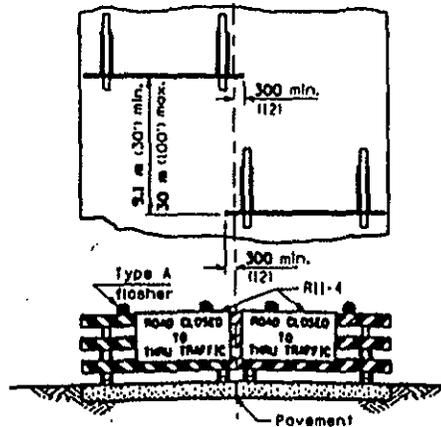
The staff shall consist of 2 sections joined by a coupling located 1.5 m (5 ft.) from the bottom of the staff. Alternate designs may be used when approved by the Engineer.

This sign shall be furnished by the Contractor and shall be used by the flagger in lieu of flags or other signaling devices.



ROAD CLOSED TO ALL TRAFFIC

ReflectORIZED striping may be omitted on the back side of the barricades. The barricades shall be to the edge of the shoulders except when otherwise directed by the Engineer or shown on the detailed construction plans.



ROAD CLOSED TO ALL THRU TRAFFIC

ReflectORIZED striping shall appear on both sides of the barricades. The barricades shall be to the edge of the pavement except when otherwise directed by the Engineer or shown on the detailed construction plans.

ROAD CONSTRUCTION NEXT X MILES **D40 CONSTRUCTION**
 G20-1101-6036 G20-2101-6024

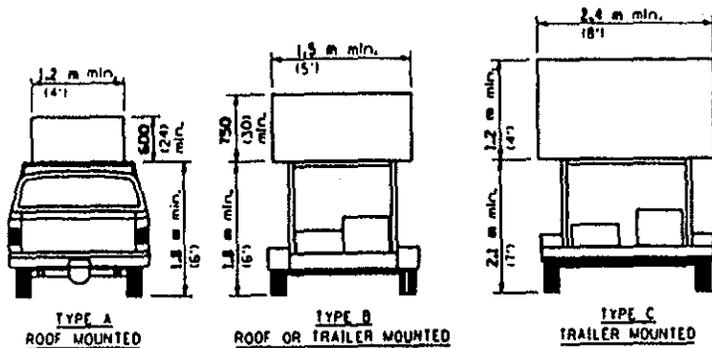
X = Distance to END CONSTRUCTION sign.

ROAD CONSTRUCTION NEXT X MILES sign shall be installed in advance of the first work area at each end of projects over 3200 m (2 miles) in length. The END CONSTRUCTION sign shall be erected near the end of these projects, unless another project is within 3200 m (2 miles) beyond the end of the job.

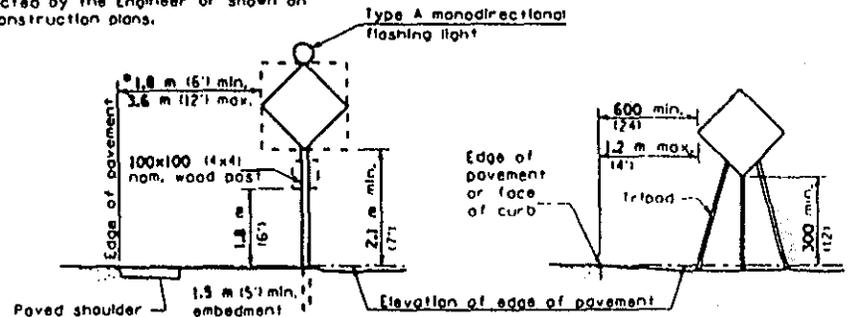
WORK LIMIT SIGNING

D-53

TYPICAL APPLICATIONS OF TYPE III BARRICADES CLOSING A ROAD



ARROW BOARDS



TYPICAL SIGN INSTALLATIONS

GENERAL NOTES

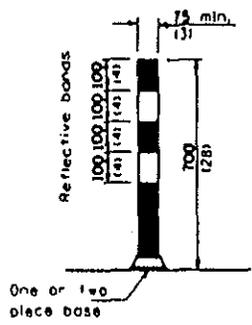
- When curb or paved shoulder are present this dimension shall be 600 (24') to the face of curb or 1.8 m (6') to the outside edge of the paved shoulder.

All heights shown shall be measured above the pavement surface.

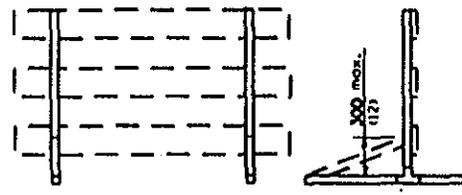
All dimensions are in millimeters (inches) unless otherwise shown.

Illinois Department of Transportation
 APPROVED: [Signature] 1995
 REVIEWED BY: [Signature]
 APPROVED: [Signature] 1995
 CR-1101-6036

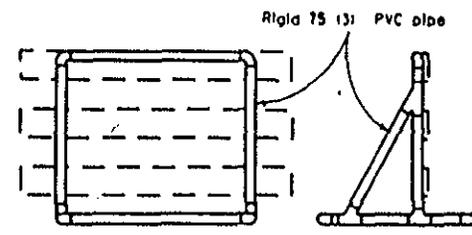
| DATE | REVISIONS | TRAFFIC CONTROL DEVICES (Sheet 1 of 3) | F-6.00 |
|---------|---|---|--------|
| 2-1-95 | Combined 2298, 2299 & 2300. Moved G.M. to Specs. Revised title. | | |
| 6-15-94 | Added lights on Ty. III Bar. Rev. ROAD CONSTRUCTION AHEAD sign. | STANDARD 2298-11 | |



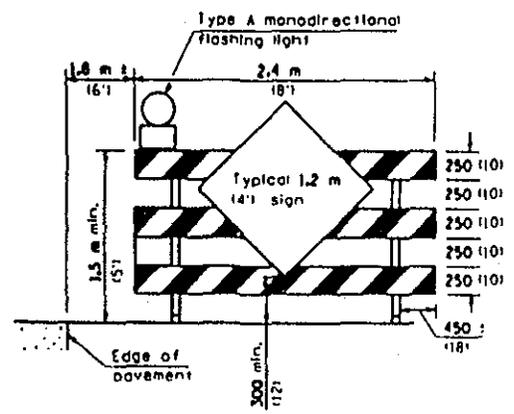
Frames shall be no heavier than:
 100x100 (4x4) (nom. dim.) wood or
 50x50x3 (2x2x3/8) steel tubing or
 50x50x5 (2x2x1/4) steel angles



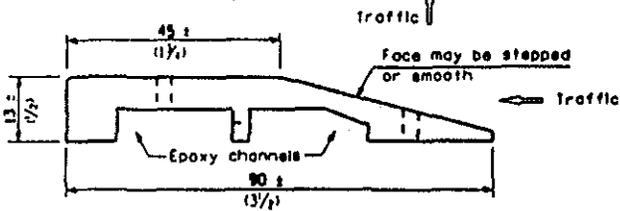
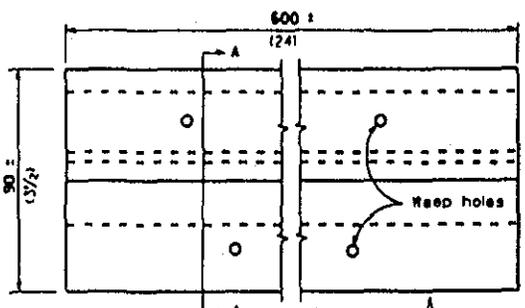
WOOD OR METAL SUPPORTS



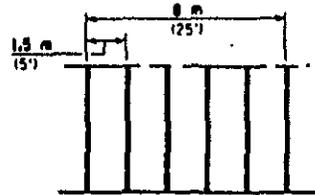
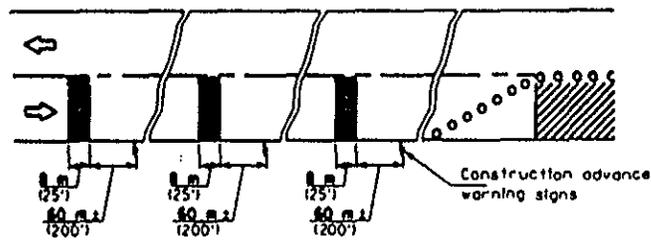
PVC PIPE SUPPORTS
 WING BARRICADES



FLEXIBLE DELINEATORS

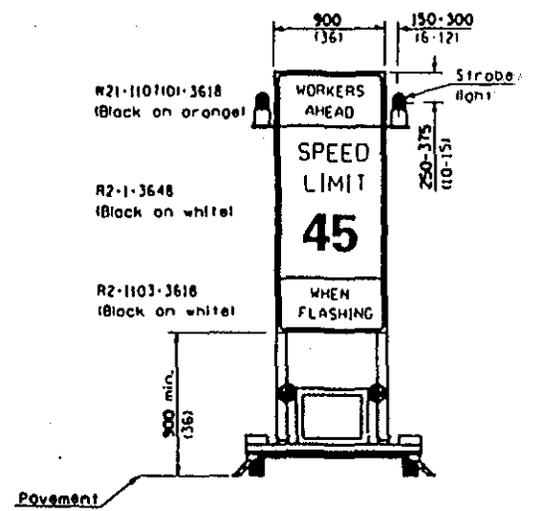


SECTION A - A
 DETAIL OF RUMBLE STRIPS



TYPICAL INSTALLATION

TEMPORARY RUMBLE STRIPS



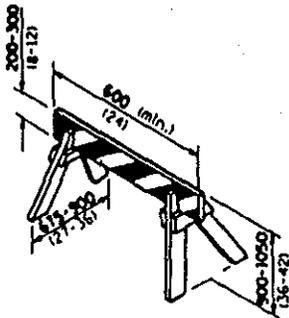
CONSTRUCTION SPEED LIMIT SIGN

All dimensions are in millimeters (inches) unless otherwise shown.

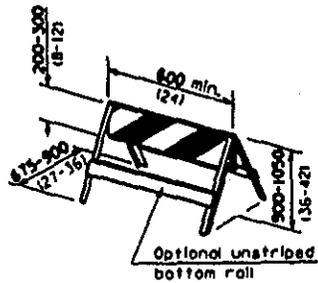
Minnesota Department of Transportation
 Approved: [Signature] 1995
 Prepared by: [Signature]
 Approved by: [Signature] 1995
 Checked by: [Signature]

TRAFFIC CONTROL DEVICES
 (Sheet 2 of 3)
 STANDARD 2298-11

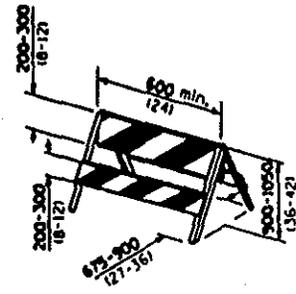
F-6.01



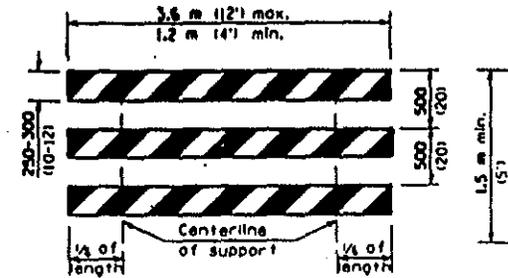
TYPE 1A BARRICADE



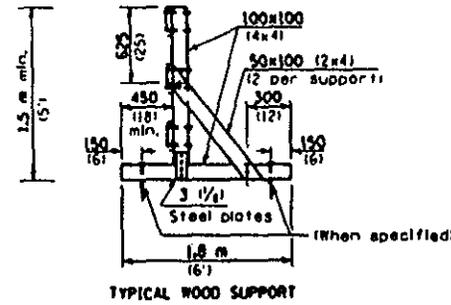
TYPE I BARRICADE



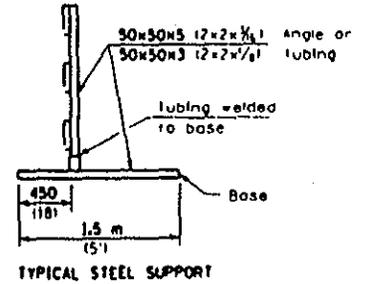
TYPE II BARRICADE



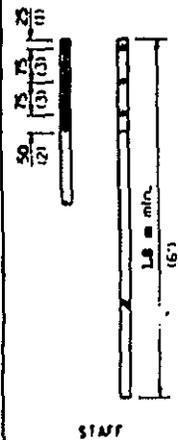
TYPE III BARRICADES



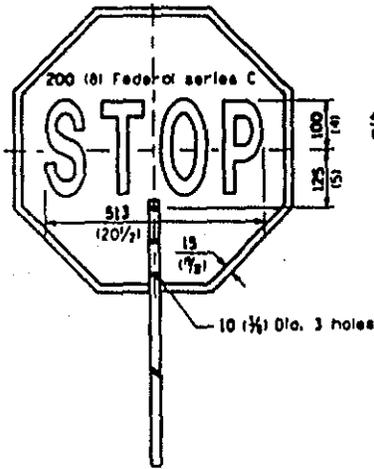
TYPICAL WOOD SUPPORT



TYPICAL STEEL SUPPORT

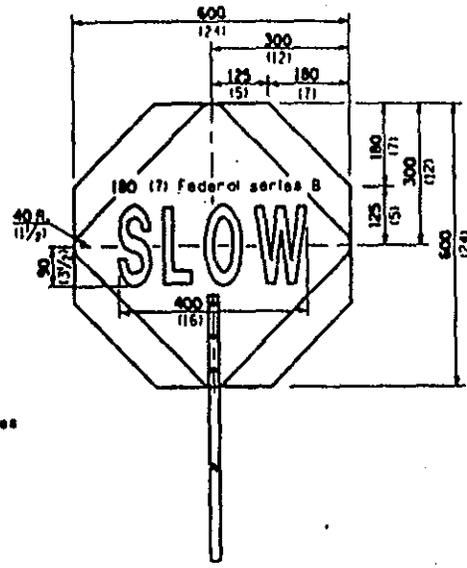


STAFF

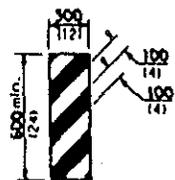


FRONT SIDE

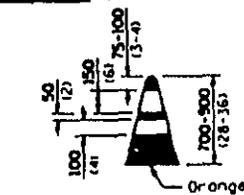
FLAGGER TRAFFIC CONTROL SIGN



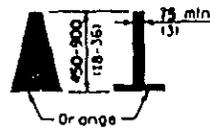
REVERSE SIDE



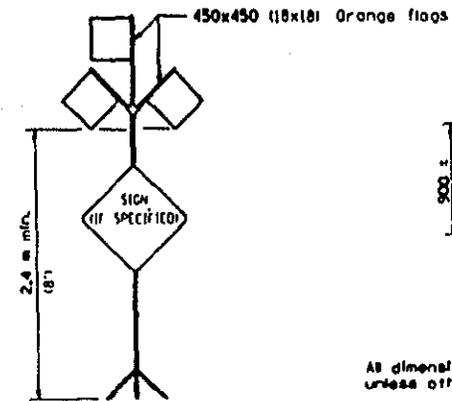
VERTICAL PANELS



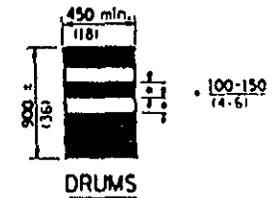
REFLECTORIZED CONES



CONES



HIGH LEVEL WARNING DEVICE



DRUMS

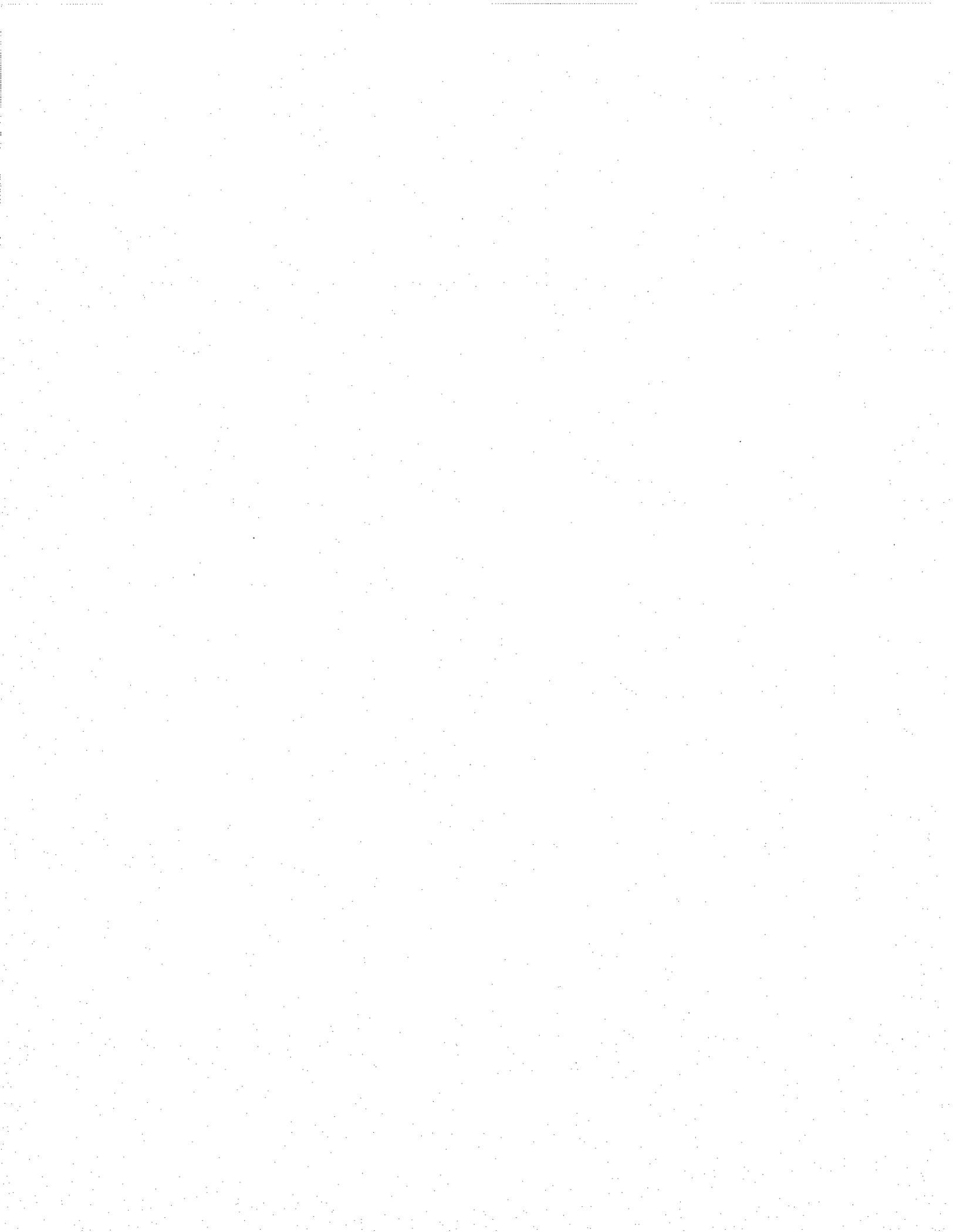
All dimensions are in millimeters (inches) unless otherwise shown.

Illinois Department of Transportation
 Approved: [Signature] 1996
 Director of Operations
 Approved: [Signature] 1996
 Chief of Staff

TRAFFIC CONTROL DEVICES
 (Sheet 3 of 3)
STANDARD 2298-11

F-6.02

North Carolina



PROJECT SPECIAL PROVISION RECYCLED PLASTIC OFFSET BLOCKS (RPOB)

1.1 GENERAL

Recycled plastic offset blocks shall meet the requirements of this special provision. RPOB shall be used in lieu of pressure-treated wood blocks and steel blocks at locations where offset blocks are required.

2.1 MATERIAL

RPOB shall be made from recycled plastic or composite, extruded into a lumber-like product, capable of being worked with conventional carpentry tools. A 6 inch x 8 inch (152 mm x 203 mm) RPOB shall be used as a one-for-one substitute for wood offset blocks on G4 (2W) wood post guardrail systems and a 6 inch x 6 inch (152 mm x 152 mm) as a one-for-one substitute for offset blocks on G4 (1S) steel post guardrail systems at locations where offset blocks are required.

RPOB shall be resistant to termites and fire ants with no more than 10% infestation expected to occur during the theoretical lifetime of the RPOB. The theoretical lifetime is considered to be 20 years. Recycled plastic is defined as plastic material which has been traditionally disposed of in a landfill. RPOB shall be fabricated to the same dimensions as wood offset blocks. Dimensional tolerances shall be $\pm 5/8$ inch in height, $\pm 3/8$ inch in width and $\pm 3/8$ inch in depth.

3.1 TESTING

The Contractor shall certify that the RPOB meets the requirements of National Cooperative Highway Research Program (NCHRP) Reports 230 or 350, respectively. Additionally, the Contractor shall certify that the RPOB is approved by the Federal Highway Administration. The Contractor shall certify that the material composition of the RPOB is recycled plastic.

4.1 CONSTRUCTION METHODS

Construction methods shall meet the requirements of Sections 862-3 and 862-4 of the Standard Specifications. For a list of potential RPOB suppliers contact Melissa Whitmill of the NC DOT Design Services Unit in Raleigh at (919) 250-4128.

5.1 METHOD OF MEASUREMENT

Method of measurement shall meet the requirements of Section 862-5 of the Standard Specifications.

6.1 BASIS OF PAYMENT

Basis of payment shall meet the requirements of Section 862-6 of the Standard Specifications.

8.1301001

TYPE III BARRICADES

The 1990 Standard Specifications shall be revised as follows:

This paragraph to be added to SECTION 1089, Page 801, Article 1089-2, (A):

Barricade support members shall be of recycled and/or recyclable polyvinyl chloride (PVC) pipe, and a minimum of three (3) inches in diameter. Support members shall be joined with, but not glued into, proper size pipe fittings. In addition, supports shall be weather proof and resistant to degradation in sunlight.

FLEXIBLE DELINEATOR POSTS

Description:

The work covered by this provision consists of the erecting of flexible delineator posts with reflectors in accordance with the Plans and this Special Provision.

General:

Flexible delineator posts shall consist of post mounted delineator units capable of clearly reflecting light, under normal atmospheric conditions, from a distance of 1,000 feet, when illuminated by the upper beam of standard automobile head lights. Reflective elements of delineators shall have a minimum dimension of 3 inches x 3 inches. Delineator reflectors are mounted on suitable posts, so that the top of the reflecting head is 4 feet above the near roadway edge. The delineator reflector shall be reflectorized yellow, red, or crystal, as shown in the plans. The delineator and supporting post shall comply with the requirements of the current MUTCD. The flexible delineator post is to be designed to withstand repeated impacts by vehicles and still remain functional.

Physical Requirements:

Materials:

The flexible delineator post shall be of a flexible, recycled and/or recyclable material which shall be resistant to impact, ultraviolet light, ozone, hydrocarbons, and shall resist stiffening with age. The post shall not be seriously affected by exhaust fumes, asphalt or road oils, dirt, vegetation, soil, deicing salts, or any other types of air contamination or materials likely to be encountered in its intended application. The post shall withstand all elements likely to be encountered in its intended applications, including freezing and thawing, rain, snow, hail, abrasion, and physical abuse without serious damage. Upon weathering, no part of the post shall exhibit serious discoloration, checking or cracking, peeling or blistering, swelling, shrinking or distortion, or any other detrimental effects. Weathering shall not cause appreciable strength or flexibility loss as compared to the original condition.

The surface of the post shall be smooth and free from irregularities or defects. It shall not soil excessively, and if soiling does occur, it shall be easily cleaned using detergent and water, or solvent.

The top of the post shall accept, and hold securely, reflectorized sheeting or prismatic plastic type reflectors. If one-piece construction is not used, connections between pieces shall be at least as strong as if constructed of a single piece.

Workmanship:

The delineator post shall exhibit good workmanship and shall be free of burrs, discoloration, surface porosity, contamination, and other objectionable marks or defects which effect appearance or serviceability.

Dimensions:

The delineator post shall have a minimum projected width of 3 inches, facing traffic at the reflector, and shall have a minimum width of 2 1/4 inches for the remainder of the post.

The installed top of the delineator reflecting head shall be a height of 48 inches above the near edge of roadway. The post length shall provide for this with adequate ground penetration for proper performance.

The post shall be straight. Straight is defined as no point along its length any more than 1/2" away from a perfectly straight edge placed longitudinally along any side of the post.

Anchoring:

The delineator post shall be designed for a permanent installation to resist overturning, twisting, and displacement from wind and impact forces.

Colorfastness:

The delineator post shall not significantly yellow or discolor with age, under a typical highway environment.

Temperature:

The delineator post and reflector materials shall be temperature resistant and stable from -20°F to +120°F (-29°C to 49°C). The delineator posts and delineators shall remain fully functional within this temperature range.

Impact Resistance:

The post with delineator must be immediately self-erecting and remain serviceable after withstanding a series of 10 vehicle impacts at temperatures of 0°F (-18°C), or above, at a speed of 35 MPH. The impacts shall be made at an

impact angle of $25^{\circ} \pm 5^{\circ}$ by a typical American-made sedan.

The same post shall also be capable of withstanding a series of 5 vehicle impacts, at an impact angle of $25^{\circ} \pm 5^{\circ}$, at a speed of 55 MPH. The impacting vehicle shall suffer little or no damage during impact. After impacts, the delineator post shall not exhibit excessive fracturing, cracking, breaking, tearing, shattering, or splitting and the delineator shall remain functional. There shall be no serious kinking or creasing as a result of the bending. The post shall be designed to prevent snagging the underbody of the impacting vehicle.

Wind Resistance:

The post shall not bend, warp, or distort excessively, when stored or installed at temperatures up to $+120^{\circ}\text{F}$ (49°C), or installed in wind velocities up to 35 miles per hour. The post shall not deflect, or oscillate excessively, in wind velocities up to 35 miles per hour.

Freezing:

The post shall not be constructed so as to entrap water which might freeze, becoming hazardous on impact, or damaging the post.

Reflective Unit Requirements:

The reflective unit requirements shall meet the requirements of SECTION 1088, Article 1088-1.

The post shall be designed such that reflectors may be installed on both sides of the post, if required. A significant difference between day and night reflective color shall be grounds for rejecting the reflectors.

Availability:

A list of some of the manufacturers and suppliers of flexible delineator posts is available upon request from the Division of Highways.

Material Certification:

Material certification shall meet the requirements of SECTION 1088, Article 1088-6, (C).

Approval:

All materials shall be subject to the approval of the Engineer.

Construction Methods:

Flexible delineator posts with yellow reflectors are required on the left side of divided highways, one-way ramps, loops, or other one-way facilities; crystal reflectors are required on flexible delineator posts on the right side of divided highways, ramps, loops, and all other one-way or two-way facilities.

The flexible delineator posts shall be installed according to the manufacturers recommendations. Catalog cuts showing the proposed delineator posts (with delineators) and method of installation shall be submitted by the Contractor for approval by the Engineer. Approval shall be obtained before any delineator posts are installed.

The quantity of delineator units shown in the plan is an estimate. The Engineer will make a determination of the actual quantity of delineators and posts for the project, and provide the information to the Contractor prior to the Contractor's placing an order for them.

Method of Measurement:

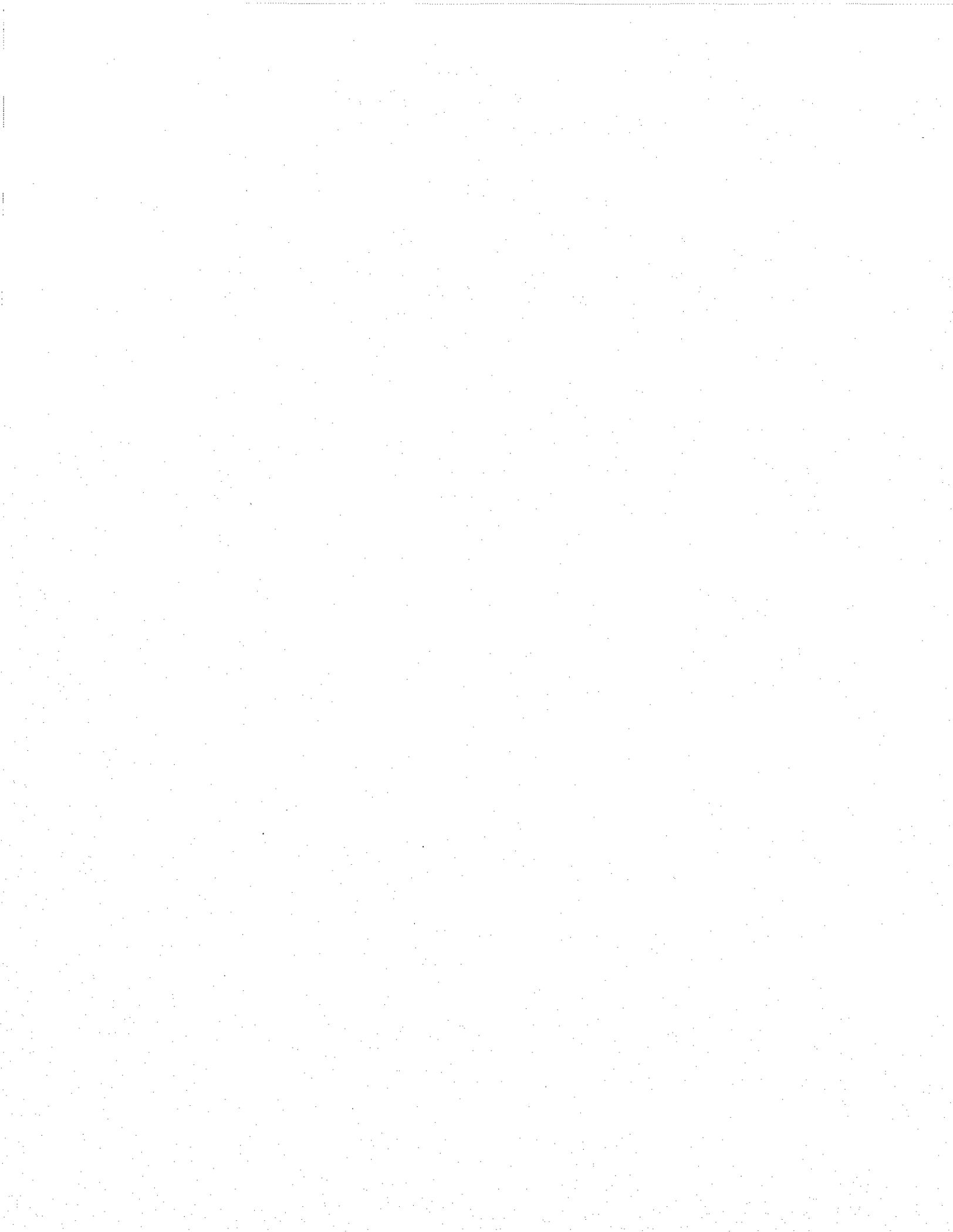
The quantity of flexible delineator posts to be paid for will be the actual number of flexible delineator posts which have been satisfactorily installed and accepted by the Engineer.

Basis of Payment:

The quantity of flexible delineator posts, of each color(s), measured as provided above in "Method of Measurement", will be paid for at the contract unit price each for "FLEXIBLE DELINEATOR POSTS (COLOR)".

Such price and payment will be full compensation for furnishing and installing all flexible delineator posts, reflective sheeting or prismatic plastic type reflectors and all other tools, labor, transportation, materials, equipment and incidentals necessary to complete the work.

New Hampshire



May 12, 1993

S U P P L E M E N T A L S P E C I F I C A T I O N

A M E N D M E N T T O S E C T I O N 6 0 6 — G U A R D R A I L

Amend the following sections of 2.1 to read:

2.1 Wood posts, blocks, and rails.

2.1.1.2 Dimensioned posts and blocks shall be made of timber with a stress grade of 1,200 psi or more for extreme fiber in bending in accordance with AASHTO M 168. All cuts and holes shall be made before preservative treatment.

Add to 2.1

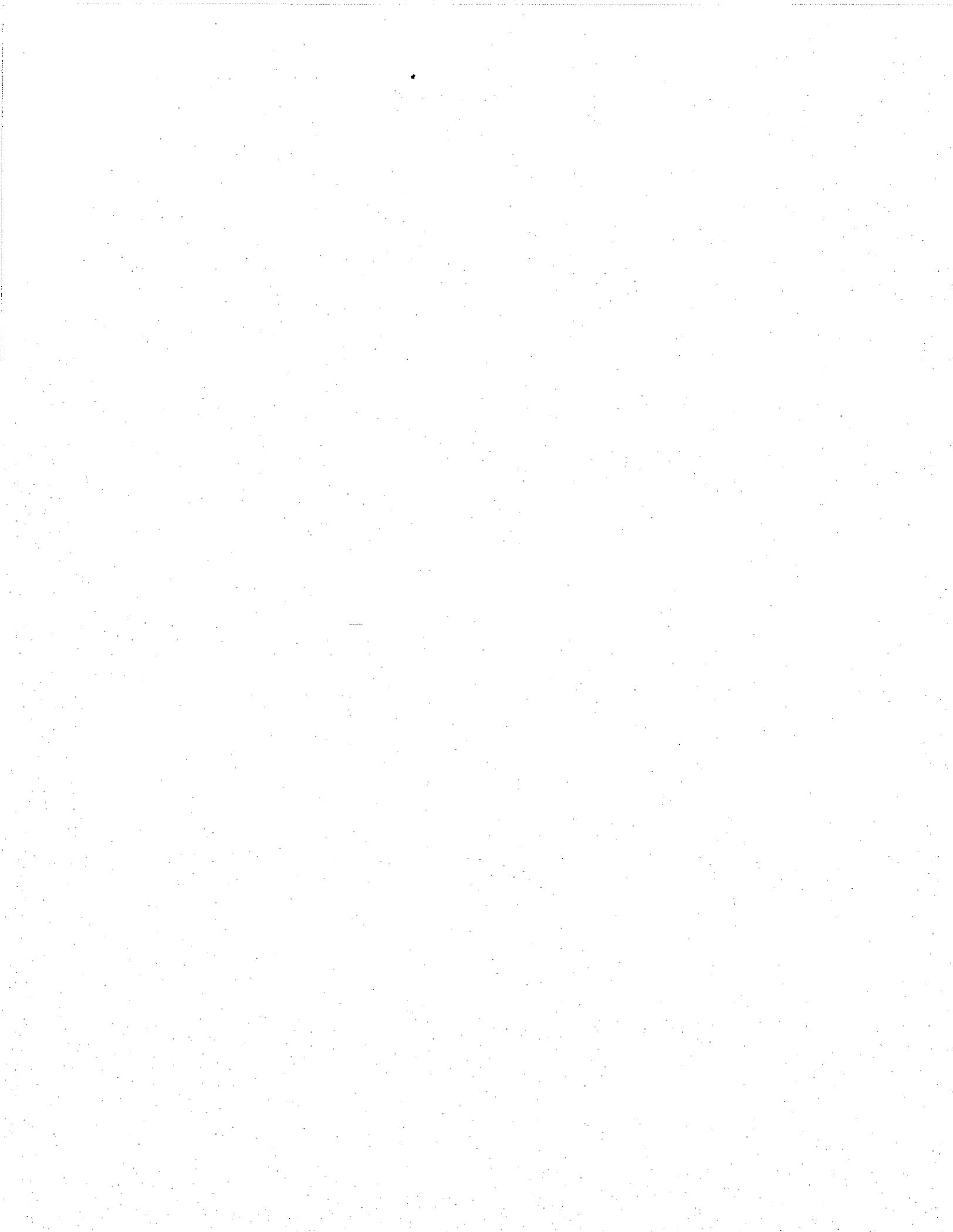
2.1.1.3 Composite material blocks tested and meeting the requirements of the National Cooperative Research Program Report 230, Test 10 and 12; approved by the FHWA, and on the approved products list maintained by Bureau of Materials & Research may be substituted for wood blocks. Composite material shall be approximately 50% recycled thermoplastic and 50% recycled wood fiber extruded into a lumber-like product capable of being worked with conventional woodworking tools. The minimum compressive strength shall be 1,600 psi and minimum specific gravity shall be 0.950. Material shall be approximately similar to the color of pressure treated posts.

Amend the following sections of 2.3 to read:

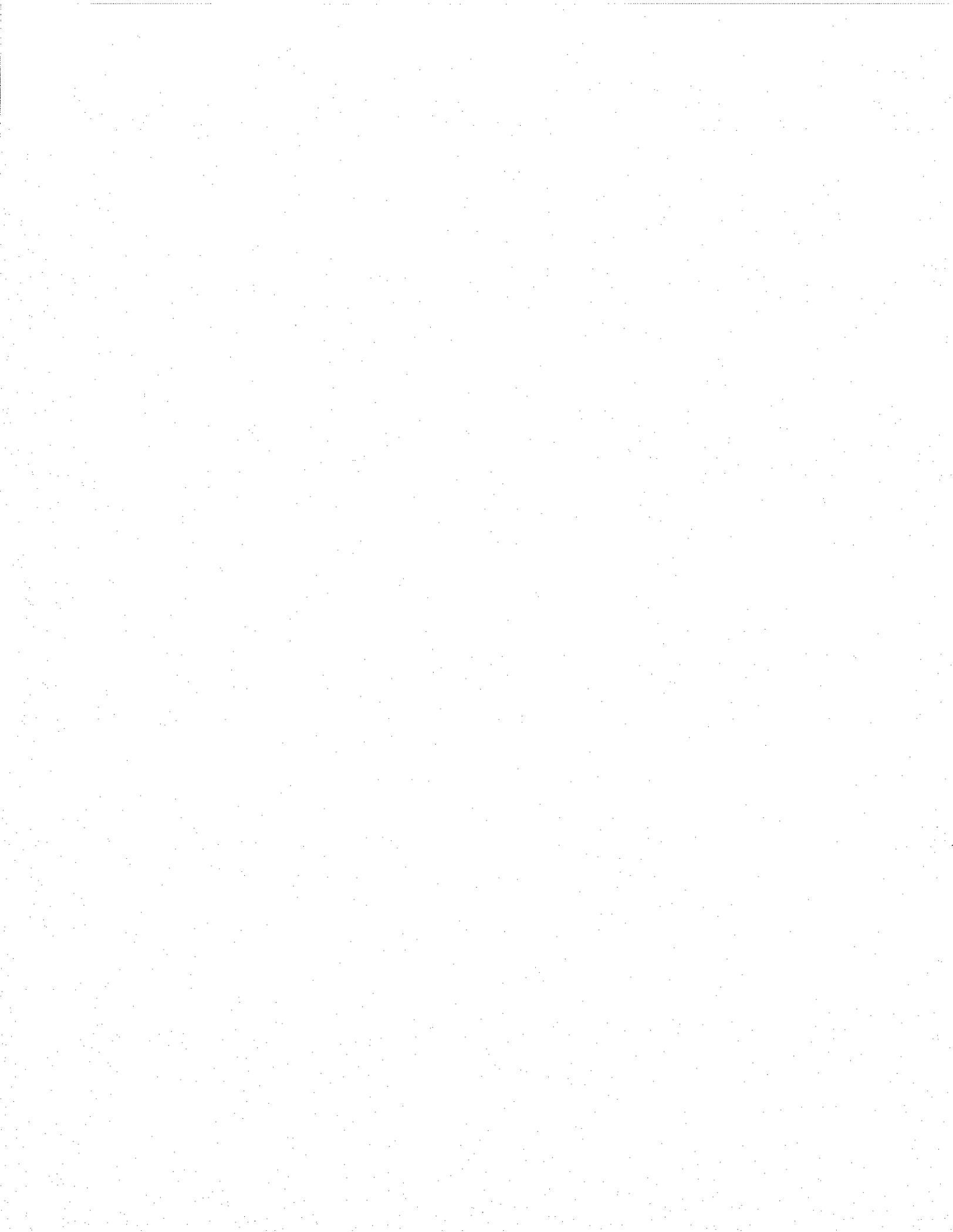
2.3 Structural shape posts and blocks.

2.3.1 Structural shape steel posts and blocks shall conform to ASTM A 36 and shall be galvanized after fabrication to meet the requirements of AASHTO M 111.

2.3.1.1 Composite material blocks in accordance with 2.1.1.3 may be substituted for structural shape steel blocks.



Washington State



Proposed Requirements for Structural Use of Plastic Lumber

Washington State Department of Transportation

Compression Strength Parallel to grain (long dimension) (ASTM D 695)
Compression Strength Perpendicular to grain (short dimension) (ASTM D 695)
Tension strength (ASTM D 638)
Modulus of Elasticity (ASTM D 790)
Modulus of Rupture (ASTM D 790)
Fatigue (ASTM D 671, Flexural Fatigue of Plastics by Constant-Amplitude-of-Force)
Material Safety Data Sheets must be submitted with each product.

The safety factors that manufacturers recommend using with their products for different applications.

The tests listed below are not yet adequately defined by the ASTM for structural applications of plastic lumber. These tests will also require full size testing and temperature variation in testing:

Nail pull out strength (ASTM D1761) and information on making structural connections.

Ultra-Violet (UV) light stability (ASTM G 53, or D 1499, or D 2565) and information on weathering outdoors with a temperature range of -20° F to +120° F. This can be in the form of a graph of exposure time in months and years vs. strength/moduli degradation for all strengths and moduli and color loss or similar format. Plan on 20 year structural life for the material.

Shear strength - ASTM committee 20.95.03 is currently working with Dr. Tom Nosker of Rutgers University developing an acceptable test to determine the structural shear strength of plastic lumber sections. We will follow the lead of the ASTM or other testing agency in this matter. NOTE: ASTM D 732 (Standard Test Method for Shear Strength of Plastics by Punch Tool) is a test of the shear strength of sheet type material. These test results for punching shear are not adequate for structural shear design. ASTM D 143 (Methods of Testing Small Clear Specimens of Timber) is not appropriate for use with plastic lumber.

Tensile, Compressive and Flexural Creep and Creep Rupture (ASTM D 2990). See NOTES 2, 3. Creep in plastics is temperature, time and stress dependent. The wide range of temperatures to which structural applications of plastic lumber will be subjected makes this difficult to predict. We will follow the lead of the ASTM or other testing agency in this matter.

NOTES:

1. All testing should be accomplished by a certified test laboratory using ASTM or other approved testing procedures.
2. Since the strengths and moduli normally change with temperature for plastic lumber these values must be provided at 0° F, room temperature and +120° F. This information should be provided in the form of a graph or a formula relating ambient temperature with all strengths and moduli.
3. The test apparatus and procedures for all ASTM tests listed need to be modified to test full size test specimens. We believe that inclusions, voids, and the possibly non linear material strength in the relatively thick cross sections used in plastic lumber will require full scale testing to be accurate.

APPENDIX E
PRODUCT DATA SHEETS

PRODUCT DATA SHEET

| | | Properties | | | | | | | | |
|-------------------------------------|-------------------------|---------------------------------|------------------------------|------------------------------|---|-------------------|------------------------------------|------------------|-------|---------------------------------------|
| Manufacturer | Product Name | Density (Kg/m ³) | Flexural Modulus (Mpa) | Tensile Strength (Kpa) | Compressive Yield (Kpa) | Shear (Kpa) | Thermal Expansion (mm/mm/°C) | Hardness | Creep | Moisture Resistant (Absorption) |
| Barricades | | | | | | | | | | |
| Aldan Lane Co. | | 913 | 295 | 8,274 | 24,132 | | .000144 | | | |
| Bear-a-Cade | | | | | | | | | | |
| Eaglebrook | Durawood | 692-775 | 675-712 | 14,893- 18,133 | .508 cm: 17,513-17,651 1.02 cm: 20,960-21,512 1.52 cm: 35,370-36,887 | 12,755- 14,134 | .000126 | | | Yes |
| Flasher Flare South East, Inc. | | 941 | | | | | | | | |
| International Plastics Corp. | Type III, Plasticade | | | | | | | | | |
| N.E.W. Plastics Corp. | Perma-Poly | 913-969 | 1,207 | 35,315 | 26,641 | | | 65 | | <.01% |
| Protection Services, Inc. | Type III | | | | | | | | | |
| Recycled Plastics Industry, Inc. | Recyclemaid | 775 | 614-707 | 17,582 | 22,098 | 14,486 | .000126 | Shore D 64/65 | | Yes |
| Recycled Plastic Products, Inc. | Plasti-Rail | 941 | 2,517 | 27,579 | 588,123 | | | | | |
| Utility Plastic Recycling, Inc. | | 969 | | | | | | | | |
| Tipper Tie | | | | | | | | | | |
| WLI | SafetyCade | 26,296 | 1,172 | 24,821 | | | | | | |

PRODUCT DATA SHEET - Cont'd.

| | | Properties | | | | | | | | |
|----------------------------------|-----------------------|------------------------------|------------------------|------------------------|---|---------------|------------------------------|------------------------------|-------|---------------------------------|
| Manufacturer | Product Name | Density (Kg/m ³) | Flexural Modulus (Mpa) | Tensile Strength (Kpa) | Compressive Yield (Kpa) | Shear (Kpa) | Thermal Expansion (mm/mm/°C) | Hardness | Creep | Moisture Resistant (Absorption) |
| Bollards/Protective Posts | | | | | | | | | | |
| Eaglebrook | Durawood | 692-775 | 675-712 | 14,893-18,133 | .508 cm: 17,513-17,651 1.02 cm: 20,960-21,512 1.52 cm: 35,370-36,887 | 12,755-14,134 | .000126 | | | Yes |
| Plastic Pilings, Inc. | | | | | | | | | | |
| Recycled Plastics Man | | | | | | | | | | |
| Refuse/Enviro Systems, Inc. | Hammer's Plastic | 913-969 | | | | | | | | |
| Delineators - Cones | | | | | | | | | | |
| Amazing Recycled Products, Inc. | | | | | | | | | | |
| International Plastics Corp. | Plasticade | | | | | | | | | |
| Utility Plastic Recycling, Inc. | | 969 | | | | | | | | |
| Work Area Protection Corp. | | | | 8,274 | | | | Cone - 80 + 5, Base - 75 ± 5 | | |
| Delineators - Drums | | | | | | | | | | |
| Plastic Safety Systems | Lifeguard Channelizer | 913-941 | 1,413 | 17,926-28,269 | | | | | | |

E-4

PRODUCT DATA SHEET - Cont'd.

| | | Properties | | | | | | | | |
|----------------------------------|---|---------------------------------|------------------------------|------------------------------|-------------------------------|-------------|------------------------------------|----------------------|-------|---------------------------------------|
| Manufacturer | Product Name | Density (Kg/m ³) | Flexural Modulus (Mpa) | Tensile Strength (Kpa) | Compressive Yield (Kpa) | Shear (Kpa) | Thermal Expansion (mm/mm/°C) | Hardness | Creep | Moisture Resistant (Absorption) |
| Delineators - Posts | | | | | | | | | | |
| Aldan Lane Co. | | 913 | 295 | 8,274 | 24,132 | | .000144 | | | |
| Carsonite | Carsonite Survivor Post | | | 17,267 | | | | | | |
| Davidson Plastics Co. (DAPCO) | Flexi-Guide | | | | | | | | | |
| Flexstake, Inc. | HD 400, 600 , Flexible and Type III Bridge Marker, One- Piece, Two- Piece, Bi- Directional Channelization Surface Mounted, Island Marker | | | | | | | | | |
| | Polyflex | 969 | 1,042 | 23,925 | | | | 66 Shore D | | |
| Greenline | One Piece Flexible, Two Piece Highway, Surface Mount, Guardrail | 1,190 | | 30% Min ASTM D638 | | | ASTM D648 | 100 Min ASTM D785 | | (.5% Max) |
| Kennco, Inc. | | | | | | | | | | |
| Plastic Safety Systems | Lifeguard Channelizer, LDPE, HDPE | 913-941 | 1,413 | 17,926- 28,269 | | | | | | |
| Scientific Developments, Inc. | Portable Traffic Delineators | | | | | | | | | |

PRODUCT DATA SHEET - Cont'd.

| | | Properties | | | | | | | | |
|--------------------------------|------------------|------------------------------|------------------------|------------------------|---|-------------|------------------------------|------------|-------|---------------------------------|
| Manufacturer | Product Name | Density (Kg/m ³) | Flexural Modulus (Mpa) | Tensile Strength (Kpa) | Compressive Yield (Kpa) | Shear (Kpa) | Thermal Expansion (mm/mm/°C) | Hardness | Creep | Moisture Resistant (Absorption) |
| Guardrail Offset Blocks | | | | | | | | | | |
| Collins & Aikman | ER ³ | | | 584,676 | 398,517 | | | | | |
| Envirocrete 2000, Inc. | | | | 14,824 | | | | | | |
| Envirowood | | 886-969 | 1,117 | | (101.6 x 101.6 mm): 3,447 (50.8 x 50.8mm): 4,137 | 276 | | | | Yes |
| Jomarico, Inc. (Div. of RPL) | Trimax | 692-803 | 3,103 | 8,618 | 4,757 (perp) 11,997 (parallell) | 5,102 | .000061 | | | Yes |
| Mobil | Trex | 969-996 | 1,207 | 8,977 | 15,244 | 3,068 | .000027 | 1,124 lbs | | 1.7-4.3% |
| Plastic Lumber Company, Inc. | | 913-969 ASTM D792 | .110 | 10,135- 11,721 | 22,063-26,200 | | .00126 ASTM D696 | 65 Shore D | | < .01 % 24 hrs. ASTM D570 |
| Recycled Technology, Inc. | Guardrail | | | | | | | | | |
| Guardrail Posts | | | | | | | | | | |
| Amour Hydro Press, Inc. | Amour Fiber Core | 886-1,246 | 35 | | 35,301 ¹ | | | | | |
| Envirocrete 2000, Inc. | | | | 14,824 | | | | | | |

E-6

¹ Allowable

PRODUCT DATA SHEET - Cont'd.

| | | Properties | | | | | | | | |
|------------------------------|----------------------------------|------------------------------|------------------------|-------------------------------|-----------------------------------|-------------------|------------------------------|------------|-------|---------------------------------|
| Manufacturer | Product Name | Density (Kg/m ³) | Flexural Modulus (Mpa) | Tensile Strength (Kpa) | Compressive Yield (Kpa) | Shear (Kpa) | Thermal Expansion (mm/mm/°C) | Hardness | Creep | Moisture Resistant (Absorption) |
| HwyCom, Inc. | Fiberglass Guardrail Post | | | | | | | | | |
| Jomarico, Inc. (Div. of RPL) | Trimax | 692-803 | 3,103 | 8,618 | 4,757 (perp) 11,997 (parallel) | 5,102 | .000061 | | | Yes |
| Mobil | Trex | 969-996 | 1,207 | 8,977 | 15,244 | 3,068 | .000027 | 1,124 lbs | | 1.7-4.3% |
| Plastic Pilings, Inc. | | | | | | | | | | |
| Recycled Technology, Inc. | Guardrail | | | | | | | | | |
| Xymax | | | 1,896 | | 22,063 | | | | | |
| Sign Blanks | | | | | | | | | | |
| Aldan Lane Co. | | 913 | 295 | 8,274 | 24,132 | | .000144 | | | |
| Composite Technologies | PFM Blanks | 1,578 | 8,550 | 55,158 | 106,869 | | .000032 | | | |
| Flexstake, Inc. | Polyflex | 969 | 1,042 | 23,925 | | | | 66 Shore D | | |
| International Plastics | DuraPlate | | 2,413 | 61,363- 67,569 | 68,948 | 41,369- 68,948 | .000068 | | | |
| Plastic Lumber Company, Inc. | Simple Signs | 913-969 ASTM D792 | .110 | 10,135- 11,721 | 22,063-26,200 | | .00126 ASTM D696 | 65 Shore D | | <.01% 24 hrs. ASTM D570 |
| SABI | 3004-H38, 3016-H38, 3105-H191 | | | 262,001 268,896 213,738 | 213,738 213,738 193,053 | | | | | |

PRODUCT DATA SHEET - Cont'd.

| | | Properties | | | | | | | | |
|----------------------------------|-----------------------|---------------------------------|------------------------------|------------------------------|---|-------------------|------------------------------------|-----------|-------|---------------------------------------|
| Manufacturer | Product Name | Density (Kg/m ³) | Flexural Modulus (Mpa) | Tensile Strength (Kpa) | Compressive Yield (Kpa) | Shear (Kpa) | Thermal Expansion (mm/mm/°C) | Hardness | Creep | Moisture Resistant (Absorption) |
| Sign Supports | | | | | | | | | | |
| Aeolian | | 692-775 | | 14,479- 17,926 | .508 cm: 17,237-17,926 1.02 cm: 20,684-21,374 1.52 cm: 35,163-36,542 | | .000126 | | | |
| Eaglebrook | Durawood | 692-775 | 675-712 | 14,893- 18,133 | .508 cm: 17,513-17,651 1.02 cm: 20,960-21,512 1.52 cm: 35,370-36,887 | 12,755- 14,134 | .000126 | | | Yes |
| Envirocrete 2000, Inc. | | | | 14,824 | | | | | | |
| Environmental Recycling, Inc. | | 941 | 1,034 | 22,063 | 20,684 | | .000085 | | | Yes |
| Envirowood | | 886-969 | 1,117 | | (101.6 x 101.6 mm): 3,447 (50.8 x 50.8mm): 4,137 | 276 | | | | Yes |
| Jomarico, Inc. (Div. of RPL) | Trimax | 692-803 | 3,103 | 8,618 | 4,757 (perp) 11,997 (parallell) | 5,102 | .000061 | | | Yes |
| MetroPlastic | DuraPost/ DuraBord | 775-855 | 455-752 | | 18,361-23,304 | | | | | |
| Mobil | Trex | 969-996 | 1,207 | 8,977 | 15,244 | 3,068 | .000027 | 1,124 lbs | | 1.7-4.3% |