Promoting Sustainability through Educating Undergraduate Students on Applications of Waste Tire Products in Civil Engineering and Transportation

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ABSTRACT

Waste tires can occupy valuable landfill space. Waste tires in stockpiles, legally or illegally dumped, may produce tire fires that are very hard to put out, and cause significant public health and environmental concerns. There are approximately 300 million waste tires generated each year in the United States. Today, most of the tires can be reutilized as tire derived fuels, in civil engineering applications, or as rubberized asphalt in roadway pavements. However, there are many challenges that prevent the successful and sustainable uses of waste tires in these areas. To overcome these challenges and to promote the sustainable uses of waste tires in civil and transportation engineering, teaching materials were developed to educate the undergraduate students who are the future engineers. To make the education program more effective and to teach more students, a series of lecture materials in more than ten different courses, instead of one elective waste management class, were developed. These lectures cover topics from freshman level such as introduction to civil engineering design, through the junior level such as strength of materials, materials testing, and finally to senior level classes such as soil mechanics, foundations, environmental, concrete, pavement materials and transportation. Each lecture developed has been taught in a real class environment at a university. The outcome has shown that the lectures greatly enhanced the students' knowledge on using waste tires in civil engineering applications and transportation. The educational process can be used as a template to promote the sustainable usage of other recycle materials.

Key words: waste tires, sustainability, recycling, education.

INTRODUCTION

Each year, about 300 million waste tires are generated in the United States. Some of these tires contribute to stockpiles both legally and illegally. Waste tires in stockpiles can pose significant public health and environmental issues. The curved shape of a tire can retain rain water to create an ideal breeding ground for mosquitoes and rodents, which can disseminate diseases, such as the West Nile virus. Tires are good heat retention materials and placed in stockpiles can ignite resulting in tire fires that are difficult to extinguish. One passenger car equivalent tire is estimated to release the same amount of energy contained in over two gallons of oil (*1*). Although the EPA does not consider scrap tires as a form of hazardous waste, tire fires release many hazardous compounds which pollute the air, soil and water (*2*). Public agencies and private companies have spent millions of dollars cleaning up tire fires across the country.

Therefore, many states have issued stockpile abatement programs, which helped to reduce the number of tires in stockpiles significantly. In 1994, it was estimated about 700 to 800 million waste tires were in stockpiles. Today, the numbers of waste tires in stockpiles have been reduced to less than 200 millions.

Based on the report by the Rubber Manufacturing Association (RMA) (*3*), the recycling and reusing of waste tires in the United States has improved significantly. For example, in 2005, about 78 percent of total number of waste tires were recycled and re-utilized, while only 10 percent of total waste tires were reused in 1990. Waste tires can be consumed in a variety of ways. The major markets are tire derived fuel, civil engineering applications, and ground rubber applications including rubberized asphalt. Tire derived fuels accounted for 52 percent of scrap tires in the U.S market in 2005, which consumed about 155 million tires. The civil engineering market consumed more than 49 million tires in 2005, which is the second largest market. Ground rubber used in rubberized asphalt consumed about 12 percent of the total tires. However, about 10 percent of waste tires generated each year still goes to landfills, which means these tires are wasted and occupy valuable spaces.

Civil engineering applications include tire derived aggregates used in: road construction, landfill applications, septic tanks, gas and leachate collection systems, retaining wall backfill, lightweight embankment fill, vibration and sound control. Tires have beneficial properties in these applications (*4*). Tire Derived Aggregates (TDA), which are shredded tires, are light weight, have very good thermal insulation, high permeability, and good vibration damping.

The ground rubber or crumb rubber market has been growing over the past several years. Asphalt rubber or rubberized asphalt is the largest single market for ground rubber. According to the Rubber Pavement Association (*5*), since 1990 more than 30 million tires have been used annually in asphalt rubber pavement, which equate to 40 times the distance from the earth to the moon when stacked on one another. Crumb rubber can beneficially modify the physical performance of asphalt concrete. It has been demonstrated that, when used properly, rubberized asphalt can increase pavement service life, reduce maintenance, lower life cycle costs, reduce road noise, increase drainage, increase safety, and improve the environment.

The applications of waste tires in civil and transportation engineering are sometimes complex and challenging. There have been flawed practices in the past, such as embankment fires in

Washington State and in Colorado due to the internal heating of TDA back in 1995 (*6*). People need to be educated in order to know how to use these special construction products. To prompt the sustainability of using waste tires in civil and transportation engineering, the major goal of this study is to develop appropriate university curricula which can be used to educate future engineers.

OBJECTIVES

The objectives of this research are to:

- Synthesize the knowledge of utilizing waste tires in civil and transportation engineering applications through literature review;
- Develop effective teaching materials to educate university students how to use waste tire products in civil and transportation engineering applications; and
- Promote sustainability of using waste tires through university education.

CHALLENGES

Using recycled materials in real applications faces many challenges and barriers, especially, if the knowledge of how to use the recycled materials such as waste tires has not been well disseminated. The challenges can involve many different people including the public, engineers, contractors, and educators.

Challenges for the Public

Not all of the public understand sustainability and utilizing waste tires as recycled products. Some of the public pay think 'It is a waste material and why should we spend time on it', While some people lack the knowledge that waste tires can be reutilized in many beneficial ways.

Challenges for Engineers

Engineers may face challenges when trying to use waste tires as an alternative for a specific application. They may not have adequate knowledge about the physical properties, long term performance, design guidelines, and construction specifications. A complete manual or guidelines may not have been available to them in the past. A lack of guidelines may make engineers feel uncomfortable about using waste tire products even though they have been informed of the benefits. Engineers don't like to take risks and could lose their licenses if a project goes wrong because of their design or analysis.

Environmental Issues

People need to be aware of the environmental aspects of using waste tire products. The chemical composition of waste tires is complex including metals, volatiles, fibers, and compounds. When a waste tire project is proposed, it will face environmental regulations that may not be well established for such applications. An environmental regulator may not want to take the risk of using waste tires if extensive environmental impact studies have not taken place.

Challenges for Contractors

Unlike construction with conventional materials, using waste tires may need to incorporate new procedures and equipment. The final cost estimates for material supply may be uncertain to some contractors. They may not have enough experience to deal with unexpected situations and they don’t want to take all these risks to bid on waste tire projects.

Challenges for Educators

Teaching materials may not be readily available to professors or instructors. They may not know how to incorporate the teaching of waste tires or recycled material into their curricula, which usually deal with conventional construction materials such as concrete, steel, wood, rocks, and soils.

To overcome the above challenges, one of the most important approaches is disseminating the knowledge through education. A significant amount of research and real world case studies have been done regarding the applications of waste tire products in civil engineering and transportation. Guidelines and standards have been developed for design and construction of certain applications. However, the curricula for educating university students, the future engineers and officials, are not readily available. Therefore, this study is to develop appropriate teaching materials for university undergraduate education.

APPROACH AND PROPOSED CURRICULA

Utilizing waste tires in civil engineering and transportation applications is a multi-disciplinary subject. No single class currently available in civil engineering can cover all the aspects of it. At the beginning of the project we compared two different approaches: (a) developing only one new class to include all aspects of waste tire applications, and (b) add teaching modules to different levels and related civil engineering classes. We found that the second method is more flexible and can reach more students. Each teaching module we created has PowerPoint presentations, assignments, and reference materials and is designed to be easy for instructors to add these modules into their curricula.

Therefore, we have proposed to develop waste tire application teaching modules for a variety of civil engineering courses from freshman level to senior level. Each module can contain one or more lectures. Figure 1. illustrates the courses that training modules can be used for.

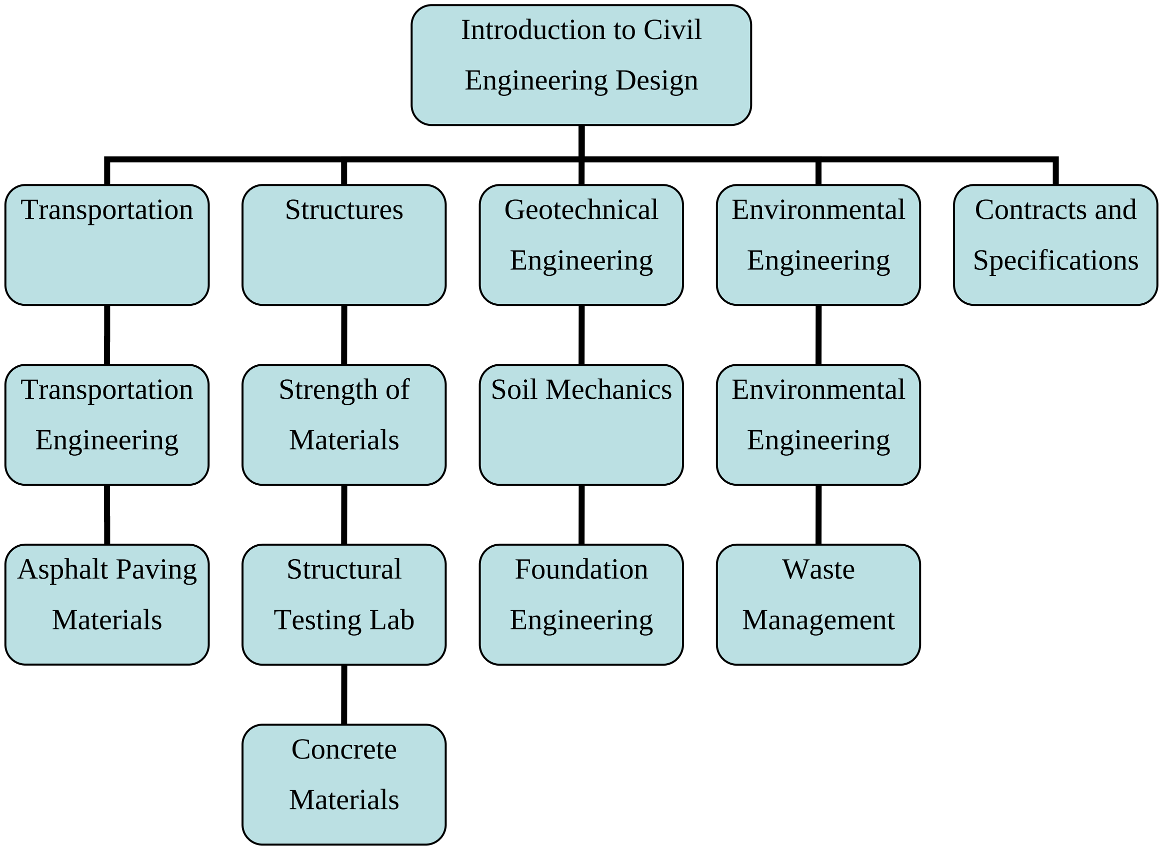

FIGURE 1. Roadmap of Teaching Waste Tire Applications in Civil Engineering Curricula

By offering teaching modules about waste tire applications at different levels in higher education, we can reach more students than any single elective class would. By the end of university education, a student may see the waste tire applications multiple times. It is a more effective way of teaching about unconventional materials, such as waste tire derived materials.

CURRICULA DEVELOPMENT

The following sections describe the objectives, scope, and major components in each teaching module or class. For each module, assignments or evaluation worksheets for learning purposes were also developed.

Teaching modules are independent of each other. The modules emphasize different aspects of waste tire applications. Some discuss the geotechnical applications, while others may illustrate pavement material modification. In addition, they don’t need to be offered all together. The format of the training materials can be flexible so professors or instructors can tailor the teaching module to their teaching needs as they please.

Introduction to Civil Engineering Design

The goal of this lecture is to introduce university students to waste tire materials and give them an overview of utilizing waste tire products in a variety of types of civil engineering applications. It is important to let students understand the significance of reutilizing recycled materials to preserve valuable natural resources. Students should understand the significance of protecting the environment. They should also promote a healthy and sustainable development of our society.

The lecture introduces the waste tire materials by mentioning the negative environmental impacts if waste tire materials were not managed properly. Each year, about 300 million waste tires were generated in the United States while about 40 million waste tires were generated in California alone. Although the majority of the waste tires were recycled and reused, a significant number of waste tires were put to landfills or stockpiles. In 1983, a tire fire burned about 7 million tires in Rhinehart, Virginia. The fire burned for nine months, polluting water with poisons, such as lead and arsenic. In 1998, a grass fire ignited an estimated 7 million tires at an unlicensed tire disposal facility in Tracy, California. It was extinguished after 26 months with water and foam. In September 1999, lightning ignited stockpiled tires in the little town of Westley, California. The fire burned for three months. It took seven years to clean up and cost about 20 million dollars. Figure 2. shows a picture of the Westley tire fire.

The lecture also covers the benefits and challenges of using waste tire derived products in civil engineering and transportation. It discusses physical properties of waste tire derived aggregates. More importantly, it gives an overview of the major applications in civil engineering and transportation, including TDA as backfill materials for retaining walls and bridge abutments, lightweight fill for embankments, insulation layer for roadway base, vibration damping materials for rail lines, and rubberized hot mix asphalt for pavement. It also gives students a roadmap of civil engineering classes that relate to waste tire applications.

FIGURE 2. Tire Fire in Westley California in September 1999 (*7*)

Strength of Materials

This lecture mainly covers the physical properties of tire derived aggregates. TDA are pieces of shredded tires that are generally between 1 inch and 12 inches in largest dimension (*8*). The common properties of TDA affecting engineering performance are: gradation, specific gravity, absorption capacity, compressibility, resilient modulus, time dependent settlement of TDA fills, shear strength, hydraulic conductivity, and thermal conductivity.

This lecture also covers a general model which is a combination of Maxwell and Kelvin models using spring and dashpot elements. The model can be used to analyze the energy dissipation and vibration mitigation characters of TDA. TDA has been used as a vibration damping material for a light rail line by Valley Transit Authority (VTA) in Bay Area of California (*4*).The results show that it is a very cost effective vibration attenuation material. As shown in Figure 3., the average vibration level of a light rail line has been reduced by 10 dB for the 30 to 250 Hz range comparing with a control section. This is a great noise reduction because dB is in log scale. The project also saved VTA approximately $1 to $2 million compared with floating slab vibration mitigation technique (*4*).

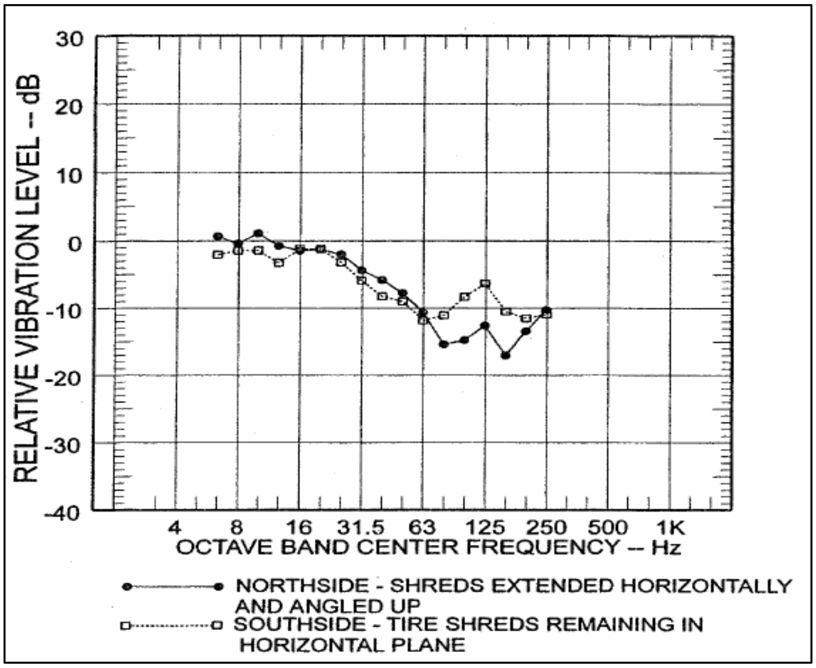

FIGURE 3. Relative Vibration Reduction for VTA Light Rail by Using TDA (*4*)

Structure Testing Lab

The lecture part of the structure testing lab on TDA discusses the stress-strain relationship of TDA. For example, this lecture introduces the common methods of measuring shear strength of granular materials, including soil, crumb rubber, and tire buffing. The lab portion of the class allows students to test the shear strength of crumb rubber using direct shear apparatus.

A literature review and comparison of shear strength parameters from many different sources were conducted. The shear strength of the TDA mainly depends on: (a) size and shape of the tire rubber pieces, (b) density of packing, (c) magnitude of the compressive normal loading, (d) gradation, and (e) orientation of tire shreds.

Contracts and Specifications

This lecture has two modules. One is on ASTM international standards; the other is for specifications on rubberized hot mix asphalt. A series of ASTM standards related to waste tire applications are covered. The major one is ASTM D6270, which has detailed definition on tire rubber, material characterization, usage, construction practices, guideline for fills, and leachate etc (*8*). The lecture also provides students the necessary background on the ASTM International.

The specification lecture starts with various types and aspects of specifications. As examples, standard specifications were illustrated using Caltrans standard specification on RHMA – O (open graded rubberized hot mix asphalt) and RHMA – G (gap graded rubberized hot mix asphalt) (*9*).

Soil Mechanics

Tire Derived Aggregate (TDA) has many unique physical properties that can be used in Geotechnical engineering. The in-place density of TDA ranges from 45 lb/ft^3 to 58 lb/ft^3, which is about 1/3 the unit weight of soil. TDA can be used as a lightweight material to construct embankments on weak, compressible foundation soils. TDA has high permeability, more than 1 cm/sec, which can replace conventional aggregate to be used as gas collection media or leachate collection material. TDA is a good thermal insulation material, which has a thermal insulation 8 times greater than the gravel (*8*). In cold climates, placing a 6 to 12 inch tire shred layer under the road can prevent the subgrade soils from freezing. In addition, excess water may be released when subgrade soils thaw in the spring. The high permeability of tire shreds allows water to drain from beneath the roads, preventing damage to road surfaces (*4*).

In the lecture material, the Dixon landing interchange project at the intersection of I-880 and Dixon Landing Road is used as a case study to illustrate the design, construction, and cost benefit of the project (*10*). The embankment for the interchange needed to be constructed on top of about 30 feet of San Francisco bay mud, which is a highly compressible soil. It required using lightweight fill material for most fill sections to reduce total settlement. For most projects building on a soft clay type of soil, using TDA as a lightweight fill material is significantly cheaper than other alternatives. The Dixon Landing interchange project used 6,627 tons or 662,700 passenger tire equivalents (PTE) of TDA. The cost savings to Caltrans was $447,000 compared to using lightweight aggregate for the project. When the purchase price of the TDA is subtracted, the cost savings is still $230,000 (*11*). Figure 4. shows the TDA compaction for the construction of Dixon Landing interchange.

FIGURE 4. Dixon Landing Interchange Embankment Fill, Compacting TDA (*12*)

Another case study for soil mechanics class is using TDA as subgrade insulation for Witter Farm Road, Orono, Maine (*4*). Frost in this cold climate region can cause heaving of the road and can crack the asphalt, while the thawing weakens the road subbase leading to rutting of the gravel and cracking of the asphalt. From the testing results, the frost depth was reduced from 55 inches in control section to about 30 inches in a TDA fill section (*4*).

The lecture also introduces using TDA for Marina Drive slope repair in Ukiah, CA (*13*). As shown in Figure 5., a road slide damaged the Marina Drive making it unusable. Using TDA as lightweight backfill material replacing typical backfill soil, less excavation is necessary and a more cost effective design can be utilized. The project used about 2,000 ton or 200,000 PTE tires (*14*).

FIGURE 5. Landslide Damaged Section of Marina Drive, Ukiah, CA (*12*)

Concrete Materials

Rubber included concrete or rubberized concrete consists of mixing tire rubber into Portland cement concrete mix by replacing portion of aggregate with crumb rubber. It changes the physical properties of concrete.

One of the most important factors about the rubberized concrete material is the mix design. From the literature review shown in Table 1, the major mix design factors are proportions of crumb rubber by volume or by weight of mix, water-cement ratio, rubber type, and rubber content.

TABLE 1. Summary of Rubberized Concrete Mix Designs from Literature

Author	Rubber Type	Rubber Content	Method of Mix Design
Kaloush et. al. (*15*)	1mm Crumb Rubber	0, 50, 100, 150, 200, and 300 lb/cuyd	Replaced fine aggregate with crumb rubber by weight, increased w/c ratio
Fedroff et. al. (*16*)	Super fine powder	0, 10, 20, and 30%	By weight of cement in mix adjusted w/c ratio to get 3 to 5 inches of slump
Tantala et.al. (*17*)	Buff Rubber	5 and 10%	Replaced 5% and 10% of coarse aggregate with buff rubber by volume
Schimizze et.al. (*18*)	Fine/Coarse Reclaimed Rubber	5% of mix design by weight	Lowered both 1. fine aggregate and 2. fine and coarse aggregate to get 5% rubber by weight
Biel and Lee (*19*)	3/8" minus rubber droppings	0 to 90% in 15% increments	Replaced fine aggregate with crumb rubber by volume gave 0 to 25% rubber by volume in mix
Eldin et.al. (*20*)	Ground tire chips, fine crumb rubber	0,25,50,75,100% by volume	Test specimens replacing either coarse or fine aggregate

A fair amount of research has been done in using waste tire particles in Portland cement concrete. Although compressive strength and stiffness of concrete mixes decrease dramatically with increasing rubber content, the ductility, toughness, and tensile strain have been shown to increase with small amounts of rubber particles. Rubberized concrete may be more flexible and crack resistant for lightweight paving. It may provide vibration damping and sound transmission mitigation. It can be used for energy absorption due to dynamic force, such as earthquakes. It may also increase the freeze-thaw durability of concrete.

Foundation Engineering

Lateral earth pressure is the pressure exerted by a fill material on the wall of a structure like a retaining wall. It can be determined from the coefficients of lateral earth pressure, which are calculated by dividing horizontal stress by vertical stress. TDA can also reduce lateral earth pressure up to 50 percent to conventional soil backfill material. It also has good drainage properties to prevent water build up behind a wall. Therefore, TDA is a very good material as backfill for retaining walls and bridge abutments. It can reduce the design thickness of the wall and use less steel (*4*).

This lecture introduces a full scale retaining wall testing at the University of Maine (*4*). The testing facility has four walls and a reinforced concrete foundation. The size of the testing facility is 16 ft. high by 15 ft. long by 14.7 ft. wide. The lateral earth pressure, horizontal displacement, interface friction between wall and TDA, were measured during the test. It was found that the horizontal stress at rest for TDA is 45 percent less than that of conventional granular fill (*21*). Figure 6. shows a picture of loading TDA fill to the constructed wall testing facility.

FIGURE 6. Full Scale Retaining Wall Testing for Using TDA as Backfill (*4*)

The lecture also introduces a case study of constructing of a real world retaining wall with TDA. Figure 7 shows a picture of the project. Caltrans and the CIWMB have constructed the 300 linear foot retaining wall, Wall 119, with TDA as lightweight backfill material along route 91, in Riverside, California. The retaining wall is 12 ft. tall, with 9.8 ft. of compacted TDA enclosed in a geotextile membrane. It has about 2 feet of soil cover. At designated locations, the forces were measured using pressure cells; the strains were measured with strain gauges; temperatures of tire shred materials were measured using temperature sensors; and the displacement of the wall was monitored by a tilt meter. The retaining project was very successful and it used 837 tons of TDA. The following picture shows the construction of the Wall 119.

FIGURE 7. TDA as Backfill for Retaining Wall 119 in Riverside, CA (*22*)

Environmental Engineering

This lecture focuses on the environmental aspects of utilizing waste tires in civil engineering and transportation. First, it introduces the negative impact if waste tire materials are not recycled and managed properly. Then, it describes the engineering properties of TDA and rubberized asphalt. It shows the beneficial usage of waste tire materials in civil engineering applications, such as lightweight fill, landfill applications, vibration damping, and rubberized asphalt pavement.

Consequently, it addresses the environmental assessment research on using TDA and rubberized asphalt. Significant amounts of research, both laboratory evaluations and field tests, have been conducted on various environments. It provides students the knowledge that environmental factors that they should pay attention to when they use waste tire applications. Generally, recycled rubber derived from scrap tires is a safe recyclable material (*23*). It is important to recognize that the impact of scrap tires on the environment varies according to the local water and soil conditions, especially pH values. It may not be safe to use when pH is too high or too low (*24*).

Transportation Engineering

The goal of the transportation engineering lecture is to inform students of the history, benefits, limitations and practice of using asphalt rubber (AR) as a paving material. This lecture is divided into four modules, each dealing with a different aspect of asphalt rubber applications.

The students are first introduced to the history of asphalt rubber being used as a paving material. Case studies of full scale AR overlay projects in California are presented. These studies outline the strategy of using AR as an overlay to repair existing distressed pavements, as well as discussing the design and results of the AR overlays. The benefits of using AR pavements as a replacement for conventional asphalt are also included. The second module discusses the structural design of AR pavements. A 2005 Caltrans study is referenced in this module to discuss the revised practices of using AR in new pavements as well as an overlay (*25*). Students are informed on the recommended design strategy for new pavements and overlays using AR. An overview of the revised practice for using AR in overlays and new pavement is also presented. This module also discusses cost analysis between AR and conventional asphalt.

Students are introduced to the manufacturing and construction process of AR in the third module. The module discusses the general paving process with an emphasis on the different practices between AR and conventional asphalt. An overview of the manufacturing process informs students how AR is produced and also highlights the operational differences when dealing with AR such as the laydown and compaction temperatures for successful placement of AR. The last module of the lecture goes into detail about the AR binder production, AR mix production, inspection of paving and troubleshooting. Some or all of these modules could be included in this class.

Asphalt Paving Materials

This lecture consists of asphalt rubber (AR) binder design, the different types of AR mixes and the cautions of using AR. The lecture defines the different types of asphalt rubber binders and discusses how each type is produced. Crumb Rubber Modifiers (CRM) are the form of waste tires added to the binder. The interaction between the CRM, the asphalt and the affecting factors are explained. When designing an AR blend, it is necessary to develop a binder profile which evaluates the compatibility, interaction, and stability between materials over a period of time.

The students are introduced to the most commonly used types of rubberized hot mix asphalt concrete, including Rubberized Hot Mix Asphalt – Gap graded (RHMA-G), Rubberized Hot Mix Asphalt – Open graded (RHMA-O), and Rubberized Hot Mix Asphalt – Open graded – High Binder content (RHMA-O-HB). The mix design, advantages, and standard specifications are described for each rubberized asphalt mixture type (*9*).

OUTCOMES

The teaching materials regarding to waste tire applications have been developed for a series of lectures for the previously mentioned ten different civil engineering courses. The teaching materials are stored on a website at CSU, Chico. All these lectures have been taught at the undergraduate level at the California State University, Chico. The outcomes showed that students have greatly improved their knowledge on waste tire material applications. They were able to demonstrate their knowledge and interests of waste tire applications through their term projects, lab reports, presentations, and homework assignments.

As an example, the following outcomes were evaluated at the Spring 2008 Soil Mechanics class:

a. Ability to design and analyze data, as well as to interpret results for a slope stability problem using waste tires.
b. Knowledge of the engineering properties of waste tire derived aggregate, and application of the properties in their engineering analyses.
c. Understanding the importance and benefits of utilizing recycled materials such as waste tires in civil engineering applications.

The students were formed into lab groups. Each group was assigned a slope stability problem for an embankment project. They needed to use simplified bishop method and ordinary method of slices to design the slope and choose materials used for the embankment. They needed to compare the conventional fill materials with tire derived aggregates. Student groups were required to submit a formal lab report and give a presentation on their findings. Figure 8. shows slope stability analysis results by students on TDA as embankment fill materials.

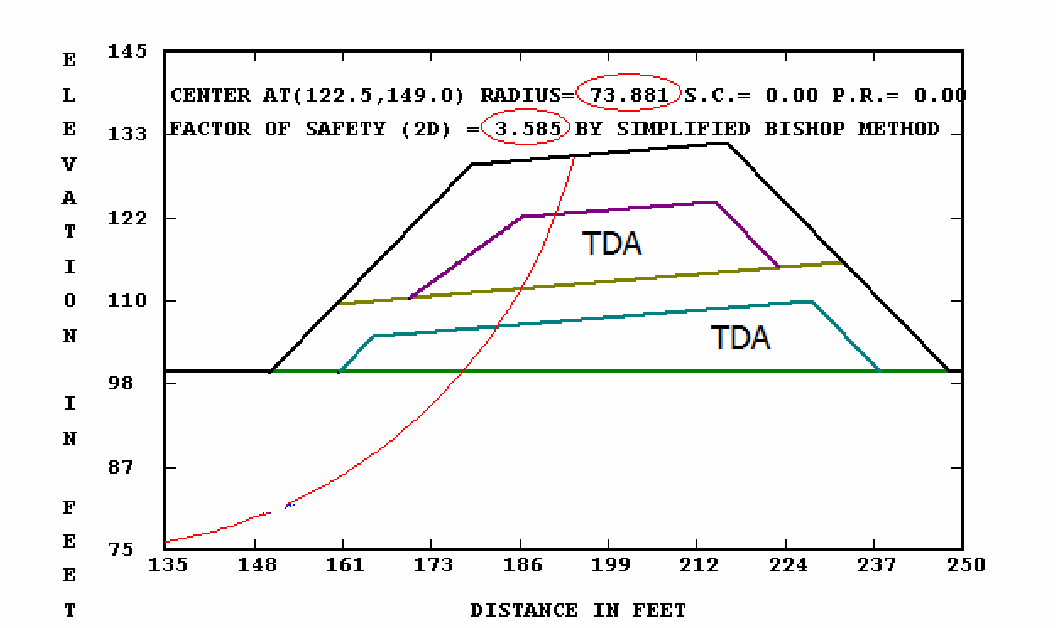

FIGURE 8. Sample Slope Stability Analysis Results using Simplified Bishop Method

Student proficiency is measured by the score on lab report and presentation. Generally, 90 to 100 percent would represent mastery, 80 percent above adequate proficiency, 70 percent adequate proficiency, and below 70 percent would be indicative that the student lacks proficiency. Figure 9. shows the scores of the lab groups in this project. Students learned the subjects very well.

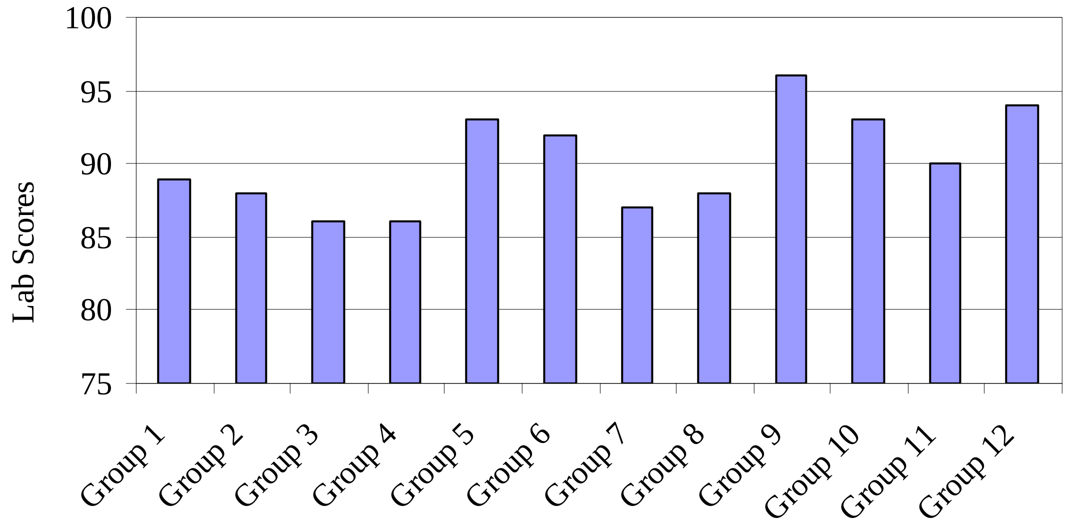

Figure 9. Lab Scores of Using Waste Tires as Embankment Fill in Slope Analysis

A website was created to store the teaching materials, which includes PowerPoint presentations, lecture notes, sample assignments and sample answers. The link for the website is:

http://www.ecst.csuchico.edu/cp2c/dxcheng/Curricula/CIWMBEducation.php

Professors and instructors can easily access the teaching materials by logging in to the website. If you log in as a professor, you will be able to use full contents of the teaching materials. The public can also access part of the teaching materials by logging in as a guest. Generally, they can only access the PDF version of the presentations. A snapshot of the webpage for professors after logging in is shown in Figure 10.

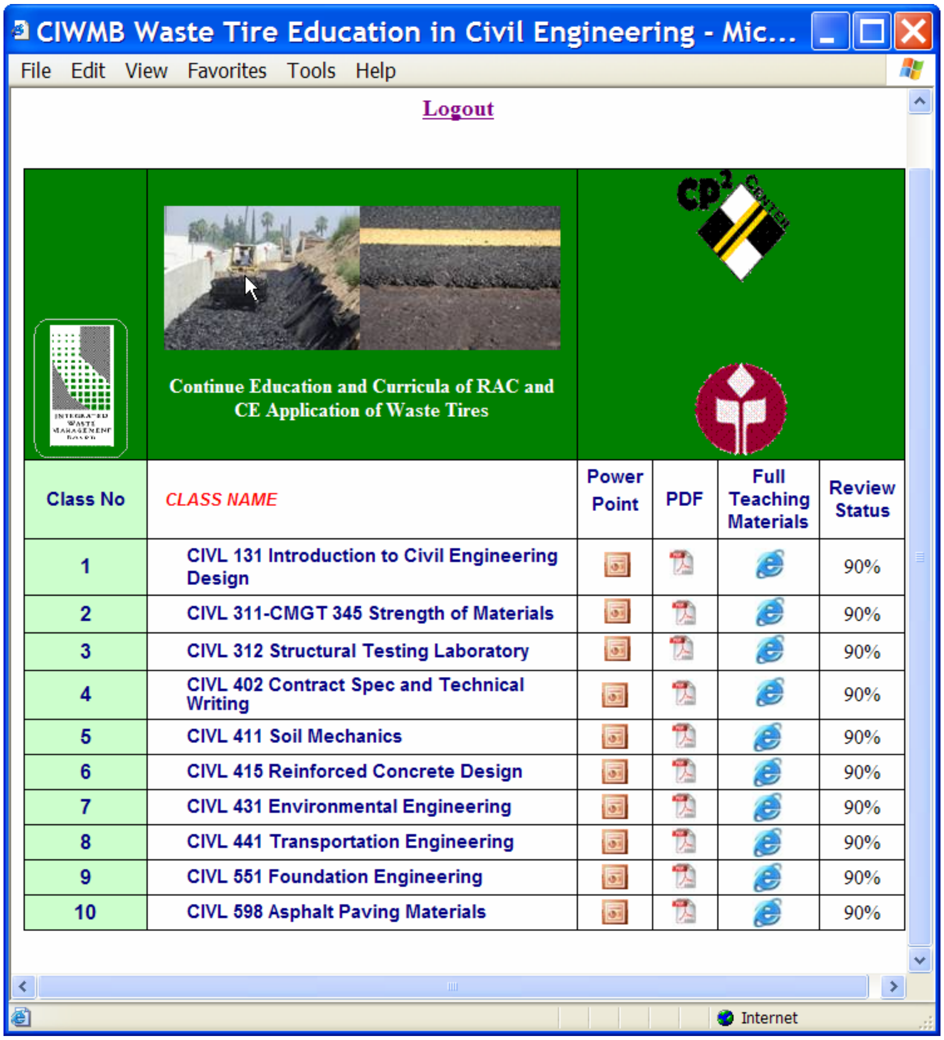

FIGURE 10. Sample Webpage to Access Teaching Materials for Waste Tire Applications

CONCLUSIONS

Each year, civil engineering applications and asphalt rubber combining together can consume more than 60 million waste tires. In order to promote the beneficial usage of waste tires in civil engineering and transportation, the education curricula including a series of lectures in undergraduate courses were developed. The following conclusions can be drawn from the curricula development project:

- Waste tire applications cover a wide range of civil engineering areas, including geotechnical, environmental, structure, and transportation.
- The teaching modules or lecturing materials were developed to cover freshman level to senior level classes. The freshman class gives students an introduction and overview of waste tire products and their applications. Junior classes cover the material properties,

testing, and standards. Senior classes cover the waste tire applications in civil engineering and transportation.

- The outcomes show that it is an effective way to teach waste tire applications and can reach more students. Students have demonstrated knowledge and interest on the sustainable usage of waste tire materials through their school work.

University students in civil engineering fields are future engineers and their knowledge on waste tire applications will affect long term or sustainable usage of recycled materials such as waste tires. It was a good experience promoting the education of sustainable usage of recycled waste tires in civil engineering and transportation by developing the university teaching materials. The education on other recycling materials can follow a similar approach.

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