COMPARISON OF FUEL CONSUMPTION ON RIGID VERSUS FLEXIBLE PAVEMENTS ALONG I-95 IN FLORIDA

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Abstract

Sustainable construction and development implies investing in the needs of today without compromising the resources of future generations to meet their needs. The components of sustainability are (1) Economic; (2) Social; and (3) Environmental. Reducing user costs by improving fuel economy from pavement type is important to advance sustainable development.

An on-going study of fuel consumption by vehicles traveling on rigid versus flexible pavements at Florida International University (FIU) Department of Civil and Environmental Engineering indicates that rigid pavements provide better fuel economy for the travelling public and commercial carriers. The FIU study along 28 miles of Interstate 95 in Brevard County indicates that travelers in passenger vehicles on rigid pavements use 3.2% less fuel compared to flexible pavements. In addition, the study shows that loaded tractor-trailers along the same corridor the rigid pavement provides 4.5% better fuel economy than the flexible pavement. These findings are consistent with research at Massachusetts Institute of Technology and University of Texas at Arlington.

Hypothetically speaking, if all pavements within the Florida State Highway System were rigid construction the annual savings in fuel consumption could be 500 million gallons and the annual savings to the public could be in excess of $2.0 billion. Environmentally, CO_2 emissions would be reduced by over 5 million metric tons annually as a result of reducing fuel consumption by 500 million gallons in Florida. While these overall benefits are extrapolated estimates, the findings of this study indicate the potential for real sustainable benefits by increasing rigid pavement lane miles into agency work programs.

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Introduction – What is sustainable development?

The United States Environmental Protection Agency (EPA) defines sustainable development as meeting the needs of the current generation without compromising the ability of future generations to meet their needs. Rigid pavements contribute to sustainable development in many ways as compared to flexible pavements.

The relationships of the three domains impacted by transportation development overlap on many of the sustainable qualities of concrete pavements. Figure 1 shows these relationships. Some of the qualities of rigid pavements with economic benefits of sustainable development also have social and environmental benefits.

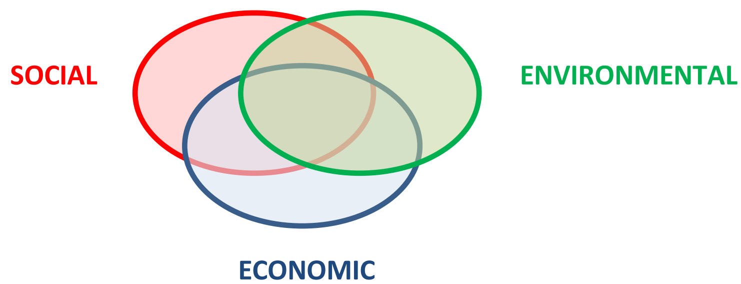

Figure 1. Sustainability Impacts of Rigid Pavements

For instance, service life of rigid pavements is estimated to be around 30 years as opposed to the estimated 17-year service life of flexible pavements. In fact, many flexible pavements in Florida require surface repairs or maintenance every five to seven years. The longer service life of rigid pavements has an economic impact because it requires fewer repairs, fewer materials, fewer construction zones requiring traffic control and fewer mobilizations and employee hourly costs.

The environmental impacts of rigid pavements as a result of the longer service life are found in the reduction of the use of non-renewal materials and fuel sources for repair. This also results in lower greenhouse gas emissions from construction equipment and vehicles idling due to lane closures and reduced vehicle fuel consumption.

The social impacts of longer life pavements are realized from the elimination of construction zones that result in lost time to the public caused by lane closures and more importantly, the elimination construction zone safety hazards that may result in loss of property or life in construction zone accidents.

Vehicle Gas Consumption and Socio-Economic and Environmental Sustainability of Rigid Pavements

Higher surface stiffness and smoother surfaces have been shown to reduce fuel consumption between 3% and 17% as compared to flexible pavements. At today's price of fuel, around $3.50 per gallon, consumers may realize a substantial savings at the gas pump. A recent study by civil engineers at Massachusetts Institute of Technology (MIT) shows that using stiffer pavements on the nation's roads could reduce vehicle fuel consumption by as much as 3 percent — a savings that could add up to 273 million barrels of crude oil per year, or $15.6 billion at today's oil prices. This would result in an accompanying annual decrease in CO_2 emissions of 46.5 million metric tons. Research at the University of Texas at Arlington (UTA) found that the difference in fuel consumption may be as large as 17% more on flexible pavements than on rigid pavements. Impacts, such as these, especially in highly congested urban areas, could have substantial sustainability implications in Florida and nationwide.

Florida International University On-going Study

Location of Study

Using the study at MIT as a backdrop, Florida International University (FIU), in a research partnership with MIT, commenced a study of fuel consumption difference on the Florida State Highway System. A segment of I-95 in Brevard County was selected for the study. Figure 1 shows the segments of I-95 selected for the study.

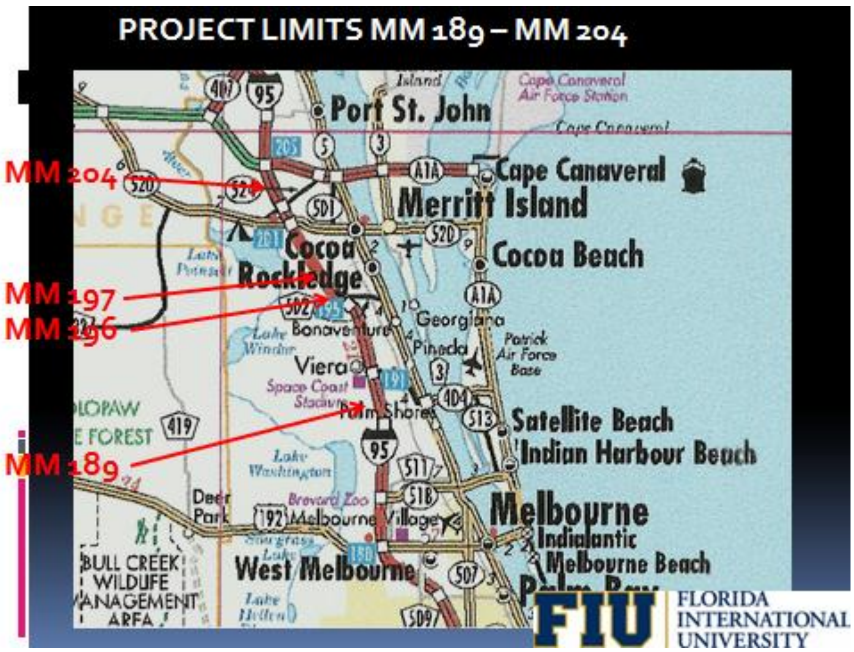

Figure 1. Map of I-95 in Brevard County, Florida

The test sections were identified as I-95 Northbound from mile marker (MM) 189 to MM 204 and I-95 Southbound from MM 204 to MM 189. Both directions of the interstate are three lanes and relatively flat with a posted speed limit of seventy miles-per-hour. The sections between MM 189 to MM 196 are flexible pavements in both directions and the sections between MM 197 and MM 204 are rigid pavements in both directions. The pavements transition between flexible and rigid between MM 196 and MM 197, in both directions. The sections provided a total of fourteen miles of data for each complete run for each pavement type. Figure 2 shows the similarity of the geometries of the test sections, with the flexible pavement in the upper photograph and the rigid pavement in the lower one.

Figure 2. Photos of Test Sections – Rigid Pavement below, Flexible Pavement above

The flexible section was rehabilitated in 2009 – 2010. The pavement structure consists of 9.25” (min) of asphalt concrete (including 0.75” of open-graded friction course), 5” (min) of limerock base and 12” of stabilized subgrade (Type B). The design AADT was 78,000 vehicles with 5.1% trucks. The current International Roughness Index (IRI) averages 48 inches/mile. Falling weight deflectometer (FWD) data are not available.

The rigid section was also rehabilitated in 2009 – 2010. The pavement structure consists of 13” plain, jointed Portland Cement Concrete, 1.0” of asphalt concrete (SP 9.5), and 4.0” of asphalt treated permeable base. The design AADT was 78,000 vehicles with 5.1% trucks. The current IRI is 46 inches/mile. Falling weight deflectometer (FWD) data are no available.

Results from the Florida Department of Transportation (FDOT) Annual Pavement Condition Survey indicate that both sections were completed within the last two years and the existing International Roughness Indices are similar with averages approximately fifty inches-per-mile. The test plan was to select days and times where traffic volumes were to be light to moderate so that the cruise control on the test vehicle could be set and maintained throughout the full fifteen-mile run in each direction without changing lanes or accelerating. After a run in the northerly direction the driver changed to the southern direction at the nearest exit. Once in the southerly direction the speed control on the vehicle was reset prior to reaching the beginning mile marker and maintained throughout the southerly run.

The purpose of this exercise was to eliminate variables that may affect fuel consumption other than the pavement surface. One variable that was introduced into the study is overall direction of the highway and wind velocity. The flexible section from MM 189 to 196 runs mainly north-northwesterly on the northbound side and south-southeasterly on the southbound side. The rigid section, from MM 197 to MM 204 runs mainly northwesterly on the northbound side and southeasterly on the southbound side. The uncontrollable effect of wind velocity (speed and direction), therefore, had an effect on results and will be discussed later in this report.

Vehicles Used in Study

The passenger vehicle used in the study was a 2011 Hyundai Genesis sedan (3.8-L/V6) with a curb weight of approximately 3750 lbs. A photo of a similar vehicle is shown in Figure 3. The Genesis was considered an average-size vehicle to represent a large cross-section of currently used passenger cars.

Figure 3. 2011 Hyundai Genesis Sedan

The heavy truck used in this study was a tractor-trailer rig provided by Commercial Carrier Corporation out of Cape Canaveral, Florida. The gross vehicle weight of the eighteen wheel rig was approximately 74,000 pounds (37 tons). A photo of the tractor-trailer is shown in Figure 4.

Figure 4. Representative Tractor-Trailer from Commercial Carrier Corporation. Approximate Gross Vehicle Weight: 74,000 lbs.

Data Collection Instrumentation

Actual instantaneous gas consumption was acquired using the On-Board Data (OBD) collection capability of the vehicles. Modern vehicles generate a large amount of operational data that is used by manufacturers to diagnose problems and monitor vehicle operational performance. The OBD port on the2011 Hyundai Genesis is located under the driver-side dashboard. A commercial OBD collection device was used to upload the desired data into a computer (laptop) database in real time. Figure 5 shows the OBD device used to connect to the vehicle's OBD port and the USB port of a laptop computer.

Figure 5. On-Board Data Collection Device from OBDCOM.

The real-time gas consumption and vehicle speed were up-loaded in real time to a Dell laptop computer. The data are entered into an Excel Spreadsheet database format for analysis at a later time. Figure 6 shows the data collection in real time on the laptop screen.

Figure 6. Real-time Data Collection of Real-Time Fuel Consumption and Vehicle Speed.

The truck data collection system was similar to the passenger vehicle utilizing the On-Board Diagnostics port on the tractor along with a laptop and compatible software.

Test Results / Observations

Once data collection was complete, the data were reduced to average fuel consumption in both directions for each of the pavement types. Overall fuel consumption averages for each pavement type were determined to adjust for wind velocity and to obtain an average over the fourteen miles of data for the rigid pavement and the fourteen miles of data for the flexible pavement. Examples of raw data displayed graphically are shown in Figures 7 and 8. Data were collected at a rate of four readings per second.

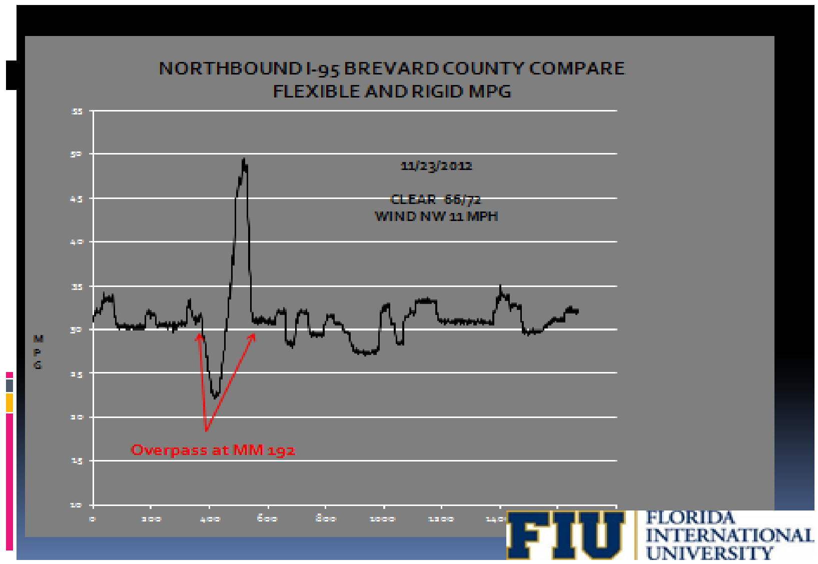

Figure 7. Northbound I-95 Flexible Pavement Section from MM 189 to MM 196

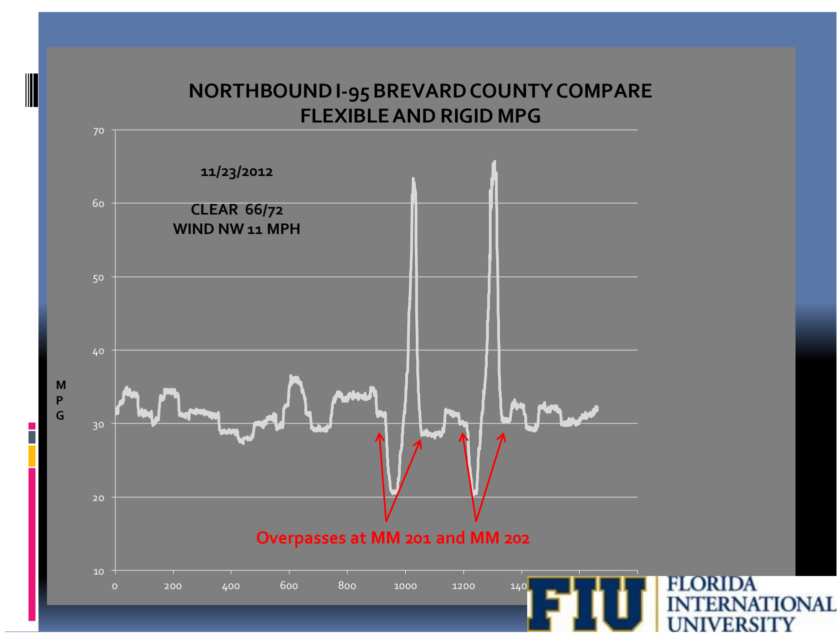

Figure 8. Northbound I-95 Rigid Pavement Section from MM 197 to MM 204.

The troughs and spikes are changes in fuel consumption on overpasses along the highway sections. The overpass on the flexible section is located at MM 192. The overpasses on the rigid section were located at MM 201 and MM 202. The affect on the average fuel consumption on the rigid section, which includes the two overpasses, was less than five one-hundredths of a mile-per-gallon. Because the overall effect was small in relation to all data collected, these data from the overpasses were included in the analysis.

The averages of data collected on the first day of testing are shown by the bar graph in Figure 9. Several observations may be made from this bar graph. First, wind velocity (speed and direction) have a substantial effect on fuel consumption. Note that the wind velocity is eleven miles per hour out of the northwest. Because these two sections run in a basically southeast to northwest direction, the net effect on the rigid pavement section is a difference in wind magnitude of twenty-two miles per hour. There was an eleven mile per hour headwind traveling northbound and an eleven mile per hour tailwind traveling in the southbound direction. The average overall difference between the two directions for the rigid pavement is 4.6 miles per gallon. Because the flexible sections run primarily in a north-northwest direction, the effect of wind was some vector component of the actual wind speed and the effects are smaller in magnitude than on the rigid sections, but still substantial. The average difference in fuel consumption along the flexible pavement sections were 3.4 miles per gallon.

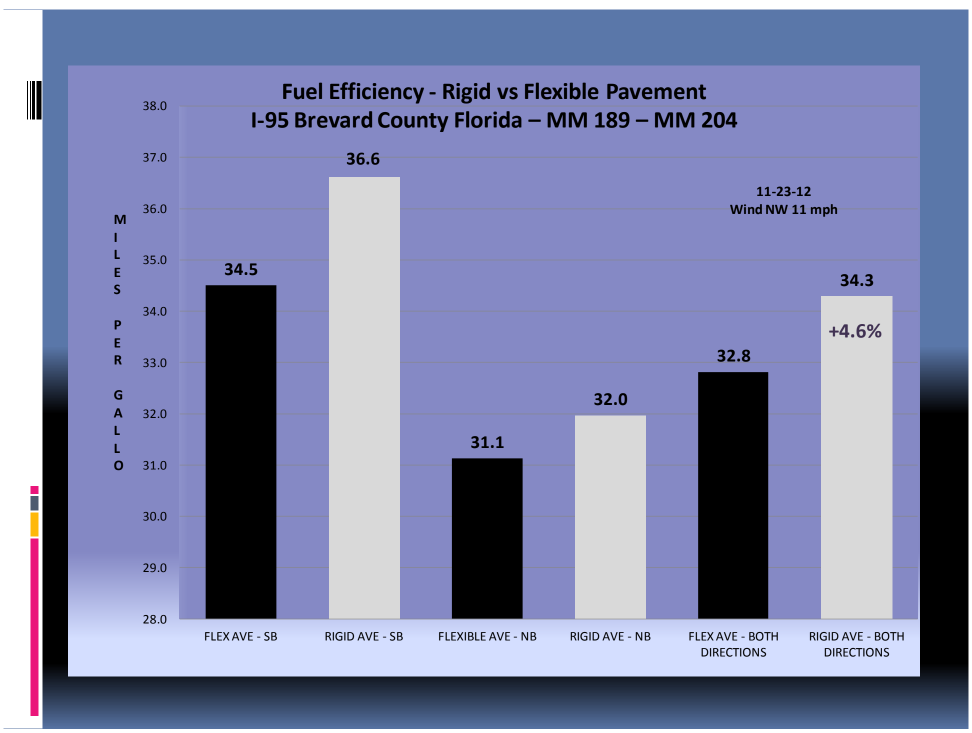

Figure 9. Average Fuel Consumption Data on 11/23/201

A second observation is whether the vehicles were traveling into a headwind or with a tailwind, the rigid pavement provided more economical gas mileage. With a tailwind, the vehicle traveling on the rigid pavement achieved a higher fuel economy of 2.1 miles per gallon over the flexible pavement. With a headwind, the vehicle traveling on the rigid pavement achieved a higher fuel economy of 0.9 miles per gallon.

The third observation is the overall averages of each pavement type in both directions indicate that the rigid pavement section provided a greater fuel economy by 1.5 miles per gallon over the flexible sections. Therefore, the rigid pavement used 4.6% less fuel than the flexible pavement over four sets of data.

Findings

Passenger Vehicle

Similar sets of data were collected once per month from December 2012 through June 2013 in order to increase the database for more reliable observations and to normalize the effect of wind velocity on fuel consumption for both pavement types.

The average IRI for both sections were equivalent at 46 inches per mile for the rigid section and 48 inches per mile for the flexible sections. The ambient temperature range was 49 to 84 degrees Fahrenheit. Each set of data collected consisted of three complete run of both pavement-type sections in both the northerly and southerly directions.

Table 1 summarizes the results of all data collected over the eight-month period. The results of the data indicate that on the average, the rigid pavement provided 3.3% better gas mileage than the flexible pavement.

Date	Air Temperature / Wind Velocity	Miles per Gallon (MPG) Difference (Rigid minus Flexible)	Miles per Gallon (MPG) % Difference	Gallons per 100 Miles (GPHM) Difference (Flexible minus Rigid)	Gallons per 100 Miles (GPHM) % Difference
November 23, 2012	62 F / 11 mph NW	1.5	4.5%	0.130	4.3%
December 12, 2012	76 F / 6 mph S	1.0	2.8%	0.078	2.8%
January 13, 2013	72 F / 11 mph SE	1.3	4.2%	0.131	4.0%
February 27, 2013	68 F / 4 mph W	1.1	3.8%	0.124	3.7%
March 9, 2013	49 F / 4 mph NNW	0.6	2.1%	0.072	2.0%
April 18, 2013	79 F / 10 mph WSW	1.0	3.4%	0.109	3.2%
May 10, 2013	80 F / 10 mph SW	1.0	3.4%	0.110	3.2%
June 13, 2013	84 F / 4 mph E	0.8	2.5%	0.080	2.5%
Overall Average	-	**1.0**	**3.3%**	**0.104**	**3.2%**

Table 1. Comparison Results from Monthly Data Collection for Passenger Vehicle

The miles per gallon data were converted to fuel consumption in gallons per 100 miles (gphm) in order to conform to research findings previously published by the Concrete Sustainability Hub at Massachusetts Institute of Technology. These data indicate that on the average, the rigid pavement provided a fuel economy 3.2% more gallons per one-hundred miles traveled.

Tractor-Trailer

The data collected for the tractor-trailer using the on-board diagnostic data collection system were collected at an average speed of forty-five miles per hour over the same sections of Interstate 95 as the passenger vehicle. The data were collected at different times. The tractor-trailer was provided by Commercial Carrier Corporation of Cape Canaveral, Florida. The average air temperature for these days was around 84 degrees Fahrenheit.

Each set of data collected consisted of three complete run of both pavement-type sections in both the northerly and southerly directions. Table 2 shows the results of the three sets of data collected from May 2013 through July 2013. The results of the data indicate that on the average, the rigid pavement provided 4.1% better gas mileage than the flexible pavement.

The miles per gallon data were converted to fuel consumption in gallons per 100 miles (gphm) in order to conform to research findings previously published by the Concrete Sustainability Hub at Massachusetts Institute of Technology. These data indicate that on the average, the rigid pavement provided a fuel economy 4.5% more gallons per one-hundred miles traveled.

Date	Air Temperature / Wind Velocity	Miles per Gallon (MPG) Difference (Rigid minus Flexible)	Miles per Gallon (MPG) % Difference	Gallons per 100 Miles (GPHM) Difference (Flexible minus Rigid)	Gallons per 100 Miles (GPHM) % Difference
May 10, 2013	84F / 9 mph SE	0.31	3.8%	0.53	4.1%
June 15, 2013	84 F / 13 E	0.33	4.5%	0.68	4.7%
July 20, 2013	82 F / 6 E	0.30	4.1%	0.63	4.5%
Overall Average	-	**0.31**	**4.1%**	0.61	**4.5%**

Table 2. Comparison Results from Monthly Data Collection for Tractor-Trailer

Discussion

According to the 2010 report from the Florida Department of Revenue, approximately 15.3 Billion gallons of vehicle fuel were consumed in Florida (1.4 billion gallons of diesel, 8.2 billion gallons of gasoline, 5.7 billion gallons of gasohol). Using data collected by Florida International University Department of Civil and Environmental Engineering when tested under similar conditions, traveling on rigid pavements consumes 3.2% less fuel than traveling on flexible pavements for passenger vehicles and 4.5% less fuel for loaded tractor-trailers on Interstate 95 in Brevard County, Florida. These findings are consistent with the model created by the Concrete Sustainability Hub at MIT. Hypothetically, if all pavements in Florida were rigid, this could theoretically amount to an annual fuel savings of over 500 million gallons of fuel and more than $2.0 billion savings to the highway users when considers an average fuel cost of $3.50 per gallon.

Commercial Carrier Corporation indicated that for every 0.10 mpg savings over the entire fleet for one year, the company realizes an additional $240,000 to its bottom line. These findings indicate that if the company could move its goods over rigid pavements similar to the sections used in this study, Commercial Carrier Corporation could add nearly $750,000 in profits. These funds could be used to upgrade its fleet, hire new employees and build larger infrastructure, all of which have a lasting positive impact in the Florida economy.

From an environmental perspective, using estimates from the United States Environmental Protection Agency of 0.00892 metric tons of CO_2 emitted per gallon of gasoline consumed, traveling exclusively on rigid pavements could reduce CO_2 emissions by nearly 5.0 million metric tons annually. (Agency). The impact on the environment is as astonishing as the economic impact to the traveling public. This is especially critical in urban areas such as Miami, Orlando, Tampa and Jacksonville where large numbers of vehicles operate in highly congested areas on a daily basis.

As a recommendation, utilizing rigid pavements in express and premium lanes could contribute to increased usage as the cost of the toll may be somewhat offset by the savings in fuel consumption, depending on the toll charged at the time of use. At any rate, the fuel savings could have a substantial positive impact on fuel costs and greenhouse gas emissions. Both factors could be used on life cycle cost analyses in pavement type selections.

Conclusions on Sustainable Infrastructure

Sustainable development encompasses economic, social and environmental considerations. The building of civil infrastructure is a critical component of overall infrastructure development. Expanding the use of rigid pavements in the development of infrastructure is one aspect that provides sustainability for future generations. In addition to the longer service lives exhibited by rigid pavements and lower life-cycle costs, this study shows the positive environmental, social, as well as, economic impacts rigid pavements provide. Increasing uncertainty of oil prices and the trend of increasing fuel prices, the infrastructure that is built today will, indeed, have impacts on the resources of future generations and their abilities to meet their infrastructure development needs.

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