February 15, 2008

Dr. Arthur Rosenfeld
Commissioner
California Energy Commission
1516 9th Street
Sacramento, CA 95814

Life Cycle Cost and CO₂ Issues for Concrete Pavement
CTLGroup Project No. 312114

Dear Dr. Rosenfeld:

At the request of Mr. Tom Tietz of the California Nevada Cement Association, CTLGroup is providing this letter documenting the benefits of concrete pavements when based on life cycle cost analysis (LCCA) and life cycle assessment (especially CO₂).

EXECUTIVE SUMMARY

Four independent, third party, LCCA studies were prepared by ERES Consultants comparing actual agency costs for portland cement concrete (PCC) pavement and asphalt concrete (AC) pavement. Results indicate that PCC alternatives have 13 to 28% lower equivalent uniform annual costs (EUAC) in units of $/lane/mile/year and 66 to 69% lower EUAC in units of $/lane/mile/year/100,000 trucks. These costs did not include user costs. The LCCA savings would most likely be greater if the user costs had been considered because the PCC pavement life, in all cases, was greater than the AC pavement life.

An independent, third party, report was prepared by the Athena Institute for six AC and PCC pavements using two life cycle assessment impact indicators: embodied energy and global warming potential. Results indicate the AC pavements have 31 to 81% more embodied energy than the PCC pavements. These results do not include feedstock energy (fuel content of the asphalt). The results for global warming potential index (GWPI), which includes CO₂, are mixed. The differences in GWPI for the AC and PCC pavements are considered insignificant by Athena. Sixty percent of the CO₂ emissions in the cement manufacturing process are from calcination and not from the burning of fossil fuels. Embodied energy and GWPI results are highly dependent on the cement content of the concrete. Using 25% fly ash as replacement for portland cement rather than the 10% assumed by Athena will improve the results for PCC pavement. Also, considering a full range of impact indicators rather than only embodied energy and GWPI will provide a more complete life cycle assessment.
LIFE CYCLE COST ANALYSIS (LCCA)

The Federal Highway Administration (FHWA) “has pursued a policy of promoting LCCA for transportation investment decisions since the Intermodal Surface Transportation Equity Act of 1991.”

Methodology

The FHWA provides extensive information on LCCA, including the following introduction, at http://www.fhwa.dot.gov/infrastructure/asstmgmt/lcca.cfm:

LCCA is an engineering economic analysis tool that allows transportation officials to quantify the differential costs of alternative investment options for a given project. LCCA can be used to study new construction projects and to examine preservation strategies for existing transportation assets. LCCA considers all agency expenditures and user costs throughout the life of an alternative, not only initial investments. More than a simple cost comparison, LCCA offers sophisticated methods to determine and demonstrate the economic merits of the selected alternative in an analytical and fact-based manner. LCCA helps transportation agencies answer questions like these:

• Which design alternative results in the lowest total cost to the agency over the life of the project?
• To what level of detail have the alternatives been investigated?
• What are the user-cost impacts of alternative preservation strategies?

The above link also provides information on LCCA requirements and procedures for California and selected other state DOT’s.

Procedures for performing LCCA are documented in publications by FHWA and American Concrete Pavement Association (ACPA). The FHWA publication emphasizes the need to include user costs. FHWA defines user costs as “the differential costs incurred by the motoring public between competing alternative highway improvements and associated maintenance and rehabilitation strategies over the analysis period. User costs are an aggregate of three separate cost components: vehicle operating costs, user delay costs, and crash costs.” FHWA gives detailed instructions on how to calculate these costs related to reduced lanes, construction detours, and traffic congestion during construction. These costs include costs of fuel due to delays and detours, the value of the driver’s time, the increased delivery fleet size, and the potential for increased crashes.

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Results

Four independent, third party, LCCA studies were prepared by ERES Consultants comparing actual agency costs for portland cement concrete (PCC) pavement and asphalt concrete (AC) pavement. Results indicate that PCC alternatives have 13 to 28% lower equivalent uniform annual costs (EUAC) in units of $/lane/mile/year and 66 to 69% lower EUAC in units of $/lane-mile-year·100,000 trucks. These costs did not include user costs. Specifically, savings were:

- **Interstate 40, Tennessee, 13 to 21% LCCA savings for PCC**: The average pavement life of the PCC sections was 2.1 to 2.5 times the average life of the AC sections (25.5 to 31.1 years for the PCC versus 12.3 years for the AC).

- **Interstate 15, Utah, 20 to 28% LCCA savings for PCC**: The average pavement life of the PCC sections was 2.5 times the average life of the AC sections (31.4 years for the PCC versus 12.6 years for the AC).

- **Interstate 40, Oklahoma, 21 to 27% LCCA savings for PCC**: The average pavement life of the PCC sections was 3.4 times the average life of the AC sections (30.9 years for the PCC versus 9.0 years for the AC).

- **Interstate 985 and State Route 400, Georgia, 66 to 69% LCCA savings on I-985 and 70 to 71% LCCA savings on SR-400 for PCC when normalized for traffic**: The

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average pavement life of the PCC sections was 1.6 to 1.9 times the average life of the AC sections for I-985 (19.5 to 23 years for PCC and 12 years for AC) and 2.6 times for SR-400 (37 years for the PCC versus 14 years for the AC).

The LCCA savings would most likely be greater if the user costs (as previously described) had been considered because the PCC pavement life in all cases was greater than the AC pavement life. Additional references are available upon request for determining user costs.

The ACPA publication EB220P, Appendix 2, provides examples of state agency expenditure streams for PCC and AC pavement. These take into account the different time lines and types of reconstruction and rehabilitation for PCC and AC pavement. CTLGroup recommends LCCA studies for California pavements utilize CALTRANS estimates of reconstruction and rehabilitation schedules.

LIFE CYCLE ASSESSMENT

Life cycle assessment (LCA) is a methodology for assessing the social and environmental aspects associated with a product over its life cycle — from raw material acquisition through production, use, and disposal. An LCA is used to assess a product’s environmental aspects and the potential impacts the product has on the natural environment.

An independent, third party, report was prepared by the Athena Institute13 on two impact indicators, embodied energy and global warming potential, for AC and PCC pavements. The global warming potential index (GWPI) is from the International Panel on Climate Change’s 100-year time horizon factors:

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\text{GWPI (kg)} = \text{CO}_2 \text{ kg} + (\text{CH}_4 \text{ kg} \times 23) + (\text{N}_2\text{O} \text{ kg} \times 296)
\]

The report compared six PCC and AC pavements in Canada as follows:

- A typical Canadian arterial road with two different subgrade foundation types
- A typical Canadian high volume highway with two different subgrade foundation types
- A Quebec urban freeway
- A section of Highway 401 freeway in Ontario

Results indicate the AC pavements have 31 to 81% more embodied energy than the PCC pavements. Accepted practice in the LCA industry is to also include the feedstock energy14 of the AC when performing LCAs. The AC pavements have 2.3 to 4.1 times more embodied energy than the PCC pavements when the feedstock energy is included. Results for individual pavement types are shown in Table ES1 from the Athena report, reproduced below.

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12 Some of the PCC pavement had not yet received rehabilitation and this age was estimated. The units of EUAC for this study were $/lane/mile/year/100,000 trucks.

13 A Life Cycle Perspective on Concrete and Asphalt Roadways: Embodied Primary Energy and Global Warming Potential, Cement Association of Canada, 1500-60 Queen Street, Ottawa, ON K1P 5Y7 September 2006. www.cement.ca

14 Feedstock energy is the gross combustion heat for any material input to a product system which may be considered as an energy source, but is not being used as such. It can be considered the fuel content.
The results assume no recycled asphalt pavement (RAP). For 20% RAP in the binder coarse for the arterial and high volume highway designs, the PCC pavements have 3.5 to 5% less embodied energy. The RAP affects the PCC pavements because they have AC shoulders and AC overlay as part of the rehabilitation. The AC pavement options have 5 to 7.5% less embodied energy when 20% RAP is used. While 20% RAP reduces the differences between AC and PCC pavements, the overall results are still significant.

The results assume 10% fly ash as a replacement for portland cement in the PCC pavement. Up to 25% fly ash replacement is commonly used in construction. A 1% replacement of cement with fly ash or slag cement results in approximately 1% reduction in embodied energy per unit of concrete. Therefore, using 25% fly ash as replacement for portland cement rather than the 10% assumed by Athena will improve the results for PCC pavement.

The results for GWPI for the six pavements are mixed, as indicated by Chart 2 from the Athena report as reproduced below. These differences are considered insignificant by Athena.

Sixty percent of the CO₂ emissions in the cement manufacturing process are from calcination and not from the burning of fossil fuels. Since CO₂ emissions from cement manufacturing are two orders of magnitude larger than any other stage of concrete production, approximately 60% of the CO₂ emissions embodied in concrete are from calcination. Using 25% fly ash as replacement for portland cement rather than the 10% assumed by Athena will reduce the GWPI of the PCC pavement options.

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Also, the Athena study considered only two impact indicators, embodied energy and GWPI, rather than a full set generally considered in LCAs. A limited set of impacts, such as only CO₂, negatively impacts concrete because of the calcination of limestone during the manufacturing process. A full set of impact indicators includes land use (or habitat alteration), resource use, climate change, ozone layer depletion, human health effects, ecotoxicity, smog, acidification, and eutrophication. Considering a full range of impact indicators rather than only embodied energy and GWPI will provide a more complete life cycle assessment and more balanced results for PCC.

Please do not hesitate to contact us.

Sincerely,

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Attachments: References submitted in a separate distribution.