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LIFE CYCLE ASSESSMENT OF ROAD CONSTRUCTION

K PRAKASH 1*, P PRATHUSHA 2*

1. *II.M.Tech , Dept of CIVIL, AM Reddy Memorial College of Engineering & Technology, Petlurivaripalem.*
2. *Asst .Prof, Dept. of CIVIL, AM Reddy Memorial College of Engineering & Technology, Petlurivaripalem.*

ABSTRACT

A two-stage study "Life cycle analysis of road construction and earthworks" was part of a more extensive Finnish research project "Assessment of the applicability of secondary products in earthworks". In the first stage of this work a life-cycle impact assessment procedure for the comparison and evaluation of alternative road and earth constructions was developed. Additionally, a database containing the environmental burdens of the most significant construction materials and unit operations was constructed. In order to evaluate the applicability of the procedure, the use of coal ash, crushed concrete waste and granulated blast-furnace slag in road construction was evaluated in case studies. The use of these secondary products was also compared with the use of natural materials in corresponding applications. In the second stage the assembled data for utilization was transferred as a practical model by creating an inventory analysis program to calculate and compare the life cycle impacts of the most common road constructions and foundation engineering methods. The analysis model includes all the significant life-cycle stages covering the production and transportation of materials, their placement in the road structures and the use of the construction. The situation after the use of the construction is not included because the structures most commonly remain in place after they have been withdrawn from service.

INTRODUCTION

Life cycle impacts are being used increasingly as a selection criterion for products and materials both in industry and in other activities. Assessment and calculation methods have developed since the early days of LCA, and the scope of its application has grown enormously. Describing the total environmental impacts of activities and products reliably and in such a way that alternatives can be compared is no simple task. The "cradle-to-grave" life cycle always involves numerous stages and activities that give rise to a number of different environmental loadings. In order to keep the amount of work within reasonable bounds, the assessments must always be limited and efforts must be made to identify the critical stages of the life cycle and those factors responsible for environmental loadings. This requires not only adherence to the basic principles of life cycle analysis but also knowledge of the product or activity in question.

The special features of the construction sector are the large volumes of materials used, the long service lives of the finished products, the need to examine constructions as a whole rather than comparing alternative materials, and the significant effect of the constructions' longevity and need for repair on their life cycle environmental loadings. The development of methods for the environmental impact assessment of materials and constructions and for their comparison on an ecological basis is regarded as being important especially in the building construction industry. The development of an internationally accepted life cycle assessment methodology for the analysis and comparison of building products and projects is also an area of research covered by Tekes´s (The National Technology Agency) "Environmental Technology in Construction" programme (1994 - 1999). This study is part of the sub-programme entitled Environmental Geotechnology, the aims of which include the reduction of industrial waste by developing recycled fills from industrial by-products.

Road construction

About 70 million tonnes of natural mineral aggregate are used each year in Finland for road construction and earthworks. In addition to road construction, a large number of carparks, market squares and other similar constructions are also built. The length of the road network, excluding forest car tracks, is over 200 000 km, of which about 78 000 km are public roads maintained by Finnra (Finnish National Road Administration), about 20 000 km are streets, some 1 300 km of which are in Helsinki alone, and 120 000 km are private roads.

Life cycle assessment according to ISO 14040

Life cycle assessment is a standard method widely used to assess comprehensively the potential environmental impact of prod-ucts or systems of products. All environ-mental aspects of the product life cycle (emissions into air, water and soil, waste, use of raw material and exploitation of nature) are taken into account. this com-prehensive approach avoids the misalloca-tion of environmental effects and provides an overview for possible impact reduction. the LCA method is described in the inter-national standards ISO 14040 and 14044.
A LCA study comprises four phases which affect one another. In the first phase the goal and scope of the investigations and the resulting system boundaries are defined. In the inventory analysis phase, all relevant materials and energy inputs and outputs are included in the system. In the assessment phase, the environmen-tal effects of the system components are assigned to different impact categories. Different materials are weighted according to their damage potential and summarized in total impact indicators. In the final inter-pretation phase, the impacts are analysed and evaluated in order to draw conclusions or make recommendations. In this study, results are presented for the LCA of the construction, use and maintenance of a motorway section 1 km in length.

SCOPE

The basic aim of the study is to provide a clear and functional procedure for the life cycle impact assessment of road constructions and for the comparison of alternative structural solutions. The assessment procedure should take account of the special features of road constructions. It was hoped that the assessment procedure would be so simple and easy to use that in future it could also be used by planners and designers.

However, the assessment should cover the main life cycle phases of the constructions as well as the most important environmental impacts, and it should also meet the other basic requirements set for life cycle analysis. The study focused especially on the comparison of industrial by-products and conventional materials in the sphere of road construction, but there was also a desire to apply the procedure to the environmental impact assessment of other constructions as well.
A comparative procedure based on effect-scoring that would complement the inventory process for road constructions was set as one aim of the study, because it was hoped to that in future the assessment procedure would also be suitable for use in connection with other planning systems, e.g. the life cycle cost analysis being developed for road constructions. These systems require that the results can be presented as simple, mutually comparable numerical values. In addition, there was a desire to simplify the assessment in cases where the user is not fully conversant with environmental impacts. Another aim was to obtain a wider view of the significance of the environmental loading data being dealt with, and thus to make it easier to set system boundaries.

The study was carried out in two stages so that in the first stage a proposal was made for a procedure suitable for the life cycle impact assessment of road construction. In order to evaluate the applicability of the procedure, the use of coal ash, crushed concrete waste and blast-furnace slag in road construction was evaluated in case studies. The use of these industrial by-products and waste materials was compared with the use of natural materials in corresponding applications. The necessary data was also collected during the studies. Excel-based formulae for each work stage were used as the inventory procedure.

The aim of the study's second stage was to transfer the assembled data for utilisation as a practical model by creating an inventory analysis program to calculate and compare the life cycle impacts of the most common road constructions. The data obtained in the first stage of the study was augmented to the extent necessary for this purpose.

DATA QUALITY

Data sources

Because of the local nature of the effects of road constructions, primarily local or material-specific data was used. Use was also made of general Finnish knowledge, which was supplemented by international sources of data where necessary.

Production of materials

The environmental loadings of mineral aggregate and gravel production were assessed mainly on the basis of information provided by material suppliers and Finnra. The environmental loadings caused by the storage, loading and crushing of industrial by-products (crushed concrete waste, blast furnace slag, foundry sand and fly ash) were assessed on the basis of information provided by their suppliers. The emissions of electrically powered equipment were calculated using the average emission factors of Finnish power production (Pirilä et al. 1999).

Transportation

It was assumed that the materials used in road construction would be transported by lorry. The quantities to be transported were estimated on the basis of information provided by Finnra, other road builders and designers, and material producers. Transportation and exhaust gas emissions were estimated using the emission factors of Mäkelä et al. (1996).

Road construction

The masses, volumes and weights per unit volume of road paving materials during storage and transportation were calculated on the basis of information provided by Finnra, material suppliers and TS data cards.

The operating times of work machines were calculated on the basis of TS data cards. The energy consumption and emissions of machines were calculated on the basis of the emission factors proposed by Puranen (1992

Road reconstruction

Road reconstruction is assumed to concern only the wearing course and to occur at specific intervals as resurfacing and remixer stabilisation works. The user of the inventory analysis program can select the number of reconstruction measures on a case-by-case basis. The data used in calculating the environmental loadings of road reconstruction comes from Finnra and firms carrying out road reconstruction works.

Leaching

The quantities of substances leaching out of materials and migrating into the soil during placement were estimated primarily on the basis of leaching studies carried out by the Technical Research Centre of Finland. The research method was primarily the CEN high-speed shaking test (pr EN 12457). The solubility of natural materials has not been studied in Finland. Moreover, foreign data comparable with data obtained by the solubility research methods used in Finland have only been available from a couple of narrow studies.

Land use

Land use is an environmental loading that essentially belongs to road construction. The development of land use assessment methods is problematic, because the consequences of land use exist on many levels and it may not be possible to identify them precisely. Moreover, the effects are often dictated by local and site-specific factors. It has not been possible to develop a simple calculation and assessment method that would be both applicable to different types of sites and capable of translating the effects of land use into a mutually comparable form.

The most important factor in road construction is generally the surface area beneath the structure itself. However, the significance of this should, in the first instance, be assessed as a part of community planning. The extraction, processing (e.g. crushing) and storage of raw materials and, for instance, the land surface area that would have been required for landfill disposal as an alternative to the utilization of by-products are more important in the comparison of constructions.

Data deficiencies and uncertainties

The availability of data on by-products is limited by the fact that their utilization is not yet well established. For this reason it is not always easy to determine the most usually employed working methods and the most general implementation methods of the work stages. As yet there is still relatively little experience- or measurement-based data on the work stages and their environmental loadings.

It is necessary to make many assumptions when calculating the operating times of work machines, because the work stages can be carried out in many different ways using machines of different ages and efficiencies. It was assumed in the calculations that the machines were of average efficiency and used in normal summer conditions.

CASE STUDIES

In the first stage of the study the use of conventional materials and industrial by-products were compared in a theoretical road construction (Eskola et al 1999). The alternative pavements and subgrades were examined separately.

Pavement structures

- The pavement structures were designed on the basis of the following assumptions:
- The structural courses are laid directly on the subgrade after removal of the topsoil. The subgrade is frost-susceptible sand till.
- The structure to be studied is main road cross-section IN-10.5/7.5. The dimensions of the cross-section are presented in Figure 3. The target bearing capacity of the structure (pavement structure class 1 AB) on top of the pavement is 420 MPa.
- The frost conditions are assumed to be of medium severity and the design freezing index 30 000 h° C. According to Finnra's design code, the combined thickness of the courses should be at least 900 mm in such conditions.
- The loading design of the case study constructions is done as conventional bearing capacity design.

Subgrades

In the alternative subgrades examined, the natural ground was assumed to be weakly bearing and compressible soft clay extending to a depth of 5 metres. The ground beneath the clay is bearing. Constructions most commonly used on shallow and deep layers of weak soil were examined as alternatives. To make comparisons easier, the depth of weak soil was assumed to be the same in all the constructions.

Landfill disposal

Landfill disposal was examined as an alternative to the utilisation of fly ash and crushed concrete waste. In these case studies it was assumed that the fly ash would be disposed of in basin structures made of blasted rock using the so-called sandwich method. It was assumed that the crushed concrete waste would be disposed of as such in the landfill. The thickness of the landfill layer was assumed to be 10 metres.

System boundaries

The system boundaries were as described in section 4. The functional unit selected for the case studies was a one-kilometre-long section of road, the structural design of which is given in Figure 3. With regard to the subgrades, the functional unit was 17 metres wide, 5 metres deep and 1 kilometre long. In the landfill disposal alternative the functional unit was the quantity of by-product used in the alternative road construction

Consumption of raw materials

The consumption of natural materials, the by-product quantities and the consumption of water in the alternative pavement structures are given in Figure 4. The consumption of raw materials in the landfill alternative for the fly ash and crushed concrete waste was also calculated in these case studies. In the by-product constructions the consumption of natural materials is primarily influenced by the extent to which different materials of the structural courses can be replaced by recycled fill. The differences between the alternative constructions are reduced by the fact that a 0.5-metre sand embankment and asphalt pavement are assumed in all the constructions. The need for water is greatest in the fly ash constructions because fly ash has to be wetted before laying to obtain the optimum moisture content in the fly ash mix.

Water-soluble substances present in the materials can be carried away by run-off water into the environment of the site and from there into the groundwater. The amount of leaching depends on the composition of the material, the amount of water passing through the material, and the manner in which it is laid. Covering with a material possessing poor water permeability, e.g. asphalt or even moisture barriers, reduces the amount of water filtering through the structure. Leaching may also be reduced by consolidation of the finished structure

Some foreign solubility data were used in the case studies, but this was replaced in later calculations by Finnish data. Sulphates, calcium, chlorides and, of the heavy metals, molybdenum, chromium and vanadium leach the most out of the fly ash. There is some leaching of sulphates and chromium from the crushed concrete. Vanadium leaches out of blast-furnace slag, and there is some leaching of sulphate compounds due to the effect of short-term washout from the structures' top surfaces. Lack of data meant that it was not possible to take account of the substances leaching out the natural materials and cement nor the solubility-reducing effect of cement pollutants.

Noise

Noise emissions are usually reported as a sound level, i.e. as the A-weighted sound pressure level (L_{pA}), which is defined as: $L_{pA}= 20 \lg(p_A/p_0)$, where p_A is the A-weighted sound pressure and p_0 the reference pressure (=µ 20 Pa). The sound level unit is the decibel (dBA). Design values are given for the noise level in a Council of State Decision 1992/93. The detrimentality of noise is usually assessed in relation to the closest susceptible point to the disturbance, or the distance from the disturbance at which the above-mentioned design noise values are satisfied is calculated.

It was not possible in this study to determine the total noise of the alternatives because the work stages occur in different places and the work machines are used at different times and for periods of different lengths. However, the alternatives were compared as follows: the noise level of each work stage was reported as the work time at which the so-called noise time (dBA • h) for each work stage was achieved. The noise times for each structural course were combined and these results were compared with each other.

Loadings caused by road maintenance

The environmental loadings caused by road maintenance over a period of 50 years were assessed on the basis of the report by Häkkinen and Mäkelä (1996). Road maintenance was assumed to take place in accordance with the Finnish road maintenance strategy (Häkkinen & Mäkelä 1996, Appendix 3) and the loadings were calculated by proportioning them to the road width. This approximate estimate of the environmental loadings of road maintenance is presented in Table 11. The program has subsequently been improved to allow the roadkeeping strategy to be defined and for the environmental loadings of road maintenance to be calculated accordingly

Land use

Land use can cause very different consequences for the landscape, soil, waters, fauna and flora. Road construction affects both the landscape and living environment of people and animals. The excavation of sand and gravel damages the soil and alters the landscape. These excavations have impacts not only on the soil, waters, flora and fauna but also on the recreational usage of the areas concerned. The crushing of aggregate causes changes in the structure and potential use of land, as local ground materials are removed and deposited elsewhere. Landscape changes and the destruction of aesthetically valuable rocky areas are also a consequence of rock blasting and crushing (Kylä-Setälä & Assmuth 1996).

CONCLUSION

Comparison of the environmental impact of concrete and asphalt pavement for motorway construction and maintenance shows that their effect on GWP is simi-lar. for ODP the asphalt pavement causes a potential environmental impact which is 430% more than with concrete. In the case of POCP, AP and EP the impact is from 160% to 220% more with asphalt. the present study shows that the environ-mental impact due to the construction of motorways, their use by traffic and their maintenance can be reduced. the poten-tial environmental impact can be reduced by optimizing the production of the con-struction materials. In the case of concrete motorways, a reduction in the clinker con-tent of the cement would reduce environ-mental impact by up to 21%; in the case of the asphalt motorways, the use of secondary fuels and the increased reuse of reclaimed asphalt would also reduce environmental impact. the evaluation of a service period of 30 years shows that durable construction methods and roads with low maintenance requirements offer significant advantages. the potential environmental impact due to traffic load is 100 times more than due to construction and maintenance together – the largest and most effective reduction in impact is possible here. numerous studies have already shown the effect of pavement surface structure on fuel consumption. A reduction in fuel consumption of about 10 % could be achieved by the improvement of pavement surface texture or evenness as well as pavement stiffness. further investigations and measures on pavement optimization would lead to more effective reduction of the environmental impact of roads. A reduction of fuel consumption of 0.5% over a service period of 30 years and for a 1 km motorway section would reduce CO_2 emission by 1 154 t CO_2-eq. A reduction of fuel consumption by 2% would lead to a reduction in CO_2 emission (GWP) well above the impact of motorway construction and maintenance together. A reduction of 10% fuel consumption for just heavy goods vehicles would save 10 760 t CO_2-eq. thus construction methods aimed at lowering fuel consumption are far more environmentally effective than construction methods tailored to low impact during construction and use.

The inventory analysis program is limited at this stage to calculating and comparing the environmental loadings of constructions only. Activities associated with the construction, use and maintenance of roads that are presently beyond the scope of the program include bridge construction, land clearance works, road-marking work, the construction and maintenance of equipment necessary for traffic control, road lighting, and regular or seasonal road maintenance work (salting, sanding, snowploughing, etc). The creation of procedures for calculating the environmental loadings of such factors would be important for assessing the impacts of material selections and the total loadings of road usage.

REFERENCES

- Anon. 1996a. Vejen mod et bedre miljo. Vejdirektoratets miljostrategi 1996 - 2000. Vejdirektoratet Rapport nr. 44. 38 s
- Anon. 1996b. Tielaitos kestävällä tiellä. Tielaitoksen ympäristöohjelma 1996. (Environmental program of Finnish Road Association). 12 s.
- Besluiten 567. 1995. Bouwstoffenbesluit bodem-en oppervlakwateren-bescherming. Staatsblad van het Koninkrijk der Nederlanden. 92 s.
- Blomberg, T. 1998. Bitumien ja asfaltin elinkaariarviot. (Life-cycle assessment of bitumen and asphalt). Seminaarissa: Elinkaariarviointi käytännön työkaluna, Neste/VTT, Keilalampi 6.5.1998.
- Blomster, D. 1989. Pitkäsuon täyttösuunnitelma. Imatran Voima Oy. Vantaa. 9 s.
- Broers, J., Hoefnagels, F. & Roskamp, H. 1994. Life cycle assessment of road embankment in phosphogypsum. Preliminary results. In: Goumans, J., van der Sloot, H. & Aalbers, T. (ed.) Environmental aspects of construction with waste materials. Elsevier Science B.V. S. 539 - 542.
- Dartsch, B. 1993. Wechselwirkungen zwischen Material und Umwelt am
- Beispiel Kraftwerksnebenprodukte. In: Materialen in ihrer Umwelt. VDI
- Berichte Nr 1060. Düsseldorf. S. 229 - 237.
- EPA. 1988. U.S. Environmental Protection Agency: Supplement B to compilation of air pollutant emission factors. AP-42. Research Triangle Park.
- Eskola, P. & Mroueh, U.-M. 1998. Kivihiilivoimalan sivutuotteiden maarakennuskäytön elinkaariarviointi. (Life-cycle assessment of the use of fly ash and FGD residues in earthworks). VTT Research Notes 1898. Espoo. 82 s. + liitt. 11 s. (in Finnish).
- Eskola, P. , Mroueh, U-M., Juvankoski, M. & Ruotoistenmäki, A. 1999. Maarakentamisen elinkaariarviointi. Life-cycle analysis of road construction and earthworks). VTT Research Notes 1962. 111 p. + app. 16 p. (in Finnish).
- Finnra (Tielaitos). 1994. Asfalttiasemien ja kivenmurskaamojen ympäristönsuojelu 1994. (Environmental Protection of Asphalt Mixing Plants and Rock Crushing plants). Finnish Road Association. Helsinki. 24 s.
- Finnra (Tielaitos). 1995. Asfalttiasemien, kivenmurskaamojen ja öljysora-aseman pöly- ja melumittaukset. (The emission and noise measurements of asphalt mixing and rock crushing plants.) Uudenmaan tiepiiri. Helsinki. 31 s.
- Finnra (Tielaitos). 1997. Design of pavements.
- Himanen, V., Mäkelä, K., Alppivuori, K., Aaltonen, P. & Louhelainen, J. 1989.
- The monetary valuation of road traffic's environmental hazards. Espoo. VTT
- Tiedotteita 943. 40 s.
- DESCOrnEt, G.: "road Surface Influence on tire rolling resistance.
- Surface Characteristics of roadways:" International research and technologies, AStm StP 1031, p. 401415, Philadelphia, 1990
- ISO 14040 (2006): Examples of environmental performance evaluation LCA (Life Cycle Assessment)
- ISO 14044 (2006): Environmental management – Life cycle assessment – requirements and guidelines
- fOrSCHunGSGESELLSCHAft für StrASSEn- unD VErkEHrSWESEn

fGSV (2009): richtlinien für die Anlage von Autobahnen (rAA); Ausgabe2008 (German)http://www.ecoinvent.ch. 2009

- kELLEnBErGEr D., ALtHAuS H.-J.; künnIGEr t. (2004): "Building Products Part III: Concrete Products and Processes". ecoinvent report no. 7,
- Swiss Centre for Life Cycle Inventories, Dübendorf
- kELLEnBErGEr, D.; ALtHAuS, H.-J.; WErnEr f. (2004): "Building Products Part XVIII: Additional Products and Processes". ecoinvent report no. 7,
- Swiss Centre for Life Cycle Inventories, Dübendorf
- LAGAnIEr, r.; LuCAS, J. (1990): "the Influence of Pavement Evenness and macrotexture on fuel Consumption." Surface Characteristics of roadways: International research and technologies, AStm StP 1031, p. 454-459, Philadelphia
- LArSSOn, r.; AnDErSSOn, r. (2004): "Benefit of reduced fuel Consumption". Economic and Environmental Perspectives – A novel Approach, 9th International Symposium on Concrete roads, Istanbul
- LunDStröm, k.; fInnSEmEnttI, O. (2003): "Environmental Impact of Concrete and Asphalt Pavements". 8th International Symposium on Concrete roads, Lissabon
- mILACHOWSkI, C.; StEnGEL t.; LOWkE D.; GEHLEn C. (2010) „Erstellung einer ökobilanz für die Herstellung und nutzung eines Autobahnabschnitts". forschungsbericht 20-f-0068, tu münchen, münchen
- nrC-CStt (2000): „Effect of Pavement Surface type on fuel Consumption –
- Phase 2: Seasonal test", CStt-HWV-Ctr-041, national research Council of Canada – Centre for Surface transportation technology, Ottawa