Part 3

ASH AND SLAG HANDLING

3.5. Applications of ash and slag from power coals

3.5.2. Road construction

3.5.2.6. Life Cycle Cost Analysis of road pavement with Greek High Calcium Fly Ash Roller Compacted Concrete

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ABSTRACT

Road pavement construction is a very high capital investment, usually of public funds. It should be based on economic and environmental protection criteria. Therefore, Life Cycle Cost Analysis is necessary for selecting the most suitable for the case design of pavement. In Greece, until now, the experience in construction of rigid pavements is very limited. Flexible asphalt pavements dominate although the great inclinations, the hot climate in summer and longer service life of concrete favor concrete pavements. The main hamper is the relatively great initial cost of construction and the reluctance of contractors to change traditionally used asphalt. However, Greek fly ash, which is specified in the 2007 Hellenic Specifications for its use in plain concrete, could be used in replacing a great volume of cement in roller compacted concrete (RCC) pavement reducing the initial cost of concrete road construction. This offers new perspectives for a low cost concrete road by using RCC.

In this study, an effort is made on economic evaluation of two alternatives, which differ in the type of pavement. Specifically, the purpose of this study is to examine and compare the cost between flexible and unreinforced rigid pavement, which are designed for greek roads with high traffic, and in particular heavy vehicles. Furthermore, it examines alternatives for the composition of concrete for rigid pavement (use only traditional cement and use of fly ash as a partial replacement of cement), and also for anti-skidding layer materials. The methodology for analyzing pavement costs takes into account, not only the initial construction cost, but also the maintenance and reconstruction cost, the user cost and the salvage value of the materials, during a standard analysis period. The method for conducting this economic analysis is known as Life Cycle Cost Analysis (LCCA) and uses basic concepts of engineering economics. The analysis comes to very useful conclusions about the cost of rigid pavements, especially for the alternatives in which fly ash is used as a partial replacement of cement. In combination with other factors and results of other studies, they will lead the decision maker to the final choice of the appropriate solution for the particular case.

Keywords: life cycle cost, high calcium fly ash, rigid pavement.

1. INTRODUCTION

Pavement construction is a very high capital investment. This investment can reach huge dimensions depending on the project-size, and is usually derived from public funds. Therefore, it is essential that the project planner or/and decision maker has to conduct an economic analysis in order to compare different scenarios. Another very important criterion that has to be considered in the comparison of alternative scenarios is the environmental protection and awareness.

Concrete pavements, in comparison with asphalt, favor in characteristics like structural strength, durability in time, maintenance requirements, serviceability of traffic volume produced especially by heavy vehicles and trucks, strength in extreme ambient conditions (hot and cold climates), economy in layers' materials, user safety and in a lot of other economic, environmental and socially parameters.

These reasons have urged plenty of countries like U.S.A., Germany, Austria, Canada, etc. to construct concrete pavements extensively. However, in Greece, until now, the experience in construction of rigid pavements is very limited due to the relatively great initial construction cost in combination with the absence of construction knowledge and the reluctance of contractors to change traditionally used asphalt.

However, the initial cost of concrete road construction can be significantly reduced using fly ash. Specifically, Greek fly ash, which is specified in the 2007 Hellenic Specifications for its use in plain concrete, could be used in replacing a great volume of cement in roller compacted concrete (RCC) pavement (Papayianni & Anastasiou 2006; Papayianni 2006). This offers new perspectives for a low cost concrete road by using RCC.

This study is an effort on economic evaluation of alternatives, which differ in the type of pavement. The purpose of this study is to examine and compare the cost between flexible and rigid pavement, which are designed for roads with high traffic, and in particular heavy vehicles. Furthermore, it examines alternatives for the composition of concrete for rigid pavement (use only traditional cement and use of industrial by-products as a partial replacement of cement), and also for anti-skidding layer materials. In other words, this economic analysis is required to answer the following questions:

a. Is economically advantageous to construct rigid pavements in Greece, especially for roads with high traffic and in particular heavy vehicles?
b. What is the financial profit (or loss) between alternative design solutions for rigid pavement construction using Greek fly ash as a partial replacement of cement in the concrete?
c. In case that fly ash leads to significantly lower cost solutions, which is the margin of its future increased price that still allows more economic solutions compared to flexible pavements?

The method for conducting this economic analysis is known as Life Cycle Cost Analysis (LCCA) and uses basic concepts of engineering economics. It is a rational method which takes into account not only the initial construction cost, but also the maintenance and reconstruction cost, the user cost and the salvage value of the materials, during a standard analysis period.

The analysis comes to very useful conclusions about the cost of rigid pavements. In combination with other factors and results of other studies, they will lead the decision maker to the final choice of the appropriate solution for the particular case.

2. DESIGN OPTIONS

In the economic analysis five different scenarios are analyzed. The study examines the cost of alternative scenarios of concrete pavement in comparison with the cost of a flexible pavement. The rigid pavements differ in the anti-skidding layer and the composition of concrete. The types of anti-skidding layers considered are (Apostolakaki 2011, FHWA 2011):

a. anti-skidding — textured aggregates of electric arc furnace slag and

b. thin anti-skidding 25mm layer using modified asphalt.

Also, the concrete synthesis differs as follows: The types of anti-skidding layers considered are:

a. traditional composition using only cement and
b. composition using fly ash as a 50 % replacement of cement.

The various pavements are designed for the same data. Thus, the width and the length of the pavement are 7,30 m and 1km, respectively. In all cases, the California Bearing Ratio (CBR) of the subgrade is equal to 16 % and the mean annual air temperature (MEAT) is 16 ^{o}C. For pavement design calculations, the daily traffic volume of commercial vehicles (>1500kg) in each direction at the time that the project is assigned to traffic, is 2.113 commercial vehicles (40 % of the total traffic volume). The percentage distribution of the traffic volume of commercial vehicles is shown in Table 2. Also, it is expected an annual traffic increase equal to 4 % (which represents the weighted average annual increase of traffic for Egnatia Odo [6]) and is considered constant throughout the analysis period.

Table 1. **Use of rigid pavement worldwide**

Country	Use of rigid pavements	Comments
U.S.A	29,3 % of the interstate system	-
Germany	25 % of high-volume motorway network	Exclusive use of JPCP
Austria	66 % of high-volume motorways	-
Belgium	40 % of motorways 60 % of rural roads 17 % of total roadway network	Wide use of CRCP
The Netherlands	5 % of motorways 4 % of total roadway network 10 % of bicycle paths	Use both JPCP and CRCP
Canada	4 % of roadway network at the province of Quebec Planning for construction of new concrete pavements	Use both JPCP and CRCP
United Kingdom	0,5 % of total roadway network	—
Greece	Absent use	—

Table 2. **Distribution of analysis' traffic volume of commercial vehicles (%)**

Type of commercial vehicle (CV)	Percentage (%)
Buses	20
2-axle trucks	20
3-axle trucks	35
3-axle trailers	6
4-axle trucks	5
4-axle trailers	8
Over 4-axle trucks	6

The economic analysis is carried out for an analysis period of 40 years and the different design options are as following:

Scenario 1: Asphalt pavement designed for 20 years with total layer thickness equal to 0,475m. The pavement designed by Egnatia Odos S.A. At the end of the design period is reconstructed in order to last another 20 years. At the intermediate periods between 0 to 20 years as well as between 20 to 40 years maintenance works are carried out in order to keep the pavement performance in satisfactory and safe level.

Scenario 2-a: Unreinforced concrete pavement designed for 40 years with total layer thickness equal to 0,410m. Aggregates of electric arc furnace slag are used for anti-skidding layer. The pavement design is done in compliance with British method proposed in 1994 and is based on a radical revision occurred in 1987 in the older method RN29. The pavement is rehabilitated by laying an asphalt concrete overlay in order to last another 12 years. At the intermediate periods between 0 to 28 years as well as between 28 to 40 years maintenance works are carried out in order to keep the pavement performance in satisfactory and safe level. In this concrete pavement type, longitudinal joints will not be constructed due to the slab width. Three different types of joints (contraction, expansion and bending) are constructed in transverse direction.

Scenario 2-b: It is exactly the same pavement structure as the scenario 2-a. The only difference is the anti-skidding surface which in this case is thin anti-skidding layer 25mm using modified asphalt. Thus the total thickness of the pavement is 0,435m.

Scenarios 2-a-2 and 2-b-2: The pavements are the same as in scenarios 2-a and 2-b respectively. The difference is identified in the concrete composition. Fly ash replaces the half volume of the cement.

The structures of the alternative scenarios and also the type and schedule of the maintenance works are represented in Tables 3 and 4, respectively.

Table 3. **Alternative scenarios' pavement structure**

Scenario 1	Scenario 2-a / 2-a-2[(1)]	Scenario 2-b / 2-b-2[(1)]
Thin anti-skidding layer 25mm using modified asphalt	Anti-skidding – textured aggregates of Electric Arc Furnace Slag (sand with spec. weight 3,020ton/m^3, quantity 3,0kg/m^2)	Thin anti-skidding layer 25mm using modified asphalt
Tack coating	Unreinforced concrete slab 0,26m (concrete type C30/37)	Tack coating

Asphalt binder course 50mm using common asphalt (tot. thick. 0,10m)	PVC film	Anti-skidding – textured aggregates of Electric Arc Furnace Slag (sand with spec. weight 3,020ton/m^3, quantity 3,0kg/m^2)
Tack coating	Sub-base of lean concrete 0,15m (concrete type C12/15)	Unreinforced concrete slab 0,26m (concrete type C30/37)
Prime coating	Joint reinforce (steel bars)	PVC film
Asphaltic base 50mm (tot. thick. 0,15m)	Asphalt elastomeric joint sealant	Sub-base of lean concrete 0,15m (concrete type C12/15)
Base 0,10m (tot. thick. 0,20m)	—	Joint reinforce (steel bars)
Sub-base 0,10m (tot. thick. 0,20m)	—	Asphalt elastomeric joint sealant
(1) The concrete in this scenario is composed by 50% replacement of the cement by fly ash.		

Table 4. **Type and schedule of the planned maintenance works for alternative scenarios**

Time (year)	Scenario 1	Scenario 2-a / 2-a-2	Scenario 2-b / 2-b-2
0	Assign to traffic	Assign to traffic	Assign to traffic
7	Routine periodic maintenance	Joint maintenance	Joint and anti-skidding surface maintenance
14	Routine periodic maintenance	Joint and anti-skidding surface maintenance	Joint and anti-skidding surface maintenance
20	Reconstruction in order to be used for 20 years	—	—
21	—	Joint and anti-skidding surface maintenance	Joint and anti-skidding surface maintenance
27	Routine periodic maintenance	—	—
28	—	Rehabilitation	Rehabilitation
34	Routine periodic maintenance	—	—
35	—	Routine periodic maintenance	Routine periodic maintenance

For the conduct of that analysis the following assumptions are considered:

a. Only the main structure of the pavement is taken into consideration for the analysis.
b. The design period of the pavement is considered equal to its service life. In case that longer service period is required, maintenance or reconstruction of the various layers is necessary in order the pavement to serve n additional years.
c. The analysis of every scenario starts from the time that the pavement is assigned to traffic.
d. In all alternative design solutions maintenance, restoration or/and reconstruction are scheduled, as it is followed in practice both in greek and international pavement section.
e. The user cost is calculated due to lost time and additional vehicle operation during delays caused by maintenance, restoration and reconstruction activities. Other reasons like accidents, feeling of satisfaction/dissatisfaction etc, that can produce user cost are neglected because of lack of respective data for Greece or non difference in the cost between the various scenarios.
f. The salvage value of the materials is assumed as a proportion of the material present value. The material value is considered equal to 60 % of their total value (material and construction value). It is taken into account that:

- The salvage value of unbound, intermediate asphalt and concrete courses is considered equal to 40 % of their present value at the end of the analysis period.
- For the surface courses, salvage value exists only in case that a number of years remain until the end of their service life.

3. METHOD OF ECONOMIC ANALYSIS

The economic analysis is conducted using the present value method. The following costs are under consideration:

a. Initial construction cost.
b. Scheduled reconstruction and rehabilitation costs at any time during the analysis period.
c. Routine periodic maintenance cost.
d. User cost due to delays and additional vehicle operation during maintenance, rehabilitation and reconstruction works.
e. Salvage value of the materials at the end of analysis period.

Present value of the total investigation is calculated using the following equation:

$$PV = K_o + \sum_{t=1}^{t=n} DC_{i,t}\left[KR_t + KM_t + KU_t\right] \quad DC_{i,t}SV$$

where:

PV: Total present value

K_o: Initial construction cost

$DC_{i,t}$: Discount coefficient for discount rate i in the year t, $= 1/(1+i)^t$

KR_t: Reconstruction and rehabilitation cost in the year i expressed in present values

KM_t: Maintenance cost in the year i expressed in present values.

KU_t: User cost in the year t during which maintenance, rehabilitation or reconstruction works are carried out, expressed in present values.

i: Discount rate

SV: Salvage value

n: Analysis period, in years. In all cases is assumed as 40 years.

The discount rate, that reflects the real rate of return on invested money, is taken 5 % (normal rate) which is equal to the suggested discount rate from the European Union. The present value of the alternative scenarios is calculated also for a range of various discount rates like 2 % (low rate), 4 % (almost normal rate), 6 % (high rate) and 8 % (quite high rate). More than one value of discount rates are selected for consideration in order to assess how sensitive the analysis is to variations in the real rate of return and to what extent the level of the discount rate may favor one design over another.

3.1. Initial construction, maintenance, rehabilitation and reconstruction cost

The initial construction, maintenance, rehabilitation and reconstruction cost of the pavement includes the cost of purchase, transportation, proper processing and placement of all materials for the full construction of the pavement. The material quantities can easily be calculated from the standard dimensions of the pavement and geometric data of each pavement structure. The unit cost of the required materials and works is taken from tables that present the material/work values for road construction and they are created by Ministry of Environment, Spatial Planning and Public Works (last update: July 2008). For these materials/works that are not included in these tables, values from companies that are occupied with these works are used. The total cost is expressed in €/m^2. Table 5 contains the cost for each individual type of material/work used for determining the construction, maintenance, rehabilitation and reconstruction cost.

Table 5. **Material – work values considered in economic analysis**

Material - Work	Cost/unit[1]
Thin anti-skidding layer 25mm using modified asphalt	5,33€/m^2
Asphaltic binder course 0,05m using common asphalt	5,19€/m^2
Asphaltic base course 0,05m	5,03€/m^2
Asphaltic leveling course 0,05m	5,00€/m^2
Base 0,10m	2,03€/m^2
Sub-base 0,10m	2,00€/m^2
Tack coating	0,33€/m^2
Prime coating	0,98€/m^2
Concrete slab type C30/37	94,00€/m^3
Concrete slab type C30/37 using fly ash as a 50 % replacement of cement	66,44€/m^3
Sub-base of lean concrete type C12/15	68,40€/m^3
Sub-base of lean concrete type C12/15 using fly ash as a 50 % replacement of cement	54,91€/m^3
Fly ash	2,50€/ ton
Anti-skidding – textured aggregates of Electric Arc Furnace Slag	17,00€/ton
Steel bars STIII	1,00€/kg
Steel bars STI	1,00€/kg
Precast slabs 12mm for expansion joint formation	10,65€/m^2
Asphalt elastomeric joint sealant	2,98€/m
PVC film	4,69€/m^2
Crack and seat	1,25€/m^2
Milling 0-4cm	0,90€/m^2
Milling 4-8cm	1,46€/m^2

(1) The cost/unit refers to complete work.

3.2. User cost

The various maintenance works have as results reduced road service level, delays, increased operating vehicle cost and probability for accidents and dissatisfaction/lack of comfort for the user. All these impacts result the user cost which is considered in the economic analysis.

In the current analysis is assumed only the user cost due to lost time (additional trip duration) and additional vehicle operation during delays caused by maintenance, rehabilitation and reconstruction activities.

The duration of the various maintenance works is presented in the Table 6. The calculation of this duration is based on the daily performance of the different works (see Table 7). The daily performance of the works comes of empirical estimation of Egnatia Odos S.A. and other companies that are occupied in the road construction section for daily working duration equal to 8 hours/day. It is also assumed that for the beginning of a new work is required the completion of the previous and that after completion of works the pavement can be assigned to traffic the next day (immediately).

Table 6. **Duration of maintenance work**

Alternative scenarios	Year	Activity	Duration (days)
Scenario 1	7, 14, 27, 34	Routine periodic maintenance	2
	20	Reconstruction	17
Scenario 2-a / 2-a-2	7	Joint maintenance	1
	14	Joint and anti-skidding surface maintenance	2
	21	Joint and anti-skidding surface maintenance	3
	28	Rehabilitation	5
	35	Routine periodic maintenance	2
Scenario 2-b / 2-b-2	7, 14, 21	Joint and anti-skidding surface maintenance	3
	28	Rehabilitation	5
	35	Routine periodic maintenance	2

Table 7. **Daily performance of activities considered in economic analysis**

Maintenance activity	Daily performance[1]
Laying thin anti-skidding layer 25mm using modified asphalt	8.700m^2/day
Laying asphaltic binder course 0,05m using common asphalt	5.800m^2/day
Laying asphaltic base course 0,05m	5.800m^2/day
Laying asphaltic leveling course 0,05m	5.800m^2/day
Laying asphalt elastomeric joint sealant	1.500m/day
Crack (per 1m) and seat	10.000m^2/day
Milling 0-4cm	6.000m^2/day
Milling 4-8cm	3.000m^2/day

(1) The daily performance refers to complete work.

For the analysis is also considered that the mean vehicle speed during the maintenance activities is reduced for passenger cars from 100km/h to 50km/h and for commercial vehicles from 70km/h to 35km/h. This reduction (50 %) leads to a delay, which is equal to 0,600 min (0,010 h) and

0,857 min (0,014 h) for every passenger and commercial vehicle for the typical road length, respectively.

The time value of the passengers is taken as [7]

- For passengers in cars the weighted average of the time cost, without correcting for the Purchasing Power Parities (PPP), as calculated by the European program HEATCO, is equal to 10,60 €/hour/passenger in prices for the year 2009.
- For commercial vehicle drivers the weighted average of the time cost is equal to 24,19 €/h in prices for the year 2009 according to the study of Traffic Consultant of Ministry of Environment, Spatial Planning and Public Works.

These values updated to prices for the year 2011 [using the Customer Price Index (CPI)] is equal to [1]:

- value of time for car and buses passengers is 11,50 €/h/passenger and
- value of time for drivers of commercial vehicles is 26,20 €/h/driver.

The time value is assumed that will be increased by 1,5 % per year. This value represents the 50 % of expected GDP growth at constant prices, assuming that the average GDP growth would be around 3 % [8]. However, this development is an assumption and cannot be taken as standard, especially because of present greek economy.

The vehicle occupancy is considered using corresponding average factors and is useful to calculate the total number of passengers. These factors are as follows:

- average vehicle occupancy factor for passenger vehicles is 1,2 persons/vehicle [9],
- average vehicle occupancy factor for buses is 24,35 persons/vehicle [8] and
- average vehicle occupancy factor for trucks and other commercial vehicles is 1,26 persons/vehicle [8]. Although, in the current analysis is assumed equal to 1, which means that only the vehicle driver is moving.

Necessary for the calculation of the operating cost of the vehicles is to consider specific values for fuel costs and cost for maintenance, tires, etc. For these costs is assumed that:

- Passenger vehicles: The analysis will be performed considering the price of gas (excluding taxes and fees) equal to 0,47425 €/lt. [1] For the fuel consumption for light vehicles are used values that represent the average consumption as a function of speed. Thus, consumption is equal to 8,11 lt/100km and 8,49 lt/100km for speeds of 100km/h and 50km/h respectively. [1]
- Commercial vehicles: The price of diesel (excluding taxes and fees) is taken equal to 0,31404 €/lt. [1] Regarding fuel consumption for commercial vehicles is assumed that the consumption is 16,57 lt/100km and 16,38 lt/100km for speeds of 70 km/h and 35 km/h respectively [1].

In both cases (passenger and commercial vehicles) the cost of fuel is obtained as the average of the updated (in prices for the year 2011) price of fuel for the years 2009-2011. Also, the maintenance cost, tire cost, etc. is not taken into account for the calculations, as the length of the road under study does not change and this means that it is common cost for each scenario.

3.3. Salvage value

As previously mentioned, the material value is considered equal to 60 % of their total value (material and construction value). It is taken into account that the salvage value of unbound, intermediate asphalt and concrete courses is considered equal to 40 % of their present value at the end of the analysis period. For the surface courses, salvage value exists only in case that a number of years remain until the end of their service life.

4. RESULTS OF ECONOMIC ANALYSIS

4.1. Initial construction cost

The initial construction cost of the alternative options is presented in Figure 1. It is obvious that the lower initial construction cost is met in the scenarios that rigid pavements are constructed with replacement of cement by fly ash and especially in the Scenario 2-a-2 (31,66 €/m^2) in which aggregates of electric arc furnace slag constitute the anti-skidding surface. Opposite, the most expensive option is the traditional constructed concrete pavement with asphalt anti-skidding layer (46,46 €/m^2).

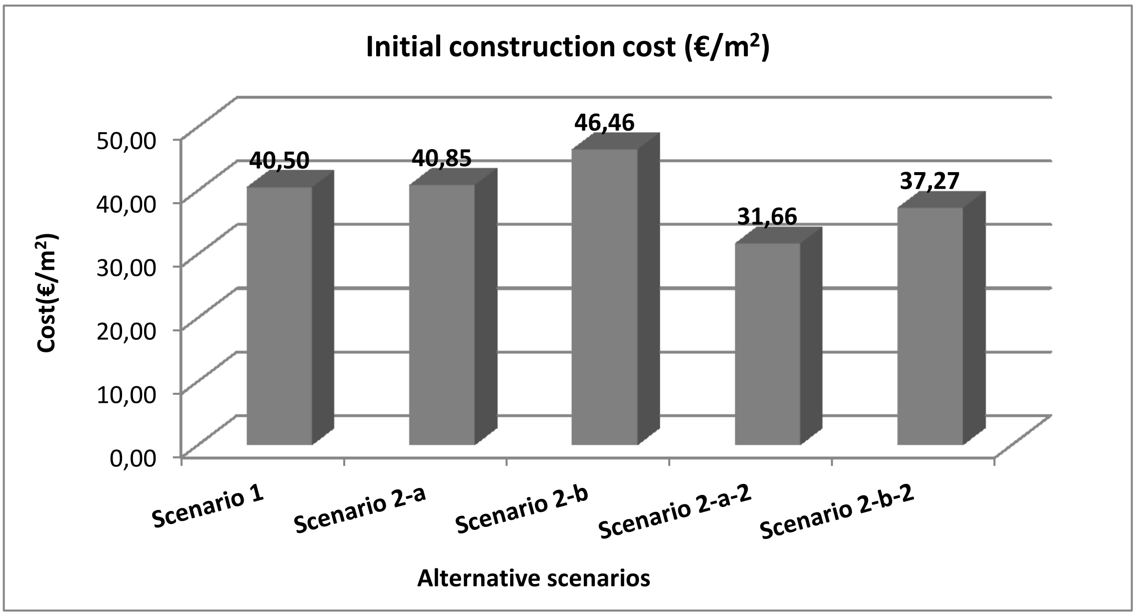

Fig. 1 Initial construction cost of alternative scenarios

The asphalt pavement has lower construction cost (40,50 €/m^2) in comparison with traditional concrete pavements, scenarios 2-a and 2-b, by 0,87 % and 12,83 %, respectively. The opposite relationship is observed between scenario 1 and scenarios 2-a-2 and 2-b-2. Specifically, the scenario

2-a-2 has lower cost by 21,82 % and scenario 2-b-2 by 7,97 % compared to scenario 1.

Moreover, it is important that the replacement of cement by fly ash reduces the initial construction cost by almost 21 % (average reduction for scenarios 2-a and 2-b) as well as that using aggregates of electric arc furnace slag as anti-skidding layer gives alternative solution cheaper by 13,56 % (12,07 % for scenario 2-a and 15,05 % for scenario 2-a-2).

4.2. Life Cycle Cost

The Life Cycle Cost of the different scenarios that are analyzed in the current study are presented for discount rate i=5 % and for a range of various values of rates in the Figures 2 and 3, respectively.

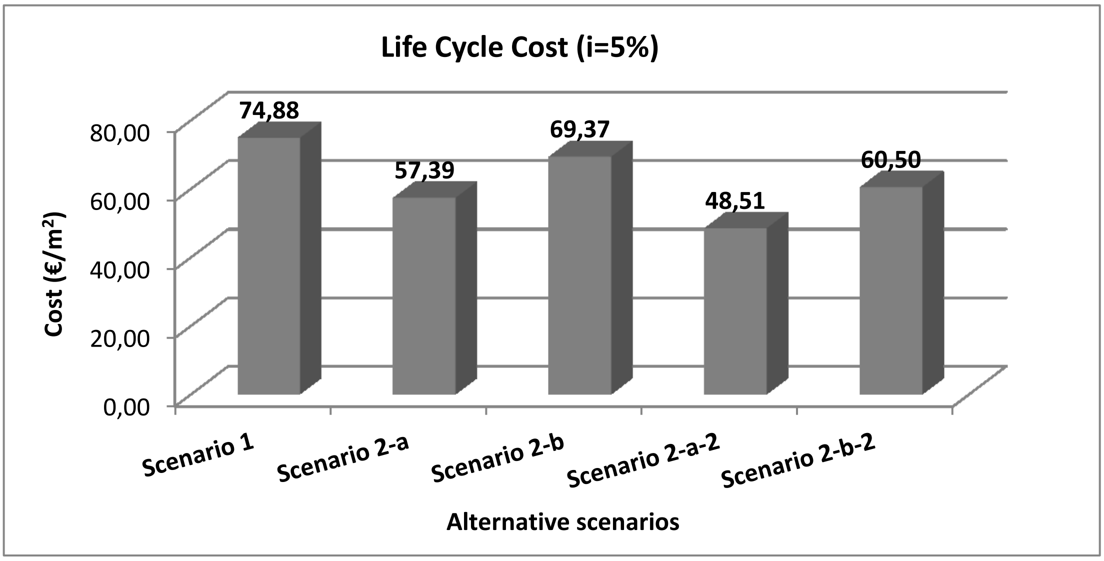

Fig. 2 Life Cycle Cost of alternative scenarios for i=5%

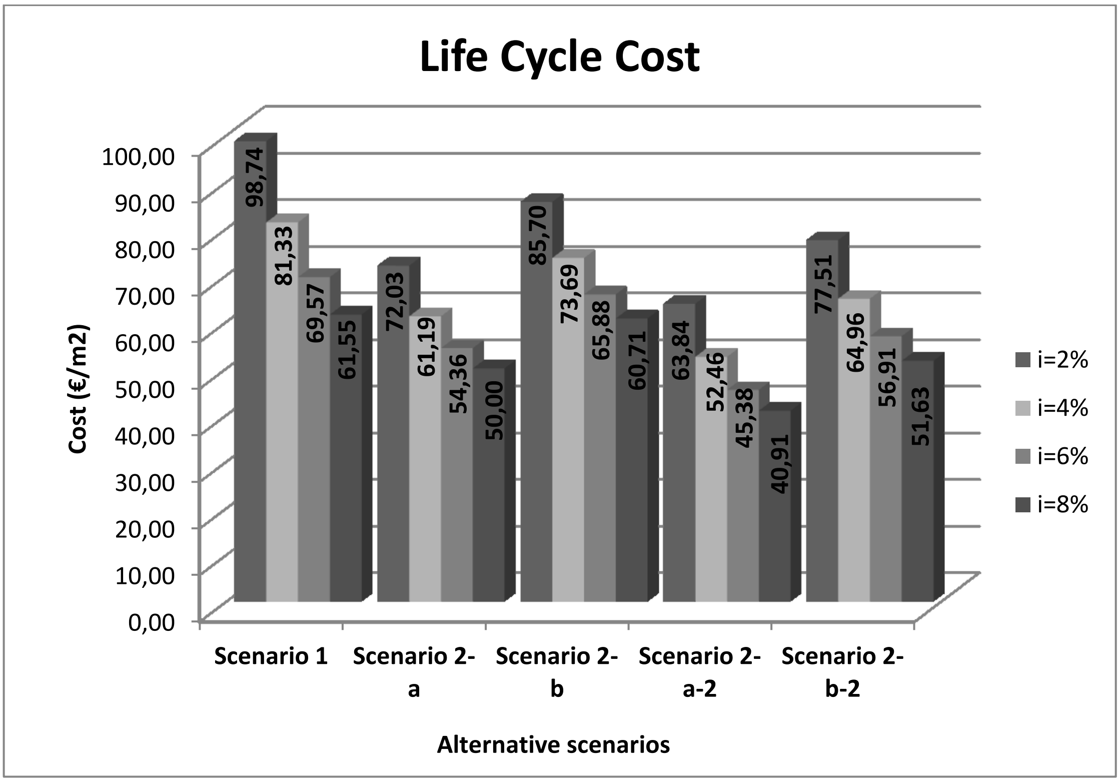

Fig. 3 Life Cycle Cost of alternative scenarios for a range of discount rates

It should be noted that the lower LLC for the normal discount rate is observed in the scenario 2-a-2 and is 48,51 €/m2. It is worth to mention that the same scenario presents also the lower initial construction cost. Contrary, the most expensive option is the flexible pavement (74,88 €/m^2). The difference between the two scenarios is equal to 35,22 %.

The comparison between flexible and traditional composed rigid pavements (scenarios 2-a and 2-b) shows that more economic is the scenario 2-a, although it has almost the same initial construction cost with scenario 1. The economic benefit is 23,37 % for scenario 2-a and 7,36 % for scenario 2-b compared with scenario 1. Similar is the relationship between the asphalt and concrete pavements in which fly ash is used.

The replacement of cement by fly ash in a proportion of 50 % leads to cost reduction of around 14 %. This reduction corresponds to the initial construction cost difference. Furthermore, the use of aggregates of electric arc furnace slag for anti-skidding layer offers solutions cheaper by almost 18,55 %.

Similar comments can be made when the scenarios are analyzed for a range of discount rates. The choice of flexible pavement requires almost 28,8 % (average value) higher investment that concrete pavements. In all cases, more economic is the rigid pavement in which fly ash and aggregates of electric arc furnace slag are used. It is worthy to be mentioned that for i=8 % the LCC of the scenario 2-a-2 is 40,91 €/m^2, price almost equal to initial construction cost of the pavement described in scenarios 1 and 2-a.

It can be also said that the choice of the discount rate is important. The higher values of discount rate that are used in the analysis lead to lower LCC. This fact has as a result the scenarios with higher initial construction cost and lower cost during the analysis period to be favored by lower rates.

4.3. Future variation of fly ash value

For the present calculations, the value of greek fly ash is considered equal to 2,50 €/ton. However, it is deemed useful to examine the future probable change of the cost of the material and the impact of this change to the initial construction cost of rigid pavements that use fly ash in the composition of concrete in comparison with the corresponding flexible pavements that are widely constructed in Greece. The critical equation is:

$$K_o^{Scenario1} = K_o^{Scenario2-a-2} = K_o^{Scenario2-b-2}$$

where K_o is the initial construction cost.

For the case of scenario 2-b-2 the solution to the relationship is equal to 55,20 €/ton which means an increase of 22,08 % of the present value of fly ash. These values are higher enough for the other scenario in which aggregates of electric arc furnace slag are used. Specifically, the value that causes the initial construction cost of the two scenarios to be equal is 146,80 €/ton. This is translated to the fact that the price of fly ash can be 59 times increased until the cost of the initial construction of the pavement in which is used will reach the value of the corresponding flexible pavement. All these results are calculated only considering that all the other parameters and values remain constant.

CONCLUSIONS

In Greece it is considered necessary to conduct further research and studies about the use of concrete pavements as the international experience and investigation has shown that they are the solution of the future. It is very important that the cost of every technical solution has to be examined more completely. The lower initial construction cost does not always mean the actually economic choice.

The use of greek fly ash in the composition of concrete as a partial replacement of cement gives satisfactory opportunities for cost reduction in comparison to flexible pavements (almost 30 %) with a clearly better environmental impact without any degradation of quality. There is also the possibility for much lower cost using other materials like aggregates of electric arc furnace slag.

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