Local Versus Full Width Pavement Rehabilitation in the Frame of Old Water Supply Network Repair

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Abstract: Since the global financial crisis of 2008, all construction related activities are now subject to cost control of each project. An important component of the optimal choice is the implementation cost. The evaluation of construction activities can be conducted by estimating their environmental as well as their cost footprint, which is also the demand and consumption measure for the societies’ needs. Water and sewerage projects have a key role in the standard of living, Public Health and environment. Therefore, water supply network replacements are important to upgrade the quality and quantity of water, through cost-effective choices.

The purpose of this study is to present and comment on the uniform cost footprint through the complete replacement of the old water supply network along with complete reconstruction of pavement compared to local repair activities. Usual practices in repair works of old networks and flexible pavement rehabilitations are presented, assessing the benefits of total reconstruction by carrying out life cycle cost analysis in terms of uniform cost per year. The project of replacing the water supply network in the municipality of Larissa, Greece for the period 2013-2019 is analyzed, linking water savings with simultaneous total pavement rehabilitation, calculating average cost per inhabitant and hydrometer, comparing cost and pavement surface area between total and localized rehabilitation activities for a twenty-year rollback period.

The fruitful findings of this research study, indicate that full-width pavement rehabilitation along with new water supply network establishment is economically advantageous compared to local rehabilitation treatments, according to the time period considered. Thus, competent authorities can use the proposed methodology as a useful tool to conclude to the optimal choice for maintaining water supply networks in a cost-effective way.

Keywords: cost footprint, local repair environmental footprint, pavement reconstruction, water supply network.

I. INTRODUCTION

Cost footprint of urban infrastructure management is linked to climate change and sustainable development, issues that are the world’s most important challenges for planet Earth. Since 2008, the impact of human activities on the environment has been systematically assessed. Analysis of the annual data collected indicates that most of the carbon

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As for the environmental footprint of asphalt, storing, dioxide emissions observed in the activities comes from the production, transportation, application and recycling of products produced. commerce and processing conventional and modified asphalt products requires attention and responsibility that becomes even more demanding once we choose to follow an environmentally friendly path. In order to reduce the impact of our activities on the environment, a number of parameters are taken into account, the most important of which are energy requirements to maintain high temperatures at all stages of the commercial / production process, the efficient management of air pollutant emissions, liquid and solid waste, as well as noise level and leakage control. The water footprint of national consumption is calculated as the total use of domestic water resources plus virtual water import minus virtual water extraction.

The purpose of this study is to present water pipes network replacement along with full-width pavement rehabilitation in the Municipality of Larissa during the 2015-2019 period, which minimised water loss of the old network while improving the quality of the water consumed by the population of the city. While usual practice is focused on localized treatments leading to significant repair costs [14], the present study proposes a comparison of full-scale rehabilitation opposed to local repair activities, in order to conclude to the optimal option.

II. PROPOSED METHODOLOGY

A. General

The types of environmental footprint are land use, carbon and water footprint. The Earth has about 12 million hectares of land divided into forests, pastures, arable areas and fisheries and residential land [3]. Land footprint is the actual amount of land required to produce a product or is used by an organization or nation and evaluates indigenous and offshore areas that are needed directly or indirectly to satisfy domestic final consumption.
Due to data limitations, land footprint studies are often focused on agricultural and forest areas [4].

The concept of carbon footprint captures the interest of businesses, consumers and policymakers. It is the sum of greenhouse gas emissions that are directly or indirectly caused by an individual, organization, event or product. The ever-increasing need for water consumption results in significant quantitative and qualitative degradation of water resources. The water footprint is part of the ecological footprint. It is an indicator of water consumption that examines the direct and indirect use of water by the consumer and producer over a period of time [5]. It is calculated, similarly to other types of footprints, for a person, community, process or business. The volume of water consumed is measured in cubic meters (m³).

Given the above, this research adopts a life cycle cost analysis in terms of uniform cost per year in order to assess the necessary expenses of full-with pavement rehabilitation along with water supply network replacement opposed to localized repair operations. The project of replacing the water supply network in the municipality of Larissa for the period 2015 – 2019 is analyzed, linking water savings with simultaneous total pavement rehabilitation, calculating average cost per inhabitant and hydrometer, comparing cost and pavement surface area between total and localized rehabilitation activities for a twenty-year rollback period.

B. Replacement and restoration projects

i. Problems with the old water supply networks

The problems with the old water supply systems are many and are summarized in the following categories [6]:

- Water losses
- Water quality
- Problematic operation of networks
- Pavement distress

Certainly, old networks are considered inappropriate, both in terms of materials and in terms of water losses from the numerous fractures of asbestos pipes as well as highly corroded iron pipes. A direct consequence of the above is the poor water quality, the defective operation of certain components (e.g. valves), isolation of networks, disruption of water supply and general disruption to more residents [7].

Also, the inadequacy of the old water supply networks results in serious defects of pavement surfaces. Excess water found in the gaps of pores is responsible for many pavement obsolescence incidents [8]. Along with the increase in the amount of water contained in the base and subbase, there is a percentage loss of bearing capacity and, in parallel, an increased loss of pavement serviceability. Since the free water flow fills existing gaps between the layers, vehicle wheel loads on the pavement surface result in water pressure increase.

Water affects the cement-treated bases as well as the asphalt base layers, causing them to decompose and weaken, resulting in a rearrangement of the internal structure of the fine granules in the aggregate mixtures. Water is responsible for causing excessive stresses in the subsoil. It also contributes to cracking from oxidation and reduces pavement flexibility. In addition to corrosion and removal of material from the pavement, pulsating water pressures also strip asphalt coatings [10]. Consequently, in addition to the danger of traffic due to subsidence (Fig. 1, 2), there is also excessive financial burden on municipalities and their businesses for their restoration.

ii. Network replacement projects - practices

Cuts containing water supply networks in the urban area are mainly along the old network with the first stage to be cut of the asphalt on both sides of the pavement, in relation to the axis of the new network, and at a width of 0.70 m. Excavation is carried out at a depth of 1.20 m using mechanical means as well as manually in the event of obstructions by other public utilities. New products such as sand and crushed quarry gravel are used in the cover process. Subsequent work includes the formation of the bottom of the cut, removal of stones that may damage new pipework and placement of quarry sand to a thickness of 10 cm. Next, the installation of new
polyethylene (PE-16atm) pipes, as well as the new special joint sections, follows (Fig. 3).

iii. Asphalt segments restoration projects in water supply trenches

Restoration work on a stripped asphalt pavement begins by layering and compacting with inert quarry material in the trench [11]. When the trench filling reaches 5 cm below the surface of the old asphalt, asphalt pre-treatment is applied and then the base layer asphalt mixture is prepared by heating in a permanent installation, condensed to a thickness of 5 cm. After laying, the asphalt mixture is compacted using a mechanical compactor, vibrating plate or small vibratory roller (Fig. 4).

The steps to implement the proposed methodology are as following:

a) Collection of water supply system historical data.
b) Cost of partial and total asphalt paving
c) Cost of flexible pavement per inhabitant for design time period
d) Paving cost per hydrometer for design time period
e) Total rehabilitated surface in design time period
f) Rehabilitation cost per square meter for design time period

After implementing all the above steps, the findings lead to the optimal choice in terms of the uniform cost values for pavement rehabilitation per year, meaning that the less cost leads to the optimal option.

III. RESULTS

A. Water supply in the Municipality of Larissa

With the aim of water adequacy, savings and accessibility as a social good, the DEYAL has invested 52.6 million €, in recent years. During the last five years (2015-2019) in the Municipality of Larissa, old water supply networks (asbestos and iron pipes) were replaced, totalling 120,000 meters, exceeding 60% of the old networks, with the aim of fully replacing the old networks by 2023 (Fig. 6). In all new projects, except for the network replacements, total asphalting of the pavements has been carried out.

B. Cost of partial and total asphalt paving in the municipality of Larissa

In the municipality of Larissa and more specifically from DEYAL, which is responsible for the water supply projects, 120 km of networks have been replaced from 2015 to 2019 and complete pavement reconstruction has been carried out on 600,000 m².

The new projects reduced the water supply losses (Fig. 7) due to leaks from 24% in 2015 to 21% today. The levels of specific water losses in the municipality of Larissa are among the lowest in Greece considering that in most municipalities in the country the losses reach 50%.

B. Cost of partial and total asphalt paving in the municipality of Larissa

In the municipality of Larissa and more specifically from DEYAL, which is responsible for the water supply projects, 120 km of networks have been replaced from 2015 to 2019 and complete pavement reconstruction has been carried out on 600,000 m².
The cost of the works, according to data by DEYAL, amounts to 4.2 million €.

At this point arose the necessity of comparing the cost between partial pavement rehabilitation with local repairs (along with the old water network maintained) and full width pavement reconstruction (along with complete replacement of the water supply).

After investigating the records in the municipal business archive, it was found that the annual cost through the bidding projects for the restoration of pavement segments, due to various damages to water networks, amounts to 250,000 €/year.

Consequently, comparing the average cost of total pavement rehabilitation, with complete replacement of networks, to partial pavement restoration over a period of 20 years, clearly shows that full width operations are more economical than local treatments (Fig. 8).

The period of 20 years was considered as a criterion for the rehabilitation of the districts of Larissa (Ag. Georgios, Hippocrates, Ampelokipi and Haravgi) through the assumption that the life cycle of a pavement replacement is about 15-20 years. After studying the diagram of Fig. 8 it is shown that the cost of full width operations (along with new water supply, PE-16atm pipes), with the costs of partial asphaltining-patches (with old network, asbestos-iron pipes), are approximately the same in the duration of 17 years, while up to 20 years it is estimated that full width treatments are more economical than local works (patches) by 19%, meaning about 800,000 € gain.

The cost of total flexible paving over a period of 20 years, per inhabitant, for a population of 200,000 (calculated on the basis of the number of hydrometers), is estimated at around 21 € per inhabitant, while the cost of local paving is 25 € per inhabitant. It is therefore understood that there are savings of 4 €/inhabitant in the first case (Fig. 9).

It is also important to convert the cost of paving per hydrometer, over 20 years, in cost per residence. So, for a total of 70,000 hydrometers in the municipality of Larissa, the cost of full width paving is 60 €/hydrometer, while for local treatments (patches), it is 71.5 €/hydrometer, respectively. The savings in the first case therefore amounts to 11.5 €/hydrometer, which in one-person households is substantially proportionate per inhabitant, thus increasing the savings in these cases.

E. Total rehabilitated surface in 20 years

A very important parameter is the rehabilitated surface between the two cases under study. In case of full width operation, for a 20-year time horizon, an area of 600,000 m² is covered, while in the case of partial treatments (patches) for the same time period, it is revealed, through the investigation of the data that an area of 300,000 m² is covered (Fig. 10).

Another very important finding of the research is the paving cost per square meter over a 20-year period. Total pavement replacement over a new water network costs 7 €/m², while local patches cost 16.5 €/m² (Fig.11). As can be seen, the cost difference is more than double between the two cases.

C. Cost of flexible pavement per inhabitant for 20 years (200,000 inhabitants)

D. Paving cost per hydrometer for 20 years
IV. CONCLUSIONS

Concluding remarks refer to water losses in the municipality of Larissa, through network replacement, have dropped from 24% to 21% over the last 5 years (2015-2019). Water quality has improved through new PE networks in relation to the problematic asbestos-iron pipes which were adversely affected by corrosion. In addition, pipeline fractures have been practically eliminated after their full replacement with PE-16atm. Following the proposed method, better working conditions in the health sector for water supply workers due to the replacement of old pipes with those of modern polyethylene take place as well as better traction of vehicles in the case of total asbestos due to full road surface coverage, as opposed to scattered patches, while less noise from passing vehicles on full pavement exits, because the seams and potholes on the pavement are limited as opposed to paving the road in a limited width.

On the implementation example, 19% savings on resources and financial savings of 800,000 € over twenty years with full width pavement operations and new networks in relation to local treatments and maintenance of the old network in the municipality of Larissa are ascertained. Additionally, cheaper per capital total paving (with new water supply network) by 16% compared to local patches (with old water supply network) over a 20-year period, meaning 4 €/resident savings, as well as savings of 11.5 € per hydrometer with total network replacement for a 20-year period are calculated. The cost of full width rehabilitation with a new water supply network is 7 €/m² while localized treatments with the maintenance of the existing old network costs 16.5 €/m², which is 51.5% more economical for the first case, for a 20-year period. The square meters of full width rehabilitation are twice those of localized treatments, over a time period of 20 years, namely 600,000 m² in the first case and 300,000 m² in the second case.

In sum, conducting the proposed methodology, competent authorities, hold a useful tool in order to conclude to the optimal choice of water supply system rehabilitation operations with a cost-effective approach.

REFERENCES

1. A. K. Chapagain and A. Y. Hoekstra, “Virtual water flows between nations in relation to trade in livestock and livestock product”, in Value of Water Research Report Series, No. 13, UNESCO-IHE Institute for Water Education, 2003, p. 26-59.
2. M.M. Mekonnen and A.Y. Hoekstra, “National water footprint accounts: the green, blue and grey water footprint of production and consumption”, in Value of Water Research Report Series, No. 50, UNESCO-IHE Institute for Water Education, 2011, pp. 8-26.
3. World Wildlife Fund. Living Planet Report. WWF International, 2012, Gland, Switzerland.
4. S. Gijum, S. Lutter, M. Bruckner, S. Aparcana, “State-of-Play of National Consumption based Indicators, A review and evaluation of available methods and data to calculate footprint-type (consumption-based) indicators for materials, water, land and carbon”, in Report for DG Environment of the European Commission, Sustainable Europe Research Institute (SERI), 2013.
5. A.Y. Hoekstra, A.K. Chapagain, M.M. Aldaya and M.M. Mekonnen, The Water Footprint Assessment Manual, Setting the Global Standard. London UK, Earthscan, Ltd, 2011, pp. 141-155.
6. P.S. Kollias, Water supplies (surface - ground water, distribution networks, installations), Athens, Lychnos Publications, ISBN 13 978-960-90957-0-1, 1998, pp. 163-171.
7. S.I. Kostopoulos, Water supply, Athens, “ION” Publishing Group, ISBN 978-960-508-096-9, 2014, pp. 75-98.
8. N. Alamanis, Gr. Papageorgiou, P. Chantzopoulou, I. Choularias, “Investigation on the Influence of Permeability Coefficient k of the Soil Mass on Construction Settlements. Cases of Infrastructure Settlements in Greece”, WSEAS Transactions on Environment and Development, Vol. 15, 2019, Print ISSN: 1790-5079, E-ISSN: 2224-3496, pp. 95-105.
9. Ch. Tsogas, Sewage and Wastewater Treatment Systems, Athens, “ION” Publishing Group, ISBN-13 978-960-405-801-3, p. 327.
10. I.D. Kofitisas, Road Engineering Data, Athens, “ION” Publishing Group, ISBN 978-960-411-185-5, 2001, pp. 314-365.
11. A.F. Nikolaidis, Flexible Pave (dimensioning methods – bituminous mixtures – friction layers), Thessaloniki, 1th ed., ISBN 978-960-91849-1-5, pp. 10-37.
12. Y. Liu, X. Zhan, M. Tillotson, W. Guo, and Y. Li, Blue and Green Water Footprint Assessment for China—A Multi-Region Input–Output Approach. Sustainability, 10, 2822. 2018. doi: 10.3390/su10082822.
13. D.A. Kampfman. The water footprint of India. Master Thesis. University of Twente. The Netherlands, 2007.
14. A. Selvakumar, R.M. Clark and M. Sivaganesan, “Costs for Water Supply Distribution System Rehabilitation”, Journal of Water Resources Planning and Management, Vol. 8, Issue 4. 2002. doi: 10.1061/(ASCE)0733-9496(2002)128:4(303).

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