Accelerated Renovation of Bridge Decks in Finland

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The Traffic Administration, Destia Oy, several other road owners, contractors and material suppliers have in the years 2009-2010 implemented six pilot projects testing accelerated methods for the renewal of bridge decks. Choosing the most appropriate repair concrete and water proofing materials together with applying strict time schedules a complete renewal for one bridge lane or an entire bridge can be done in 1-2 weeks. Te intensive supervision on sites seems to result into better quality despite of the hectic conditions on site. However, quality control and site test allowing no hindrance to the work will be a challenge. Most of this may be solved by testing materials in advance and applying simple site tests. The moisture content monitoring in pilot projects requires better understanding of the relative humidity absolute humidity equilibrium. The temperature and quality of concrete has impact on this sensitive equilibrium curve.

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Accelerated Renovation of Bridge Decks in Finland

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1. Introduction

In the years 2009-2010 Finnish Transport Agency, several other road owners, Destia Ltd, contractors and material suppliers have implemented five pilot projects in purpose to test accelerated methods for the renewal of bridge deck water proofing and road pavement. The work typically includes the upper surface repair necessitated by thaw-frost deterioration and chloride penetration. This repair normally takes time. However, by choosing the most appropriate concrete types and water proofing materials and by applying strict time schedules a refurbishment for one bridge lane or the entire bridge can be done in 1-2 weeks. The same work made applying conventional methods takes 5-8 weeks depending on weather conditions.

The bridge deck renovation works comprises of the following work phases:

1. Construction of traffic steering systems
2. Removal of existing road pavement on the bridge and water proofing
3. Drilling of bridge deck drain pipes
4. Chiselling and rinsing the deteriorated concrete
5. Casting leveling concrete
6. Shot-blast cleaning or other roughening of the top surface
7. Waterproofing works, either by epoxy compacting and laying of sheet membranes or by shot spreading of water proofing compound.
8. Laying new road pavement

The first three work steps do not require any special attention. The contractors have already efficient working methods. The preparation of the bridge deck by water jet chiselling as well as the laying of leveling concrete are the most critical works steps. The concrete shall be suited for thin layers, have a good bond to the existing bridge deck and it shall harden and dry faster than conventional concrete. The water proofing compound or epoxy used to compact the water proofing substrate shall harden in a few hours to enable quick spreading of the next layer and the implementation of quality tests.

Casting of leveling concrete as well as spreading of water proofing requires dry weather. The subcontractors involved in this works are too busy for waiting at the site for proper weather. Tight time schedules require the construction of a shelter on the bridge deck.

The purpose of this development project was to utilize existing materials and technologies, not to develop new ones. The pilot project was chosen in cooperation with bridge owners and contractors among ongoing contracts. A perquisite was that the contractor had a reliable concept for the work and that he was interested in developing faster methods.

2. Repair of concrete deck

After the existing asphalt, water proofing as well as deteriorated concrete are removed the new concrete will have a thickness of 3-5 centimeter. This repair shall be implemented over the entire bridge deck. Leaving out less deteriorated areas makes judgment during repair complicated. Such inconvenience shall be avoided when bridge shall be repaired quickly.

In the pilot projects two types of leveling concrete was used:

1. Self compacting fine grade Concrete SRL 60/6/RH having cube strength of more than 50 N/mm² in 3 days and a water cement ratio is 0.4.

2. Fast hardening fine grade concrete RAPI-tec® having cube strength of more than 25 N/mm² in 1 day. The water cement ratio is unknown but it seems to be close to 0.6.

To avoid the repair concrete coming off, the shrinkage shall be limited to some 0.5-0.7 ‰ in 56 days. It is as important to have good bond between the old and new concrete. A theoretical study reveals that shrinkage will cause horizontal stresses in the connection area of the magnitude of 7-8 N/mm² while the vertical stresses are only half of that, figures 1 and 2. If there is good bond, small vertical cracks or yield lines will appear at the intersection. This will reduce horizontal stresses and stresses perpendicular to the seam will completely disappear. The bond between the old and new concrete is by this in practice flawless. In case the bond is insufficient, the leveling concrete will come off as huge plates.

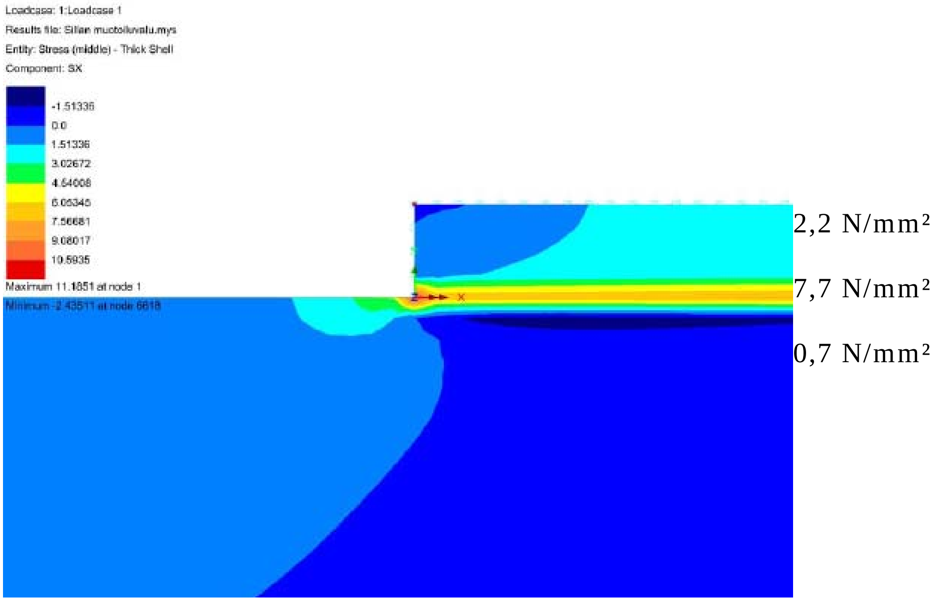


Figure 1. Horizontal stresses.

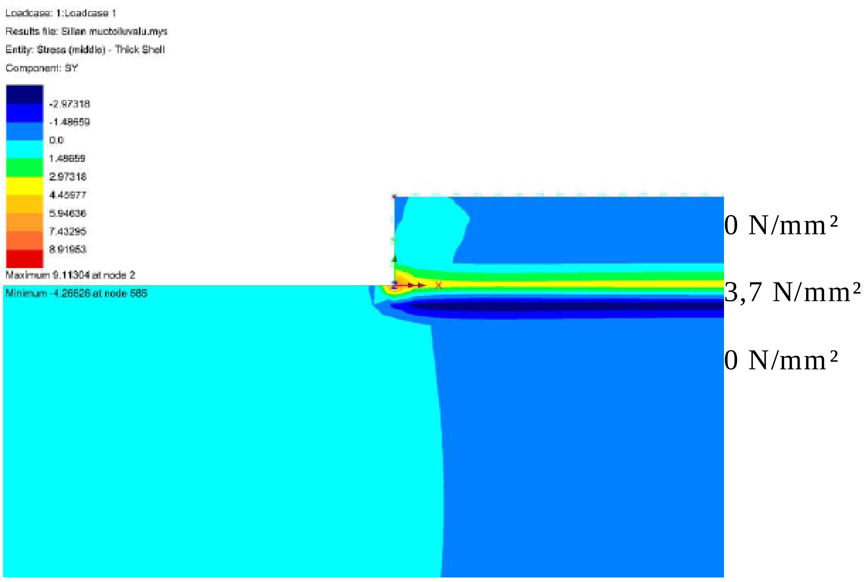


Figure 2. Vertical stresses.

Good bond is considered to be 1.5 N/mm² or more. Local undershoots have seldom been any major problem. Failures normally occur when the removal of deteriorated concrete was insufficient or when the new layer is laid on a dirty surface.

3. Hardening and drying of the repair concrete

According to general quality requirements, the water proofing substrate shall have a moisture content of less than 5.0 mass-% AH or 93 % RH. The limit on the relative humidity is not meaningful since the relative humidity depends on the temperature, the pore size and other features of the concrete. The relative humidity easily decreases to 80 % RH at a temperature of +5 °C. However, if the temperature goes up to some +35 °C, the relative humidity will be close to 100 % RH. This is caused by the vaporization of capillary bonded water in the pores of the concrete.

The relative humidity - temperature curves of the two concrete classes have been evaluated in figure 3 using the equilibrium curves from a research report from 1974 /1/. The relative humidity of bridge concrete is assumed to be in equilibrium with the average relative humidity of the air that is 80 % RH at +5 °C. When the temperature rises to +35 °C or +45 °C, the relative humidity will rise to 100 % RH. The relative humidity increasing in a concrete having a water cement ratio 0.4 is steeper than in a concrete having a water cement ratio 0.7. Using figure 3 as a background for the monitoring result drafts, the dryness of a bridge concrete can be better assessed.

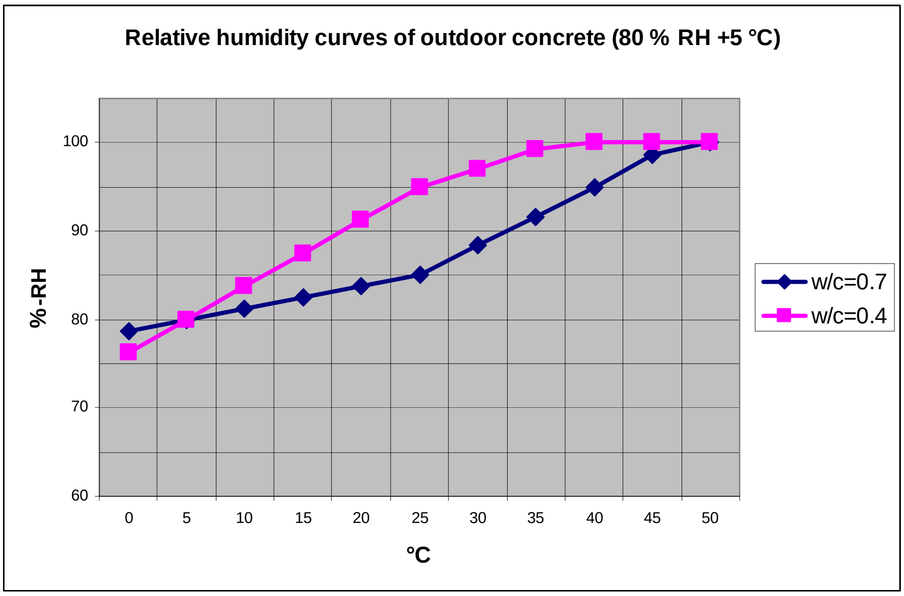
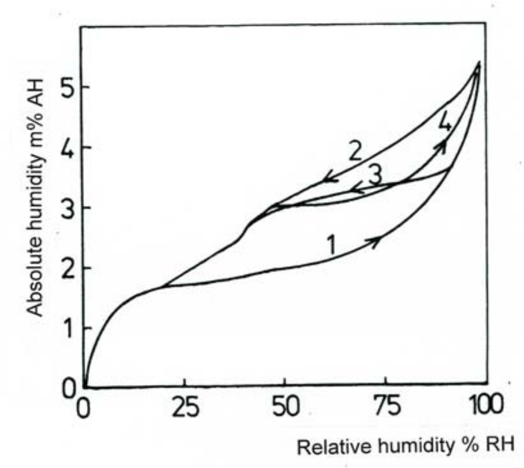
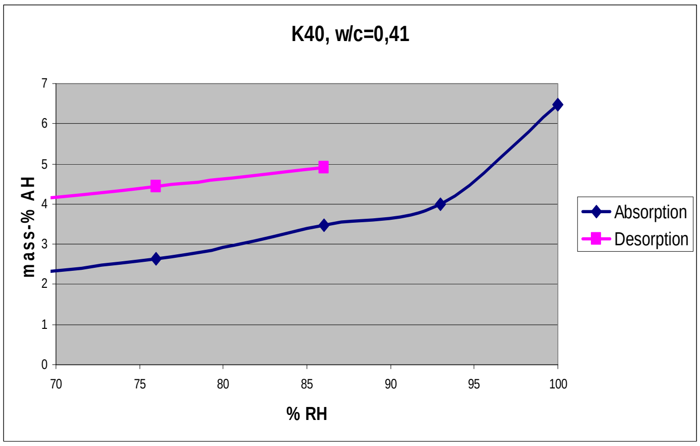


Figure 3 – Relative humidity – temperature curves.

The curves of figure 3 are valid in stable condition, which can be achieved only in a long time after several wetting and drying circles. In the initial stage the water content - relative humidity curve highly depends on whether the concrete is in an absorption (wetting) or a desorption (drying) stage, figure 4(a) and figure (4b). The lower line (blue) of figure 4(b) is starting at the left from a completely dry concrete. The line above (red) is starting at the right from a completely wet concrete. When the two concretes have reached the balance with the outdoor air, that is some 80 % RH, there is a gap of almost 2 % mass-% AH between the two lines. Due to this hysteresis and curvature of the equilibrium moisture curves, it is difficult to determine the absolute humidity of concrete by relative humidity monitoring. From figure 4(b) it can be seen, that the absolute humidity remains high even though the relative humidity decrease to 90 % RH.





(a) (b)

Figure 4 – Absolute humidity - Relative humidity equilibrium curves, figure (a) according to handbook /2/ and figure (b) according to Tampere University of Technology publication/3/.

The results from relative humidity monitoring for concrete SRL 60/6/RH are presented in figure 5 and 6. The concrete is a self compacting concrete having a water cement ratio close to 0.4. The low water – cement ratio could guarantee drying to a level as low as 3 mass-percent AH. However, this level is not reached due to capillary rise of water coming from the deck below, which has been wetted a by water jet chiselling and rinsing.

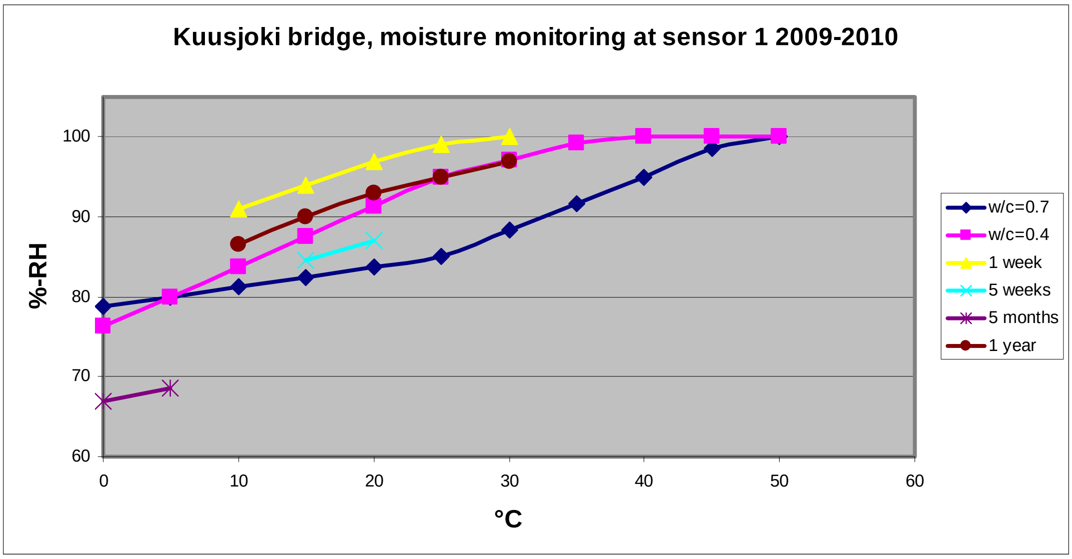


Figure 5 – Moisture content monitoring 1 at Kuusjoki Bridge one week – one year after casting.

Similar monitoring was implemented for the concrete RAPI-tec®. Despite of the high water cement ratio drying measured as relative humidity was even faster than for the concrete SRL60/6/RH. However, samples dried in an oven reviled that the absolute humidity content was as high as 8-9 m-% AH. It is so far unknown whether the water is absorbed in huge pores or is chemically bond to an easily vaporized compound.

Other moisture content monitoring has reviled that there often is an unintended fluctuation of the water content from one section to another. The concrete mix is not always homogenous enough and particularly thin concrete layers are sensitive to excessive water from rain flow or from wet concrete below. At sensor 1 (figure 5) the concrete seems to be dry enough. At sensor 2 (figure 6) the situation is not as good. Further laboratory tests shall revile how sensitive the water proofing and the concrete are to frost damage at high moisture content.

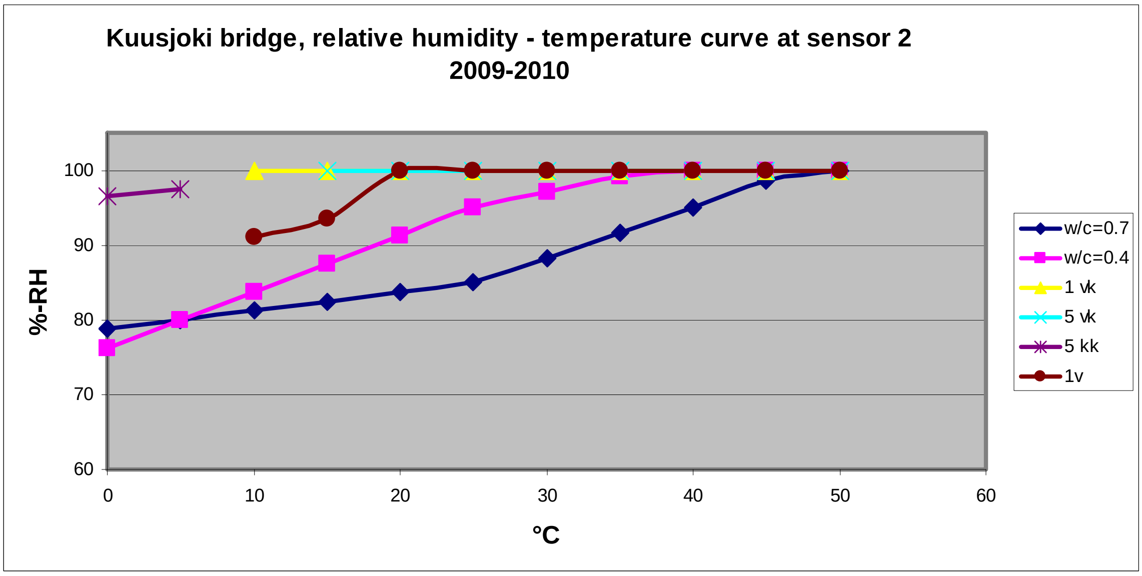


Figure 6 – Moisture content monitoring 2 at Kuusjoki Bridge one week – one year after casting.

4. Water proofing

In the pilot projects two type of water proofing were used:

1. Eliminator water proofing, a liquid spread water proofing comprising of 2 layers of roller spread primer and 2 layers of shot spread water proofing. The total thickness is some 3.0 mm. In addition there is bond coat layer as top layer to ensure good bond between water proofing and asphalt.
2. Two layers of epoxy 300 and 600 kg/mm² for compacting the concrete and two layers of sheet membranes. To ensure good bond between epoxy and sheet membranes ships are spread on top of the second layer of epoxy.

The bond to the substrate of both Eliminator and epoxy shall be more than 1.5 N/mm² provided that the substrate is cured and dry enough and properly prepared by shot-blasting. Neither Eliminator nor epoxy seems to be too sensitive to a reasonable level of water content. Sufficient dryness is easily achieved in the top surface. The bond seems to be more dependent on the strength of concrete.

In case the bond is not good enough, heat shocks will make the water proofing bubble. At such extreme situations it is not easy to measure the pressure under the water proofing. When hot asphalt is poured, the pressure wills probably at least for some minutes reach the upper limit, that is the vapor pressure of a fully saturated vapor in a closed container, figure 7.

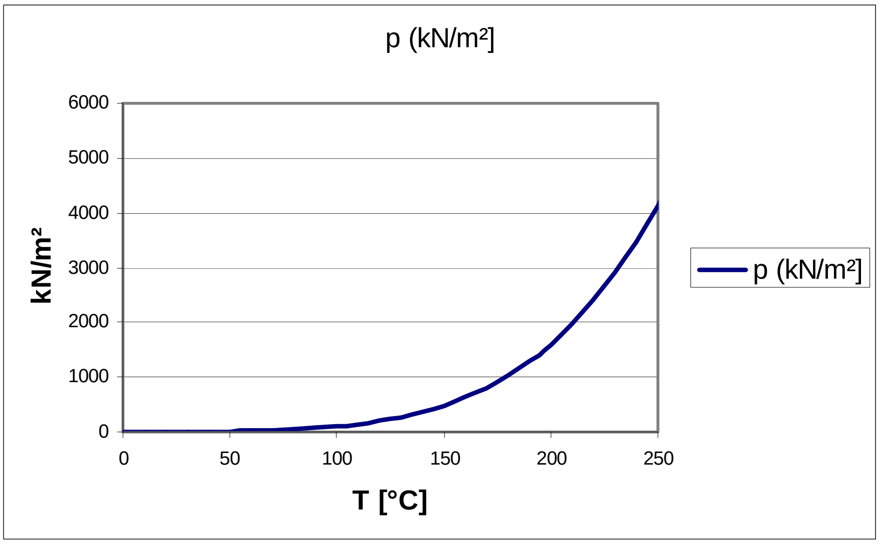


Figure 7 – Vapor pressure of fully saturated steam.

There will be a few heat shocks on the bridge deck during construction. For the Eliminator water proofing, the first heat shock comes when the first asphalt layer is laid. The manufacturer has submitted test results applied on a 20 mm steel plate having a 3 mm layer of Eliminator on top of it, figure 8. Heat transition is pure in concrete; therefore figure 8 may not directly be applied to a concrete surface. It seems that the heat insulation effect of Eliminator on a concrete deck is 50-100 °C.

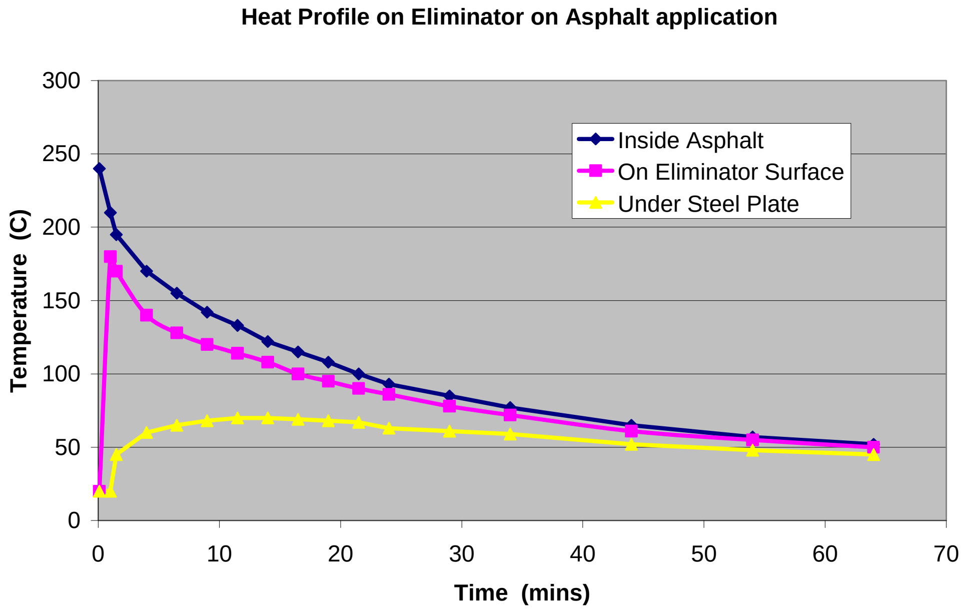


Figure 8 – Pressure of fully saturated vapor.

The heat insulation effect of the epoxy layer is not known. Bubbling has so far not been observed. The bond should be at least 1.5 N/mm² when the first layer of membrane is glued by hot mastic asphalt but even a bond of 0.6 N/mm² seems to be acceptable. Applying the first membrane by welding has caused a lot of problems elsewhere. Welding obviously will cause temperatures up to 200-300 °C resulting into fire damages in the concrete and the epoxy to come off.

5. Pilot projects

In 2009 two small pilot projects were implemented, Kuusjoki and Suonenjoki Bridges. The Kuusjoki Bridge could be closed for the public traffic for 10 days. The bridge deck was not severely deteriorated. The water jet chiselling did not take too much time and the quality requirements for the bond to the substrate were easily achieved. The Suonenjoki bridge needed repair in two phases. The deck was severely deteriorated and the quality requirements could never be met. The epoxy needed much more hardening time than the shot spread Eliminator. The waterproofing works took 2 days for Eliminator and 1-2 days more for the epoxy compacting sheet membrane water proofing.

Table 1. Pilot projects 2009.

Bridge	Kuusjoki	Suonenjoki	
Year	2009	2009	2009
Deck-m²	110	135	
Phase	1	1	2
Levelling Concrete	SRL-FIN	SRL-FIN	SRL-FIN
Waterproofing	Eliminator	Epoxy/memb	Epoxy/memb
Total time	10 days	14 days	13 days

In 2010 there were three pilot projects. The bridges where typical viaducts on important traffic routes. The traffic volume was substantial on all of them. At Pihlajanmäki and Luoma Bridges, the time schedules were not pressed to the limit. Some 2-3 days per work phase could have been spared if necessary. However, the time schedules were tight enough for requiring rapid methods and shelters to be built. The work could not be stopped at rainy days.

Table 2. Pilot projects 2010.

Bridge	Pihlajanmäki		Luoma			Professors Road	
Year	2010	2010	2010	2010	2010	2010	2010
Deck-m²	1330		700			440	
Phase	1	2	1	2	3	1	2
Levelling Concrete	SRL-FIN	SRL-FIN	SRL-FIN	SRL-FIN	SRL-FIN	RAPI-tec®	RAPI-tec®
Waterproofing	Epoxy/mem	Epoxy/mem	Epoxy/mem	Epoxy/mem	Epoxy/mem	Eliminator	Eliminator
Total time	14 days	17 days	13 days	12 days	9 days	7 days	7 days

At Professors Road bridge the bridge deck was badly deteriorated and contaminated by chlorides. The deck needed chiselling to a depth of 10 centimeter, which was below the upper reinforcement layer. Since the bridge is a continuous slab bridge, the reinforcement could not be released over the entire cross section. Therefore the renewal of the upper surface was done in 2 meter wide lanes. By using rapid concrete RAPI-tec®, no more than one day was needed between the lanes. Due to short curing time the pull off strength of the water proofing was just a little bit above 1.0 N/mm^2 instead of 1.5 N/mm^2, which was the original requirement. Despite undershoots in requirements both in the bond between leveling concrete and bridge deck and in Eliminator and the concrete, no bubbles or other damage were detected.

6. Summary

Bridge decks can be successfully repaired in a time of on week per lane. However this will put the following requirements on the conditions of contract:

1. The main contractor shall be in charge of supervision on site. The consequences of failures shall be born by him, transfer of responsibilities to subcontractors shall not be allowed.
2. Spreading of leveling concrete shall be implemented by certificated subcontractors in a similar way as water proofing contractors are certificated.

3. The leveling concrete shall be in conformity with the work progress; laboratory tests shall verify the requirements to be set on drying and curing time as well as on the pull of strength of the epoxy or other water proofing materials.

The costs of a conventional bridge deck refurbishment comprising of bridge deck repair, leveling concrete, water proofing and pavement are 250-300 €/ m^2. Applying the rapid methods introduced in this project will increase the costs by 40-100 €/m^2 depending on the thickness of the layer to be renewed. The intensified supervision of the works together with better quality tests at a rapid progress seems to result in better quality compared to works applying conventional methods.

6. References

/1/. Sven Pihlajavaara: Lecture on practical estimation of moisture content of drying concrete structures. Concrete seminar. Technical Research Centre of Finland. VTT. Helsinki. 1974b. 174 p.

/2/. Fukthandbok. Lars Erik Nevander, Bengt Elmarsson. 3.upplagan, Svensk byggtjänst 1994.

/3/ Ralf Lindberg, Jyrki Wahlman, Jommi Suonketo, Elina Paukku. Kosteusvirtatutkimus. Tampereen Teknillinen korkeakoulu, julkaisu 119, Talonrakennustekniikka, Rakennustekniikan osasto 2002.