User costs as one of main advantages of precast concrete application in highway construction

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Abstract. Road user cost primarily refer to the monetized components of road (re)construction impacts, such as the user delay costs, vehicle operating costs, crash costs and emission costs. Objective of this paper is to analyze and appraise the advantages and benefits of the innovative prefabrication approach in contrast to traditional cast-in-place construction method. The goal is to reduce these additional costs borne by motorists and the community at-large as a result of road construction activity to their minimum through application of the prefabrication. Assessing two basic possible approaches to highway infrastructure construction - casting the road pavements and structures either in place or precast off the site - it can be concluded that the initial capital investment costs do not vary much. Substantial differences can be recognized when comparing their life-cycle costs and an extent to which their construction process affects the public, environment and the local economy. Prefabrication of any structure component off-site offers major construction time and user cost savings in comparison with the traditional cast-in-place methods of construction. Precast prestressed road pavements’ technology and precasting bridges’ parts and elements offers dramatic increase in durability, while it also substantially decreases construction time and resulting user costs.

1. Introduction
European highway infrastructure is aging at higher pace than expected as it is used by increasing volumes of road traffic. As an example to illustrate the above stated - volume of traffic on the backbone Czech highway “D1” approximately doubled between years 2010 and 2016. Even though an increase in traffic volumes on the rest of European highways is not that high, it is a steady reality in every country, only with a few years’ pause as the result of world financial recession between 2008 and 2012, according to Eurostat [1]. Economic recovery since this hiatus in a long-term traffic volume growth can be tracked by another Eurostat’s data on total number of vehicles, i.e. total car fleet in almost all of the EU member states which has grown over the last five years again [2].

1.1. Alternative means of transport
Changing the ways public uses personal means of transport is a very complex issue. So far it has been partly successful regarding long distance travel as a result of high capital investments into the fast train railroads. Otherwise lowering the numbers of passenger cars on highways for the short and mid haul was not achieved either. Regarding heavy transport, efforts to relieve overloaded highway network by shifting its volumes to the railroad so far mostly fail. This is mainly due to high demands on flexibility
and speed of supply required by the manufacturing and retail industry and also due to various complications that transport companies must face while switching from road to track and back.

1.2. Growing need of road maintenance

European highway network is aging faster than expected during its planning and construction. Such an unexpectedly increasing usage and consequent hard wear of the whole road infrastructure requires big volumes of repair and reconstruction works. Logically, the needs of its maintenance grow proportionally to its increasing usage. At the same time, this maintenance must be performed on a continuous basis while serving steadily growing traffic flow with minimal disturbances. Road network users demand that this refurbishment and new construction is done faster and with limited road closures, traffic congestion, delays and detour complications. This applies for all the European highway networks in general, but for the high-traffic areas the most.

1.3. Proposing the problem solution

The current situation of steadily increasing demand for highway construction capacities can be without any doubt defined as extraordinary. Analyzing existing capacities of the construction industry in Europe, as of March 2017, they still have not got over 80% of their pre-recession volumes [3]. To answer the demand for investment and maintenance construction services, current capacities are evidently not sufficient. There is a solution for such an extraordinary capacitive demands in the analogy to the residential housing problem in the sixties and seventies: application of the prefabricated construction systems using the technology of precast prestressed concrete elements.

2. Precast prestressed concrete

Public highway administrations are challenged to find ways to build new and more durable routes and to restore those already existing quickly and with minimal impact to its users and with the repairs being as durable as possible. Precast concrete road pavement and bridge construction systems - cast off-site (in a plant or next to the site) and installed rapidly off the rush hours - have that potential to transform highway network construction and maintenance. Not only do they cut limitations to the traffic and enhance safety during construction, they also bring in the higher quality product meaning the increase in its durability.

To summarize above stated, precast prestressed concrete technology brings unmatched durability for the newly constructed road pavements and bridges (for both – substructure and superstructure; tunnels are not addressed in this paper due to their relatively rare occurrence and technical specificity) and along with this feature also the lowest level of disruption to the traffic during its implementation.

2.1. Technology and its advantages

Precast concrete technology is not new as it had been used by the ancient Romans already. However it considerably developed since then from the composition of the concrete mix, through adding steel to increase tensile strength to new ways of casting and curing.

Main advantages of precast concrete over the cast-in-place (i.e. in target placement of the pavement or object) are generally as following. Precast pavement panels or bridges’ elements can be cast and cured in a controlled environment at a precast plant, providing greater control over consistency of the concrete mix, procedures of vibration and proper curing. Precast objects reduce or eliminate curling, strength, and air-entrainment problems that are common with conventional concrete paving [4]. Importantly, precast objects are also being both prestressed during their plant production and post-tensioned during their installation, which is not possible for the cast-in-place approach.

Prestressing in the plant significantly improves performance (most importantly the tensile strength) by inducing compressive stresses in the panels. This effectively prevents cracking and strengthens them for better onsite manipulation preventing them from bending and torquing. This durability not only slashes maintenance costs over the life of the roadway but significantly cuts user costs through the reduction of the repair cycles.
As proved by testing project of the Texas Department of Transportation from 2002 [4] and suggested by El-Reedy [5] post-tensioned panels provide the same design life as thicker conventional concrete pavements using thinner slabs; therefore, a 200-millimeter post-tensioned pavement would have the same life as that of a 355-millimeter conventional pavement. Post-tensioning also increases durability by minimizing or even eliminating cracking, and ties the individual panels together, promoting load transfer between the panels. Additionally, post-tensioning not only reduces the required pavement thickness, but also greatly increases durability, lessening or even preventing cracking in the pavement [6]. This increases the life of the pavement and contributes to a reduction in maintenance costs.

3. Application
As mentioned before, there is a vast and successful experience with the prefabrication in Europe. In the Czech Republic, resp. Czechoslovakia, it is the same, mainly in the housing construction. Even though it is in decline recently, the expertise and skilled labor force is still available. This provides a solid basis for its new way of mass application.

3.1. Precast Concrete Pavement Systems
In precast concrete pavement system construction, adjacent panels are assembled sequentially and tied together onsite through either post-tensioning or cast-in-load transfer systems. Precast concrete pavement systems can be used for single-lane replacements, multiple-lane replacement (an additional lane may be needed to accommodate materials and equipment) or full-width road construction [7]. Using the precast concrete parts for the road’s pavement speeds up the construction time two to three times against the traditional cast-in-place approach, if well organized. Such a pavement can be used, i.e. driven on the very next day after its installation as no curing of the newly laid road surface is further necessary.

3.2. Accelerated Bridge Construction
Precasting bridges’ parts and elements offsite is also very beneficial as bridges are generally among the most expensive objects constructed and also serve as a natural bottleneck for the traffic flows and so speeding up the construction process is very beneficial. The precast technology is applicable and needed for both – replacement or rehabilitation of existing bridges and construction of the new ones. It is the main factor in the new approach to process these two construction needs called Accelerated Bridge Construction (ABC). ABC concentrates on the innovative planning, subordinates design to the technology, uses resources and techniques to accelerate the bridge construction and maintenance without compromising the safety anyhow. It is mainly about the new approach to the construction management system. However, our main concern lies in the possibilities and the role that the precast technology plays in the ABC concept. Similarly, with the precast pavements, it is mainly about cutting the construction time, i.e. the limitations to the existing traffic, and about increasing the durability due to higher quality of the factory-made concrete. Based on that, it does make sense to precast most of the bridge elements - a pile, pier column, pier cap, beam, deck and barrier/railing as well, i.e. all but column’s footing, which is usually cast-in-place. Regarding the construction cost – the result is dependent on the quantities as when being high, they definitely turn the economics in favor of the prefabrication, unification and standardization. Regarding user costs, which might easily exceed those of construction if limiting the high traffic areas for a long time, precast is a clear winner (see the Case Study below).

3.3. Case study
As an example of the precast pavement technology and organizational approach it is this project organized by the Virginia Department of Transportation in fall 2009 illustrating its potential very well. The objective was to rehabilitate the 40-year-old exit ramp from highway I-66 to U.S. no.50 in
Virginia, USA, with the precast concrete pavement systems. It was a $5 million project to replace distressed pavement slabs in a high-traffic area outside Washington D.C., i.e. a heavy-traffic area.

Conventional repair with cast-in-place concrete would have required about 100 days with traffic congestion from lane closures, but the precast slab approach allowed closure of one lane at a time for about 35 nights of work and made all lanes available for rush-hour traffic. Every night’s cycle included the removal of the existing concrete, preparation and grading of the roadway sub-base, and preparation and placement of the new pavement slabs [7].

3.4. Work zones safety
Reducing time of work zones’ existence in the moving traffic also dramatically increases safety of everyone involved. It is mainly workers, who are fully exposed to the risk of collision with the consequences that are mostly fatal for them. Nevertheless on average, 85% of deaths in work zones were to drivers and passengers in cars according to U.S Federal Highway Administration [8]. To illustrate the occurrence of these accidents, based on the same source, there were approx. seven hundred fatal accidents in the work zones in the USA in 2014 and slightly above 200 fatal plus non-fatal injuries in the UK [9].

4. User costs
Road user cost (RUC) is defined as the additional costs borne by motorists and the community at-large as a result of road construction activity. User cost primarily refer to the monetized components of road construction impacts, such as the user delay costs, vehicle operating costs, crash costs and emission costs. Above these, there are other off-site components such as noise, business and local community impacts which are hard to monetize since the factors that influence their computation are often site-specific and no generalized method or tool is yet able to determine them accurately [10]. Nevertheless, it is the software tool HDM-4 which is in Europe most widely used to assess the mentioned costs with relatively satisfying precision [11].

Qin and Cutler [13] developed the detailed methodology on the road user costs’ calculation aiming to set incentive or disincentive compensation for contractors, quantify project-specific liquidated damages, select the ideal sequencing of a project, and forecast the long-term effects new construction will have on the traveling public. Gathering and maintaining local and up-to-date RUC data is also extremely important to any public highway administration, as underestimation of road user costs results in increased costs to the traveling public, while overestimation results in overpaying on incentives for early completion of construction projects. Obtaining proper RUC also helps to justify the deployment of new technologies that can accelerate the construction process for pavement and bridges [13]. Precast technology for pavements and accelerated bridge construction approaches comply with that perfectly.

But limiting the time of the road construction time does not only reduce the probability of work zone crashes, it also brings substantial cost savings to the road network users. Any road or even lane closure time brings substantial costs to the general public and business sector regarding loss of labor hours, lowered comfort, gasoline wastage and resulting decrease in overall society’s production effectivity [12].

As mentioned in the Case Study, the difference in closure times with the precast and cast-in-place approach can be as big as days and weeks versus months and years. Possible size in all above mentioned types of savings and benefits is evident. Problem is that many European governments, respectively their highway network administrating bodies generally do not attribute that much importance to the user costs inflicted by the traffic limitations. This is most probably caused by their relative “invisibility” in comparison to the construction costs. It is out of question that high user costs have serious national economic impacts and deserve a lot more attention.

5. Conclusions
As indicated above, selecting the method to use for the highway (re)construction should be significantly influenced by the value of the corresponding user costs.
Traffic volumes continue to rise in the European highway infrastructure and its users increase their demands regarding its comfort and quality. Because the capacities of the construction industry are limited, utilization of rapid construction methods is becoming to be a necessity. Prefabrication, respectively precasting seems to offer all that is needed in the current situation:

- Higher pace of construction works to answer the need to cut the time of traffic flow limitation.
- Higher and stable quality due to better controlled production process in the dedicated facility and the benefits of pre- and post-tensioning.
- Long-term durability thanks to the higher quality material used.
- Less frequent maintenance of the critical parts of the network – highways’ pavements and bridges.
- Higher economical effectiveness due to mass production of all standardized elements (mainly pavement panels and bridge elements) and achieved economy of scale.

In comparison with the very slow and labor intensive cast-in-place method, precast prevails in the current conditions and requirements of current highway network. Nevertheless, it has its opponents too – many designers and contractors. It is unpopular because of lower possibility to create every project unique and to achieve higher possible mark-up. Public demand for the quality and comfortable highway travel will hopefully move the state highway administrations to overcome their influence and let them exploit the potential that the precast prestressed method certainly has.

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