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Life Cycle Environmental and Economic Impacts of the use of concrete bridges with UHPFRC

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Abstract

Motivated by mechanical properties and durability against severe exposure, increasing use of Ultra High Perfomance Fiber Reinforced Concrete (UHPFRC) in the last decade has openned a new harizon for engineers and designers in the area of construction. This new technology can herald change in construction industry in the future decade. The need for the new world infrastructure development, the limited resources and raw meterials used, and the destructive environmental impact of related products of construction industry have shown the importance of dominating an ideology based on quality with reducing environmental impact and increased economic efficiency. UHPFRC, as a new generation of concrete, has been studied by environmental and economic life cycles since its inception. The objective of this study is to compare the economic and environmental impact of UHPFRC bridge construction with NSC bridge construction in a period of 100 years using the Life Cycle Assesment (LCA) methodology. The study has been performed in Ahvaz, Iran. The analysis shows that the costs of UHPFRC within 100 years are around one third of the NSC costs within the same period. The pessimistic estimate of the enivonmental impact of UHPFRC especially in global warming equals the NSC impact.

Keywords: Life Cycle Assesment, UHPFRC, Environmental Impact ,

1. INTRODUCTION

Concrete is one of the most popular man made products ever in human history. The ever-increasing consumption of concrete and its usages have expanded so widely that on average 1 ton of concrete is produced per person each year [1]. In the meantime, concrete is considered as an effective subset of construction materials making it the third largest CO2 producer among Europe's industrial products [2].Although the importance of the production of cement as a bonding agent in the development of construction, especially in developing countries is undeniable, studies continue to show that cement as the main bonding ingredient used in concrete accounts for about 7% of the total amount of CO2 emissions into the environment [3], [4]. For example, the establishment of the UK's first cement production plant in 1824 [5] followed by the rapid increase in CO2 emission at the beginning of the 19th century [6] suggests the importance of the impact of this material on CO2 emission into the environment. Therefore, it is necessary to propose a combination of strategies for using cement and related products while controlling the destructive effects these may have on the environment.

Reinforcement of natural resource management systems can be considered a contributing factor in this respect, leading to lower consumption of raw materials and natural environment and reduction in CO2 emissions. New developments taking place in the field of concrete technology have greatly helped professionals in the field of natural resource management. Achievements gained since 1999 in implementing UHPFRC concrete used in the reconstruction of bridges [7, 8] and then using ECO-UHPFRC concrete [2] heralds the arrival of and access to concretes with high capability and low emissions. It is obvious that the results of scientific achievements in the production of new types of concrete can be analyzed and compared with the same techniques used in other traditional methods in the long run.

LCA (Life cycle assessment), a methodology based on ISO 14040 standard [9] for calculating the environmental effects, is a tool that can increase the effectiveness of these scientific advances, and would provide a clearer picture especially as regards the environmental impact.

This paper is aimed to compare the economic and financial effects of the construction of a concrete bridge using conventional methods as opposed to UHPFRC concrete during a 100-year operation (life service) period. Taking into account the results obtained along with the environmental impacts during the operational period, the present paper opt for the method that meets the needs of society and the environment during the life cycle of the bridge. The calculated economic and financial effects is a combination of the initial cost of construction, the cost of routine maintenance during the operational period of 100 years and the cost of demolition of the old bridge by the end of its functionality which will be presented in terms of cost per square meter deck area. Given the importance of the effects of CO2 on the environment, environmental effects, as the sum of the effects of construction, 100-year maintenance and the ultimate demolition of the bridge by the end of the period, are presented in terms of weight as Kg CO2.

Concrete life cycle assessment (LCA) is in fact defined as collecting and analyzing data and outputs of a product system as well as its potential impact on the environment throughout its life cycle. [9] In other words, LCA is a tool that analyzes the effects a product may have on the environment, during its cycle of life and at all levels.[10] According to this definition, the environmental impact of a product from the first moments of its production to its complete annihilation is studied. Providing possible estimates of the cumulative environmental impacts resulting from all stages of the product’s life cycle, LCA is a technique for assessing the environmental aspects and potential impacts associated with a product, a process or a service. In order to achieve its goal, it involves compiling an inventory of energy and material inputs and environmental releases, assessing the potential environmental impacts associated with defined inputs and emissions to the environment, and interpreting the results to aid decision-making. The two international organizations ISO and SETAC have developed LCA as a tool for environmental management. ISO14044 [11] defines LCA as "a set of systematic procedures to gather and assess the environmental impacts associated with energy and material inputs and outputs of a product system throughout its life cycle", and according SETAC [12] "LCA is a process for evaluating the environmental impacts associated with a product, process or activity by identifying and quantifying the energy and materials and waste released to the environment, evaluating the impacts of energy consumption and emissions to the environment, identifying and evaluating opportunities to improve the environment including the entire life cycle of a product, process or an activity from the extraction and processing of raw materials to manufacturing, transportation and distribution, use, reuse, maintenance, recycling and final disposal." The closer the perceptions of product producers and consumers to cradle-to-grave concept, the easier it would be to achieve a sustainable approach. Materials are used in the manufacturing process cycle of exploitation, degradation and re-reaching another level of raw materials to manufacture other products.

Due to the large amount of natural raw materials used in its manufacture, concrete is one of the products that requires a sustainable approach in the process of its manufacture and operation. It should be noted, however, that due to the particular environmental conditions under which it is used, concrete is a substance that experts do not have detailed and representative information relating to its use and life cycle [10]. Thus, defining a rational strategy by considering the effects of its construction and operation will be of paramount importance. In this paper, the standard approach of ISO 14040-14044 [9],[11] is adopted as a framework for the methodology in four steps: 1. Defining the purpose and scope 2. Inventory analysis 3. Impact analysis 4. Interpretation and implementation, which are aimed to correctly identify and analyze the behavior and sustainability of concrete. Figure 1 illustrates the framework is intended for LCA studies based on the standard set.

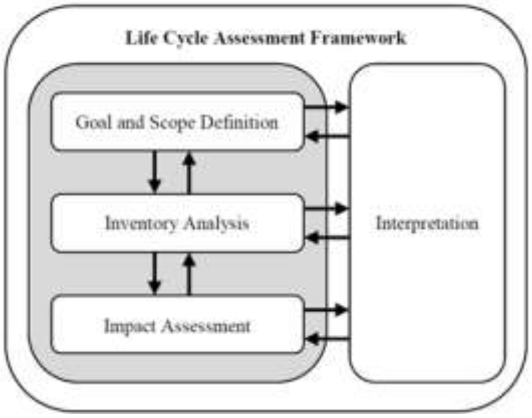


Fig.1 Life Cycle Assesment Framework

2. UHPFRC HISTORY

UHPFRC is currently the latest advanced High Performance Concrete product. In order to get a more homogenous product course aggregates are not used in UHPFRC mixtures. The density is increased by the use of silica fume along with sand and cement, contributing to the compactness. However, due to use of large volume of fine materials the mixture becomes brittle; therefore steel fibers are added to achieve a high range of ductility. The ductile behavior of this material enables it to deform and support flexural and tensile loads, even after initial cracking. Furthermore, the almost impermeable behavior of this material contributes to the long life performance by enhancing the durability[13] The extremely low permeability of Ultra-High Performance Fibre Reinforced Concretes (UHPFRC) associated with their outstanding mechanical properties make them especially suitable to locally "harden" reinforced concrete structures in critical zones subjected to an aggressive environment and to significant mechanical stresses. Composite UHPFRC-concrete structures promise a long-term durability which helps avoid multiple interventions on structures during their service life [14]

Extensive progress has been made in developing and producing this type of concrete in the world, introducing a wide variety of concretes with different titles to be released in several businesses, each with different mechanical capabilities of UHPFRC concrete. Table I shows some typical examples of such concrete.

Due to their exposure to extreme environmental conditions and the too much exposure of some of their parts to the passing traffic on the deck layer, bridges are generally eroding much of their life cycle. Efforts to improve the resistance of concrete bridges during the past decade have led professionals to look for ways to use durable concrete with high sustainability and mechanical resistance against aggressive environmental conditions.

The concept of application of UHPFRC for the rehabilitation of structural members has been proposed by Brühwiler in 1999, as an ‘‘everlasting winter coat’’ provided by a thin UHPFRC overlay on the bridge superstructure in zones of severe environmental and mechanical loads (exposure classes XD2, XD3) and only where worth using it [2].In 2004, during the European project SAMARIS, UHPFRC was first applied for rehabilitation of existing concrete

1. Typical example of such concrete

Mechanical prop	**CRC(15)**	**RPC(16)**	**DUCTAL(17)**	**CEMTEC(18)**	**BSI(19)**
Compressive strength(GPa)	140-400	200-800	150-200	180	190
Bending tensile strength(GPa)	30-200	30-50	25-40	25	90
Young's Modulus(GPA)	40-80	50-60	50-55	50	60
Density(kg/m3)	2600-3000	-	2500	2500	2700

structures in Europe. A bridge over the river La Morge in Switzerland was rehabilitated and widened using UHPFRC of the CEMTECmultiscale® family[14] . In 2006, a 3 cm layer of CEMTEC® was applied on a barrier wall. The mixture contained 6% of steel fibers by volume. Internal tensile stresses develop in the new layer due to early age shrinkage restrain by normal concrete. The UHPFRC layer was designed by using numerical analysis to resist these stresses[20] In July 2009, UHPFRC was applied for the first time for rehabilitation of a bridge deck over Šoka River in Slovenia[2].

MIKTI 's french project focused on composite bridges , use of BVC© for bridge construction in france , use of new Ultra High Performance Concrete called RESCON, made up of local austrian materials , Use of Ductal® for bridge construction in Canada and US Highway Bridges ,are the serial use of this new product [21].

3. STATEMENT OF THE PURPOSE AND SCOPE

As stated earlier in the introduction, this study examines the concurrent economic and environmental impacts resulting from the construction of a concrete bridge with conventional and traditional practices as compared with when UHPFRC concrete is used, during a hypothetical 100-year period operation. The concurrent calculation and analysis of both economic and environmental effects as the very characteristic of this essay lets decision-making process and the selection of the parameters not be centered around a single parameter, by incorporating various parameters to select the correct and suitable method. Clearly, the issue of environmental impact involves several parameters, but because of the importance of the direct effect of CO2 on the rise of the global warming phenomenon, the analysis concentrates on the environmental impact of CO2 released from concrete production process. The effects will be studied in terms of three intervals, namely the manufacturing of the concrete and its components, the process of operation, repair and maintenance of the bridges, and ultimately the demolition of the bridge will be studied. The same approach is adopted in comparing the economic effects.

4. CHARACTERISTICS OF THE STUDIED REGOIN AND CONCRETE

The studied bridge is supposed to be located in Ahvaz(Iran) and due the proximity this region to the Persian Gulf, it is considered as one of the areas with severe environmental conditions. Due to its location in the downtown, and because of the release of household and industrial wastewater into the river, the bridge will be heavily exposed to severe corrosion and sulfate invasion.

The bridge total span will be 40.6 m and consist of two equally divided sub-spans. Connecting two sides of the river, the bridge will host a large amount of traffic crossing the river. The nearest bridge located in this area is 14 km away which will be used at the time of restoration and repair of the bridge. Figure 2 depicts a view of this bridge.

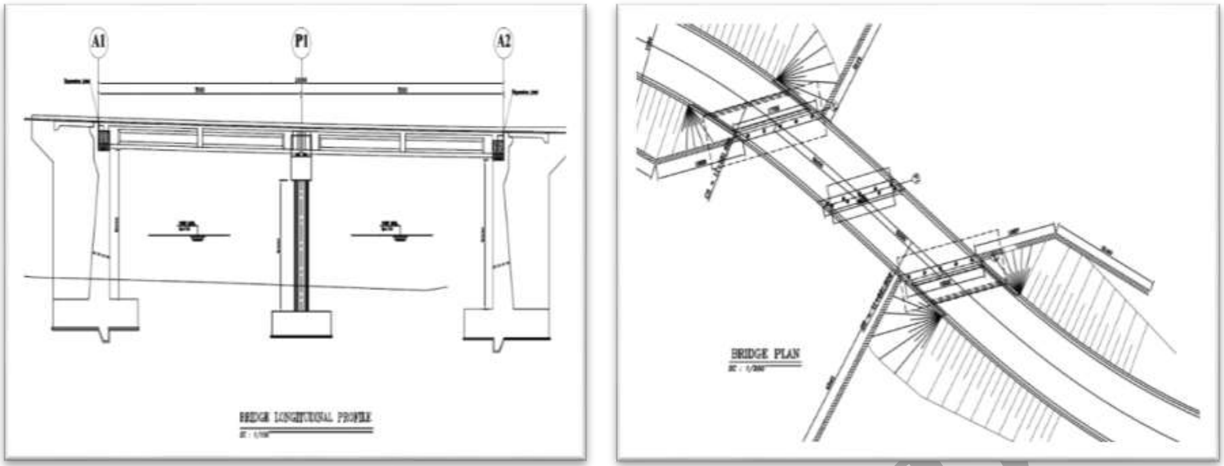


Fig.2 views from bridge study

2. Proposed mix design and source distances

Material Component	UHPFRC		NSC	
	Quantity	Distance	Quantity	Distance
	kg/m3	km	kg/m3	km
Cement	967	120	385	120
Silica fume	338	522	-	-
Fine sand	542	130	690	130
Coarse Aggregate		130	1060	130
Added water	184	-	185	-
Super plasticizer	20	3500	4.9	3500
Total water/binder	0.18	-	0.48	-
Steel fiber(4%)	314	4200	-	-

According to the calculations made for both cases, a significant reduction of the percentage of concrete volume was observed in UHPFRC as opposed to NSC. That is, in the case of NSC, the concrete has a volume equal to 2129 cubic meters whereas in UHPFRC the concrete volume is 1288 cubic meters. Table II illustrates the proposed mix design and the distance of the source of production or provision of any of the constituent elements used in both types of concrete up to the location of the ready-mixed concrete plant. It is worth mentioning that the micro silica used in the mix design was taken from Azna(Iran), the super plasticizer from German, and the steel fibers from France, all of which located at distances of 522 km, 3500 km, and 4200 km from Ahvaz respectively.

5. CALCULATION METHODOLOGY

In Figure 3 the boundaries of studied system can be seen. According to these figures, as far as the economic impacts are concerned, the bridge life cycle costs involve the materials preparation process and the running costs during the manufacturing and maintenance of the types of concrete studied. As regards environmental impacts, in both NSC and UHPFRC concretes, in addition to the formation process of the ingredients of the concrete, its manufacturing, mixing, and transportation processes are calculated as well. Due to the need for the repair and maintenance of this type of concrete in different years, each graph repeatedly compares the economic impacts of the manufacturing processes and the costs for

NSC concrete implementation as well as the production, mixing and transportation processes within the environmental boundary during the maintenance period (after construction).

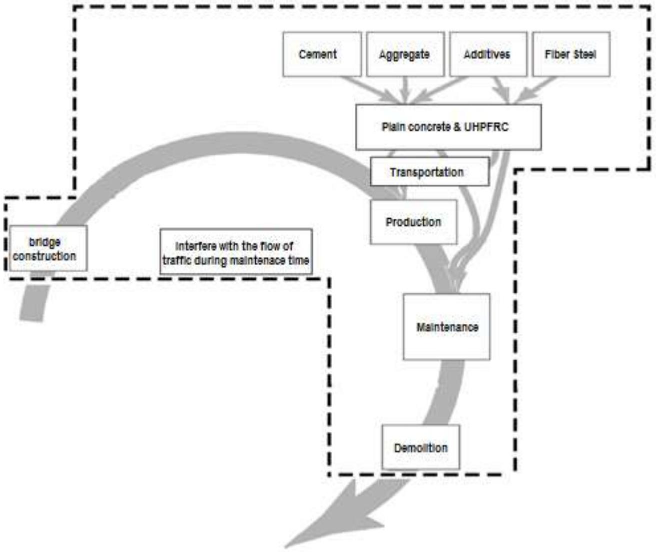


Fig.3 system boundaries

6. INVENTORY ANALYSIS

A. Impact coefficients

The life cycle impact assessment (LCIA) phase of LCA is the evaluation of potential human health and environmental impact of the natural resources and environmental releases indentified during the inventory and important exists between life cycle impact assessment . (LCIA) does not necessarily attempt to quantify any specific actual impacts associated with the product, process, or activity. instead, it seeks to establish a linkage between a system and potential impacts [22]

In this study, the coefficients used are based on the environmental impacts resulting from the amount of CO2 emissions in form of a set of numbers that are shown as kg CO2. The results of the calculation in CML01 methodology are shown in terms of the global warming potential of a hundred-year period (GWP100).This reduction can be justified as the main impact of concrete industry is CO 2 emission caused by both the fuel combustion and the limestone decarbonation in the clinker kiln[23],[24]

Calculation of life cycle is based on the impact of the constituent elements limiting the system. The coefficients are summarized in Table III below. According to the results for concrete structures [25], studies have shown that the environmental impact of site work is negligible compared with that of the manufacturing process and transportation of materials and products. Therefore, calculations can be limited to the manufacturing process and transportation of materials and products. Results of the European Union Directive [26] show that in some cases, substances such as silica, which might be recognized as a waste material at first glance, have come to function like by-product materials. Therefore, the environmental impact of such materials on the environment will be calculated differently with different coefficients. It should be noted that if micro silica is assumed to be a waste product, the results of the calculations would only affect the production site and transportation to the ready mix plant [27]. Thus, in this study, as in Herbert [2], the coefficient 3.1 x 10-4 kg CO2 is used to calculate the environmental impact of micro silica as a waste.

To calculate the environmental impact caused by the production and transport of steel fibers, results of Stengel's studies [28] have been used. The location of fiber manufacturing in relation to the implementation site can have a considerable impact on the amount CO2 emissions. Since the environmental impacts of manufacturing steel fibers are determined by the energy needed to supply electricity for the manufacturing plant, energy transfer from the country supplying electricity to the manufacturing country (if these are not identical) will have a significant impact on the rate of CO2 production. Perhaps using fibers whose production site is located at a greater distance from the implementation site, in case there is a smaller distance between the electricity power plant and the manufacturing plant, is more cost-effective than producing the fibers in the implementation country when it calls for supplying electricity power with greater transportation distance. Finally, the effects resulting from the longer process of mixing UHPFRC compared with NSC concrete are derived from studies of Chen [29], and are included in calculation.

3. Environmental impact factors

process	Impact factor (kg co2)	process	Impact factor (kg co2)	process	Impact factor (kg co2)
Demolation		Plasticizer	0.75	Water	0.00017
concrete	0.0147	Micro silica	0.00031	Plasticizer	0.00017
asphalt	0.0178	steel fiber	2.68	Micro silica	0.00017
Production (per kg)		asphalt	0.009	steel fiber	0.00017
Cement	0.84	Transportation(per kg km)		asphalt	0.00017
Sand	0.0024	Cement	0.0001	fabrication	
Gravel	0.0043	Sand	0.00017	ready mix plant	3.7 per m3
Water	0.00015	Gravel	0.00017	sand blasting	29.8 per hour

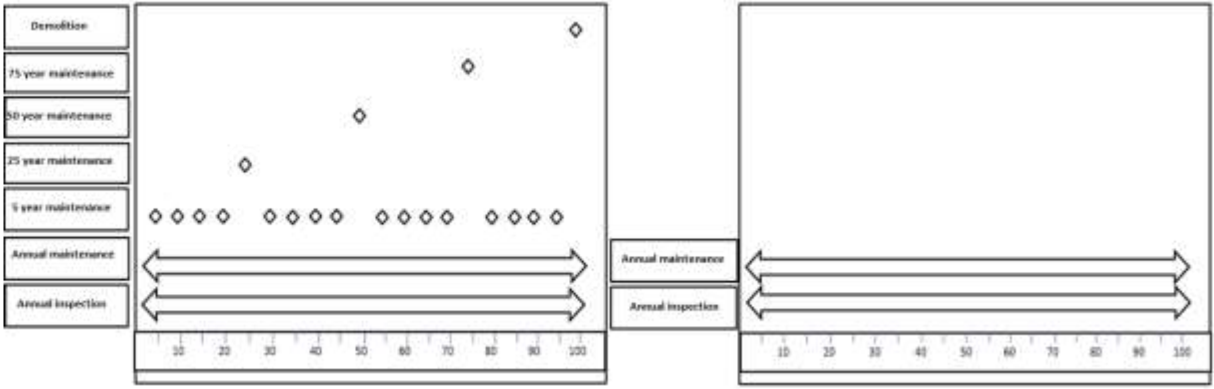


Fig.4 NSC & UHPFRC maintenance plan

B. Assumptions

That the concrete used in a bridge is influenced by a variety of factors such as environmental factors, unexpected environmental events like floods or earthquakes, and other factors such as the development of the bridge or the construction of a new bridge beside it to change the traffic flow will lead to increased uncertainty in the economic and environmental analysis. One option that can help pave the way for easier calculations is using a cautious scenario in the post-production period for the maintenance of the studied concretes during the course of their life cycle.

Of course, compliance of these assumptions with the conditions and location of the bridge and the related history based on regional calculations is both necessary and indispensable for reducing the risk in calculations. In this study, based on the related history and the restoration and maintenance of traditional concrete bridges in the region, the maintenance plan of 100 NSC-concrete bridges are extracted. (Figure 4)

As mentioned in the previous sections, using UHPFRC concrete in bridge has a history of less than two decades [7], [8]; thus, like NSC concrete, there is no codified history and archive of structural events during its operational period. However, several studies have been conducted on the mechanical properties and durability of these concretes, showing their incredible capabilities. All the durability properties such as resistance to chloride attack and penetration, resistance to alkali-silica reaction of cement and aggregates, high resistance to abrasion [30, 31] as well as high resistance to Freez -

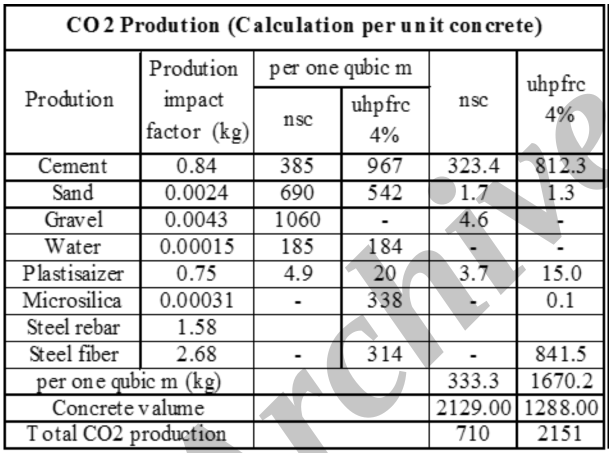
Thew [32] phenomenon along with the proven mechanical properties of this concrete [35] lead us to assume that for the hypothetical 100-year life span of the UHPFRC concrete only maintenance and inspection costs can influence the economic and environmental calculations. [36] The 100-year maintenance plan period for the two types of concrete based on the factors considered in this study can be seen in Figure 4.

7. IMPACT ANALYSIS

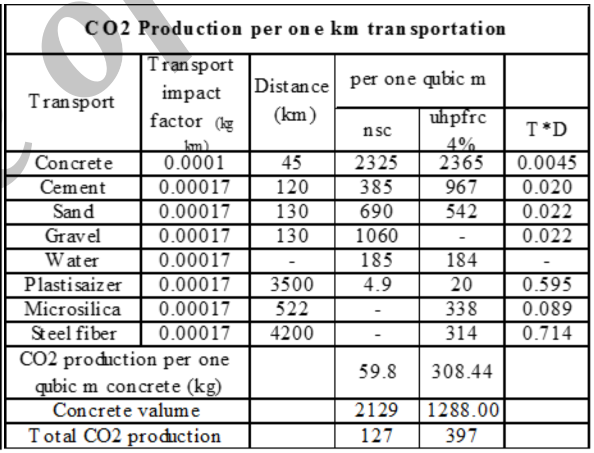
A. The environmental results of the manufacturing process

Table IV shows the results of producing one cubic meter of NSC concrete and UHPFRC concrete based on the mix designs used. As can be seen, the amount of CO2 released into the environment resulting from the production of one cubic meter of UHPFRC concrete is 1670 Kg compared to the amount obtained for NSC concrete which is about 333 Kg. It is very clear that the 1337 Kg per cubic meter difference for UHPFRC concrete production due to the excessive consumption of cement and the presence of about 314 kg of steel fibers has a significantly high impact. In the computing phase, the amount of each of the two concrete volumes is calculated. The amount of concrete used in the bridge with NSC concrete is 2129 M3 while constructing the same bridge using UHPFRC concrete with respect to its mechanical properties and its very high performance, needs only about 1288 M3. After calculating the amount of the concrete needed and the amount of CO2 emitted from each of the two concretes tested, the total amount of CO2 released in the production process will be 710 and 2151 tons for NSC and UHPFRC concretes respectively. As can be seen, for producing each cubic meter of concrete, the amount of CO2 emissions in case of UHPFRC concrete is 5 times greater than that in NSC concrete. Since the volume of the concrete used in UHPFRC is 60 percent more than that in NSC, this difference will lead to a 3-fold reduction in the amount of CO2 released in case of NSC.

4. Environmental results of the manufacturing process



CO2 Prodution (Calculation per unit concrete)					
Prodution	Prodution impact factor (kg)	per one qubic m		nsc	uhpfrc 4%
		nsc	uhpfrc 4%		
Cement	0.84	385	967	323.4	812.3
Sand	0.0024	690	542	1.7	1.3
Gravel	0.0043	1060	-	4.6	-
Water	0.00015	185	184	-	-
Plastisaizer	0.75	4.9	20	3.7	15.0
Microsilica	0.00031	-	338	-	0.1
Steel rebar	1.58				
Steel fiber	2.68	-	314	-	841.5
per one qubic m (kg)				333.3	1670.2
Concrete valume				2129.00	1288.00
Total CO2 production				710	2151



CO2 Production per one km transportation					
Transport	Transport impact factor (kg km)	Distance (km)	per one qubic m		
			nsc	uhpfrc 4%	T*D
Concrete	0.0001	45	2325	2365	0.0045
Cement	0.00017	120	385	967	0.020
Sand	0.00017	130	690	542	0.022
Gravel	0.00017	130	1060	-	0.022
Water	0.00017	-	185	184	-
Plastisaizer	0.00017	3500	4.9	20	0.595
Microsilica	0.00017	522	-	338	0.089
Steel fiber	0.00017	4200	-	314	0.714
CO2 production per one qubic m concrete (kg)			59.8	308.44	
Concrete valume			2129	1288.00	
Total CO2 production			127	397	

Another fundamental factor affecting the calculation of environmental impacts is the transportation process of the produced concretes and their constituent elements. Consumption of large amounts of micro silica and steel fibers and the large distance of transportation from the production to the construction sites in this project causes the transportation factor to emit 5 times more CO2 into the environment than in NSC concrete. The 40 percent reduction in the production of concrete in UHPFRC concretes together with the amount of CO2 released as a result of transporting one cubic meter of concrete and the constituent elements in consumed amounts will reduce this difference from 5 times to 3 times. (Table IV)

Figure 5 illustrates the effect and percentage of each constituent element of the concretes during the construction stage which includes production, transportation and fabrication. It can be clearly discerned that in NSC concretes, cement is responsible for more than 83 percent of the CO2 released whereas in UHPFRC concretes, as a result of the merger of all phases of construction stage (production, transportation and fabrication), steel fibers and cement are responsible for about 54 percent and 42 percent of CO2 emissions respectively.

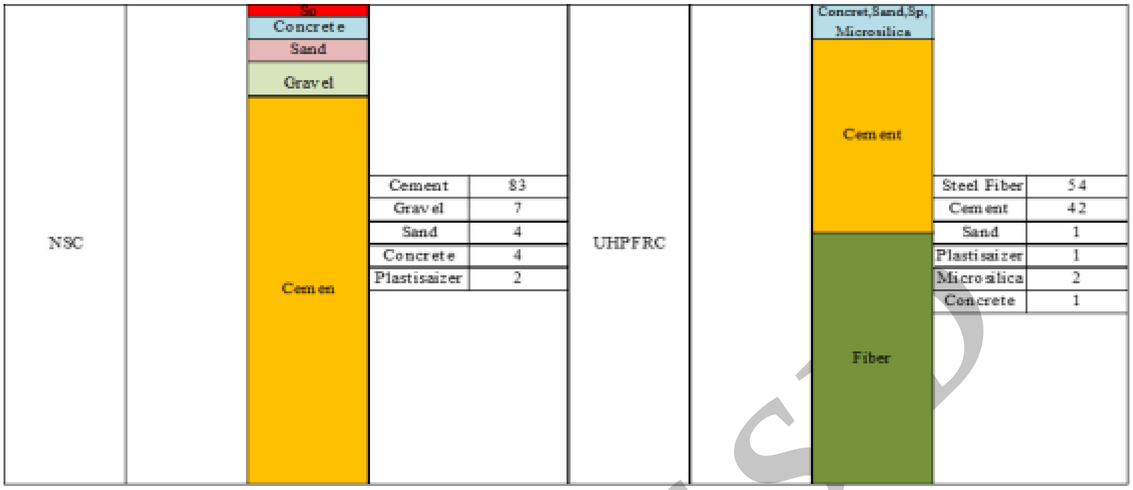


Fig.5 effect of each constituent element of the concretes during the construction stage which includes production

B. Environmental consequences of the maintenance and operation period

As stated in the Assumptions, based on the observations of the bridges in the region and the recorded history for the NSC concretes used for similar purposes, a particular scenario was adopted for calculating the impacts of the 100-year maintenance period for UHPFRC and NSC concretes. Under this scenario, the annual maintenance processes, the repairs at the 5th, 25th, 50th and 75th years, the removal of the deck concrete at the end of the 50th year and its reconstruction, and the final demolition after the end of the 100-year period will all produce 986 tons of CO2 in the construction process and 317 tons in the process of transportation. However, no necessity for repairs at the 5th, 25th, 50th and 75th years in case of UHPFRC and the presence of only biennial maintenance courses will, based on the projections of bridge maintenance period, produce 177 tons of CO2 in the manufacturing process and 50 tons in the transportation process into the environment.

One of the most fundamental parameters which should be considered in the calculation of environmental impacts of NSC concrete is the concrete removal and reconstruction of the bridge deck at the 50th year after construction. Environmental impacts caused by changes in the direction of traffic flow during the period of reconstruction and removal of the bridge deck concrete during this period are of paramount importance. This difference can be observed by estimating the number of passing cars during this period and the rate of CO2 emissions from vehicles in the traffic created. To calculate this factor, the estimated number of cars passing through each day, with regard to the critical position of the bridge in the traffic flow, is considered to be 600 vehicles per day. Due to the fact that the closest bridge as the only possible resort is 14 km away, the imposed distance resulting from the change in the direction of traffic is considered to be 28 km (round trip).

Considering a typical process for demolition and reconstruction of the deck concrete to be a 90-day period and by including the coefficient of 0.217 kg co2 eqkm-1 [2] as the impact of traffic, the amount of CO2 released into the environment during the reconstruction of the deck will be 879 tons. This amount is 70% of the total CO2 produced from the production and transportation of NSC concrete. Overall, after a 100-year period, it can be seen that the amount of CO2 released into the environment for both concretes will be about 2900 tons.(table V)

C. Economic impacts of the construction period

The estimated costs associated with the preparation of the elements needed to produce a cubic meter of NSC concrete are 715760 Rs while due to the high costs and excessive use of steel fibers in UHPFRC concrete, the costs are 16741290 Rs.

This 23-fold difference in the preparation process of the constituent elements of each of the two concretes envisages dim and unexpected economic prospects for the UHPFRC concrete. However, two parameters reduce the gross difference in the final cost of the manufacturing process. The first factor is the shortened course of building a bridge with UHPFRC concrete. A120-day difference over the construction of two bridges will lead to a cut of about 4800000000 Rs in costs of performance factors and machinery during the construction period. The second factor is the reduced volume of concrete used in UHPFRC concrete compared to that in NSC concrete. The combined effect of these two factors plus the initial costs render the cost difference of production per cubic meter of the studied concrete to be around 3.5 times less than that of NSC concrete (Figure 6). However, by applying the final volume of each concrete and due to the reduced concrete volume in UHPFR compared with NSC, the final costs of UHPFRC will be 2 times as much as those of NSC

5. Total amount of CO2 released in to the environment after 100 years

	CO2 emission per ton								Total CO2 emission at 100 years per ton
	Concrete production in construction period	Transportation in construction period	Fabrication	Concrete production in 100 years M&R period	Transpotation in 100 years M&R period	Fabrication in 100 years M&R period	Traffic deviation in deck rihabiliation period	Concrete demolation	
NSC	710	127	8	986	177	11	820	77	2916
UHPFRC4%	2151	397	5	317	59	1.0		-	2930

	NSC	UHPFRC
Initial cost per unit valume (toman)	71576	1674129
Labor cost per unit valume (toman)	565054	560403
Total cost per unit valume	636630	2234532
Total valume (m³)	2129	1288
Total cost (toman)	1355385270	2878077216

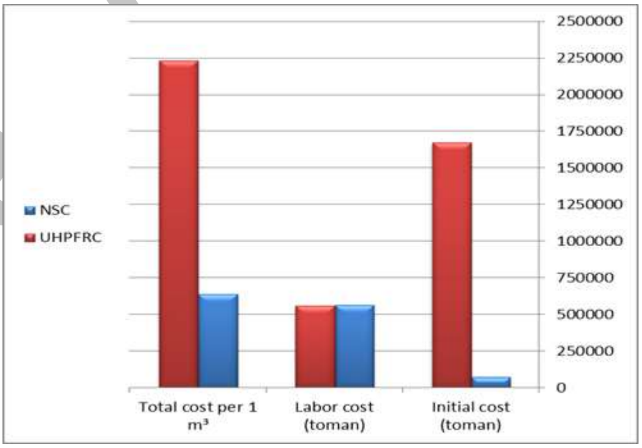


Fig.6 Costs comparison table

D. Economic impacts of the maintenance and operation period

As stated earlier, the calculations regarding the 100-year maintenance period for NSC concrete should be based on Fig. (4). It follows that there will be 99 annual maintenance and inspection periods, 16 five-year maintenance periods, and the 25th, 50th and 75th year maintenance periods will happen only once each. In the meantime, the costs of demolition and reconstruction of the deck concrete at the 50th year and the final demolition of the bridge at the end of the 100th year should be included in the economic calculations. As with the UHPFRC concretes, since there is no need for considering the 5th, 25th, 50th and 75th year maintenance costs or the costs of demolition at years 50 and 100, only the annual maintenance and inspection costs will be considered. It is worth mentioning that the optimal performance of UHPFRC concrete in bridges makes it possible to promote the annual maintenance costs to every two year. Estimations of the costs of the 100-year period for each of the two bridges by considering the 3 percent annual rise of prices in the following equation for calculating the economic value of this bridge in different years are shown in figure7.

$$\mathbf{Rn = ICC + (1+r)^{n/2} * n * (MC + IC) + (1+r)^{n/2} * [n/5] * RC5 + (1+r)^{25} * RC25 \quad + (1+r)^{50} * (RC50 + SD50) + (1+r)^{75} * RC75 + (1+r)^{n} * DC}$$

The results show that in the 42nd year after the construction of the bridge, the costs for the two bridges will be the same, and thereafter the bridge with UHPFRC concrete will show a more favorable economic behavior compared with the one made with the NSC concrete.

No	Year	NSC (mil toman)	UHPFRC (mil toman)
1	1	1374	2887
2	5	1498	2926
3	10	1662	2982
4	25	2517	3138
5	30	2793	3299
6	35	3105	3406
7	40	3459	3528
8	50	5508	3820
9	75	10817	4923
10	100	19265	6824

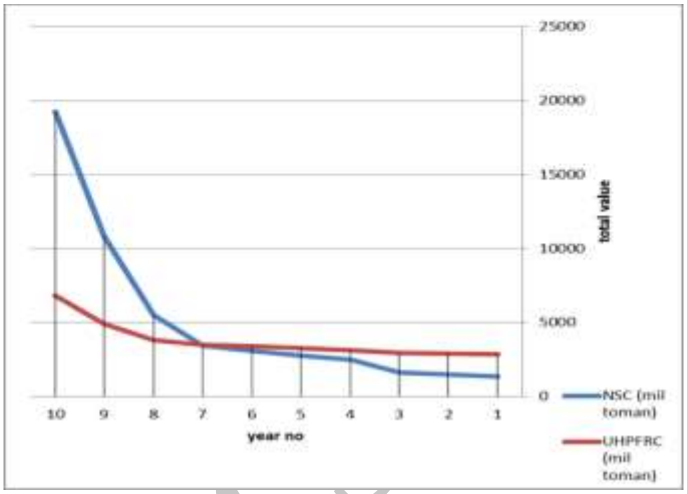


Fig.7 100 years cost estimation

As can be seen in the graph, there is a leap in the 25th year of NSC concrete due to the maintenance and repair costs of the 25-year period. A greater leap will occur in the 50th year due to the additional costs for the demolition and reconstruction of the deck concrete and the more profound effect of the price growth. After this period, due to the impact of annual price growth, it can be observed that the costs in both concretes get momentum.

8. CONCLUSION

Based on estimations of both environmental and economic impacts of NSC and UHPFRC concretes in a 100-year period, and the current costs in Iran as well as the parameters related to CO2 emissions caused by the ingredients and other processes associated with the construction and operation of a bridge extracted from the references cited above, we draw the conclusion that if the operational life of a bridge built entirely of UHPFRC concrete is more than 42 years, such a bridge would be more cost-effective than a bridge built with NSC concrete, and in a span of 100 years the associated costs will be one-third of those of NSC concretes. Of course, it should be noted that this conclusion is solely for bridges that are constructed entirely of UHPFRC concrete, and costs for conditions where in UHPFRC is used only to repair or modify the cladding concrete of bridge decks or other parts will be different and possibly less.

At the end of a 100-year period, UHPFRC concrete will bring about less environmental impacts in terms of CO2 emissions compared with NSC concrete over the same period. This is mainly because of the high levels of CO2 emissions in the production of concrete, caused by the cement and steel fiber used in UHPFRC which have impact coefficients far higher than those of other constituent elements in ordinary concretes. To reduce the environmental impacts of UHPFRC concrete while maintaining the expected quality, it is recommended to substitute certain amount of cement with materials such as Micro silica, Fly ash and Limestone which have lower impacts in order to cause less CO2 emissions into the environment. One of the most influential factors in CO2 emissions into the environment is the transportation of the constituent elements of the concrete. Based on our calculations, about 73 percent of the CO2 produced in the manufacturing process was caused by the transportation process of steel fibers. Therefore, it should be stressed that the distance from the purchase location of the steel fibers be considered in advance, and as far as possible environmental considerations take priority over economic ones in the preparation of fibers.

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