ABC-UTC June 2023 Monthly Webinar: FHWA’s Lightweight Concrete Bridge Design Primer – ABC Applications		
#	**Questions**	**Responses**
	Pre-Webinar Questions	**Note: It is recommended that the FHWA *LWC Bridge Design Primer* be consulted for more information related to questions and answers appearing below.**
1	How does the anchorage design differ between lightweight concrete (LWC) and normal-weight concrete (NWC)?	The only way that the use of LWC may affect anchorage in concrete (either development lengths or post-tensioned anchorages), is the potentially reduced tensile capacity of LWC. This is accounted for in design by the lambda factor. However, in the AASHTO LRFD, there is an option to specify the splitting tensile strength of LWC, and if specified to be equal to the expected splitting tensile strength for NWC, the reduction factor will be one. This is reasonable as demonstrated by quite a number of tests.
2	Are there differences in creep and shrinkage behavior, deflections, and shear strength between lightweight concrete and normal-weight concrete?	There is a common idea that creep is a problem for LWC, largely based on the sag that occurred on the Parrotts Ferry Bridge in California, constructed in the late 1970s. But this sag was the result of a number of factors, including the absence of continuity tendons in the design. I hope to write a paper on this someday soon. Recent research and testing has shown that creep for LWC is not significantly different from NWC. Shear strength would be affected by the potentially reduced tensile capacity of LWC. This can typically be addressed in design. But it can also be dealt with by specifying the splitting tensile strength of the LWC. When the AASHTO LRFD Specifications first came out, LWC had a resistance factor (phi) for shear of 0.7 while NWC was 0.9. This was a problem for LWC designs. I heard that LWC was considered for one segmental concrete bridge but the low resistance factor made the design uneconomical. However, the low resistance factor for LWC was based on a lack of data to evaluate the resistance factor for LWC. After industry provided data and research was conducted, it was determined that the same resistance factor can be used for LWC and NWC, removing this obstacle to the use of LWC. The LRFD Specifications have implemented this in the current edition.

3	How does the use of lightweight concrete affect the wind load design on bridge substructures?	I am not sure what is intended by this question. I am aware of one situation where LWC was not considered for the deck on a long-span truss bridge replacement because reducing the weight of the structure would negatively affect the design of the bridge for wind loads. But usually, reduction of dead load will be beneficial for the design of a bridge.
4	Is lightweight concrete applicable for prestressed concrete uses? What are the specifications, etc., for lightweight prestressed concrete?	The *LRFD Bridge Design Specifications* fully address the design of LWC for bridges. Some construction related issues must often be addressed as LWC is probably not addressed in local Standard Specifications. To support the claim that LWC is applicable for use in prestressed concrete, several examples are given here - and see also the LWC Primer. The longest girder fabricated in the US was made using LWC to enable shipping. Virginia DOT has constructed a number of bridges with LWC girders and decks, including several post-tensioned spliced girders. There are pretensioned LWC girders constructed in the 1960s that are still in service today. There is no structural reason not to use LWC for prestressed or even post-tensioned girders.
5	If lightweight concrete offers so many advantages over regular-weight concrete, why aren't we using it everywhere?	Good question! In many cases, designers think that LWC has significantly different properties. The main one is the modulus of elasticity. It may also reduce shear capacity or extend development lengths. Others think that creep and shrinkage are an issue, but the presentation and Primer show that it is not an issue. However, the most significant issue for most people is cost. If a designer looks only at the higher cost of the aggregate, one would wonder how it could be reasonable to use it. But when one looks at overall project costs, especially including full recognition of the benefits of the lighter weight of the structure, then the costs can be offset by the savings. People are just not aware of this, and the industry had stopped promoting LWC for many years, so the message has not been getting out.
6	Please comment on the application of lightweight concrete for MASH-compliant bridge barriers. Are you aware of any state DOTs using lightweight concrete in their bridge barriers?	I am not aware of any testing of LWC barriers for MASH compliance. However, LWC has been used successfully for barriers by several states for a number of years. It is expected that performance would not be significantly different from NWC barriers if the compressive and tensile strengths of the LWC are the same as the NWC.

7	What is the service life and durability of lightweight concrete compared to normal-weight concrete?	Durability of LWC is typically equal to, or even somewhat better, than for NWC due to a number of factors that are discussed in the presentation and Primer. Test and field experience have shown that LWC bridges have performed well. Please see the LWC Primer for more details and examples.
8	What is the track record for bridges using lightweight concrete, and are there any special details needed for using this material?	Performance has been good. See the FHWA report published in 1985 by T Y Lin International that reviews performance of bridges completed by that time. Many of those bridges are still in service. These include both decks and prestressed girders. Additional durability concerns are addressed in the LWC Primer. Details needed to promote durability for LWC structures are no different than for NWC structures. It has even been shown that grinding and grooving of LWC decks should not negatively impact durability of those decks - see the LWC Primer.
9	What are the AASHTO and ASTM required tests for lightweight concrete, especially in relation to fiber-reinforced polymer reinforcing (bond development, etc.)?	Please see the LWC Primer for the tests required for LWC, although tests are the same as for NWC, except for the aggregate specifications. There are some modifications for LWC for several of the test methods that are discussed in the LWC Primer.
10	What types of lightweight aggregates (LWAs) are used (kiln fired and naturally occurring aggregates)?	The LWAs discussed are manufactured which allows greater control of properties of the aggregate. Some natural LWAs exist, as well as some other sources of LWA, but they are generally not included in the material specifications for aggregate being used for structural concrete for bridge construction.
11	What lightweight concrete density is used for design compared with 150 pounds per cubic foot of normal-weight concrete?	Typical densities of structural LWC used in bridge construction are 115 to 125 pcf. However, all-LWC can have a density as low as 100 pcf or possibly slightly less. These densities are typically compared to 145 pcf for NWC, although this can vary from 140 to 155 pcf in different regions of the country. All of these densities are for plain concrete, without reinforcement, so when computing dead load, an allowance for reinforcement needs to be added - typically 5 pcf, but that allowance is not always adequate and should be checked for heavily reinforced members.

12	Who are the major lightweight suppliers in the U.S., and are the lightweight aggregate properties relatively consistent?	The map in the presentation shows the locations of plants manufacturing LWA. The map can also be accessed from https://www.escsi.org/. LWA suppliers often have terminals which supply locations distant from the source. Structural properties of the LWA from different sources do vary, just as with NWA. For most applications, LWA from the different sources perform well for bridge construction.
13	Does the lighter weight of LWC have any effect on consolidation or settling time or slump?	LWA is just a lighter rock, so it behaves pretty much like normal aggregate. Setting time is not affected. Some people expect that the lighter LWA particles will float in the concrete, potentially leading to segregation. However, segregation problems are minimized if the LWA is adequately prewetted and the concrete is not over-vibrated. Typically, a well-proportioned mixture will not segregate. The lighter weight of the concrete does result in slightly reduced slump measurements compared to NWC mixtures with the same workability. This is simply due to the reduced weight that drives the slumping of the concrete.
14	Can you provide more design examples?	Design examples would certainly be helpful, although there are very few details that differ from designs using NWC. The main difference is the fact that the lambda factor is not equal to 1.0 for LWC, but is defined by the density of the concrete. The reduced lambda factor typically used for LWC results in the reduction of the concrete shear contribution and an increase in the development lengths for nonprestressed reinforcement. However, as discussed in the presentation and LWC Primer, this effect can be reduced or eliminated by specifying the splitting tensile strength of the LWC. The new edition of the *PCI Bridge Design Manual* will include a LWC girder design example. But such examples simply show how to make the calculations. The most valuable calculations are the comparisons between LWC and NWC designs. Several references are given in the LWC Primer for such design comparisons, although the calculations are not given in those references, just the results.

15	When will the price come down for lightweight concrete?	As discussed in the webinar, LWA is manufactured by expanding the raw materials in a rotary kiln which requires high temperatures. So there will always be a higher price for LWA compared to conventional aggregates. There is also often a significant cost for transportation of the aggregate. However, the total cost of LWA is relative, as the cost of NWA may also vary. Several years ago, I looking at the variation in cost difference or premium for a LWC mix and a similar NWC mix for prestressed girders for two prestressed concrete girder fabricators. One fabricator was located within about 60 miles from the LWA plant, while the other was located in a different state, more than 550 miles from the LWA plant. However, the cost premium for LWC mixture was less for the fabricator far from the LWA plant because they had to ship their NWA from a great distance, while the fabricator close to the LWA plant was located adjacent to their source of NWA. This shows that there are many factors that affect the relative costs of LWA and LWC.
	Questions during Webinar	
16	Can lightweight concrete be used in link slabs?	LWC can certainly be used for link slabs. In fact, the performance of the link slab would likely be improved because of the lower modulus of elasticity of the LWC. The lower modulus would tend to reduce the cracking potential of the link slab as it is subjected to deformations from the movement of adjacent spans.

17	If it is not addressed in the presentation, can you comment on this product being used for internal curing?	LWA can be used for internal curing. In fact, all LWC for which the LWA is prewetted prior to batching (this is the standard procedure for LWAs in the US), will provide internal curing to the concrete. FHWA is promoting the use of internal curing using prewetted LWA as part of their Every Day Counts 7 (EDC-7) program. They are developing and are making available resources that assist bridge engineers in using the concept of internal curing to improve conventional concrete mixtures. In this case, a fraction of the NW sand is replaced by an equal volume of prewetted LWA, which will release the internal curing water into the concrete. The reason that LWA is used is that its increased absorption allows it to deliver water to the interior of the concrete for internal curing, rather than using the LWA to reduce the density of the concrete. The unit weight of internally cured concrete will be slightly reduced but the reduction is usually small and does not significantly affect the mechanical properties of the concrete.
18	At one time was there a moratorium on the use of lightweight concrete on bridge decks because of big chunks popping out? What happened that led to the use again of lightweight concrete in bridges?	I am not aware of such a moratorium, unless it might have been in Louisiana where apparently some local LWA was used which I understand was not adequately checked for quality prior to use. So just as with NWC, if there are quality issues with the mix or its constituents, bad performance can certainly result. Such issues are not typical for the current sources of LWA and LWC, as is clear from the many bridge projects that have lasted for many years, regardless of when they were constructed. For the LWA sources available today, I do not think that there have been any significant changes in processes over the years, other than improvements in efficiency.
19	What is the price of lightweight concrete relative to UHPC (Ultra-High Performance Concrete), specifically in relation to the cost of shipping?	I do not have cost data for specific LWC mixes, and even if I did, mix costs for one location do not necessarily reflect the cost for other locations because of the many variables involved. The cost data shared in the presentation and in the LWC Primer that are reported by a prestressed girder fabricator in Washington state is useful because it demonstrates that the effects of the high cost of LWA and transportation resulting from shipping the LWA across the country are greatly reduced when it comes to the total cost of a girder. I do not have any knowledge of the cost of UHPC. The two types of concrete are probably going to be used in different applications, although both may be used for decks, especially if the precast waffle slab concept proves viable with UHPC.

20	Does lightweight concrete, with its lower Ec (modulus of elasticity), have more deflection and vibration?	A LWC bridge will have somewhat greater deflections. If only the deck is LWC, then the change in deflection will likely be small. If both deck and girder are LWC, then the deflections will be larger. Vibrations would also be increased somewhat, but I am not aware of any problems with vibrations in LWC bridges over the years.
21	For the I-5 / Skagit River Bridge cost comparison, did the girder cost include the savings from not having to retrofit piers?	No, the cost shown in the table was only the price of the finished girders, and I do not believe that the cost included girder delivery costs, which would likely be reduced. The cost and schedule savings from not having to retrofit the pier would reduce or eliminate the minor increase in the cost of the girders.
22	Is the formula for the calculation of the elastic modulus "E" provided in AASHTO LRFD valid in the case of lightweight concrete?	Yes. The revised equation adopted by AASHTO in 2014 was developed to provide a better estimate of measured modulus of elasticity values for both LWC and high strength concrete. It should be noted, however, that there is fairly wide scatter in modulus of elasticity values for all types of concrete.
23	Does the use of lightweight concrete help to reduce temperature effects in bridges?	Yes. The coefficient of thermal expansion (CTE) of concrete is reduced with the addition of LWA. See the data for typical deck concrete mixtures shown in Slide 40 in the presentation, which is also discussed in the LWC Primer. The CTE for sand-LWC was about 80% of the CTE for the control mixture, with the CTE for all-LWC was less than 70% of the CTE for the control mixture. There was also a small reduction in CTE for the internally cured concrete since the quantity of LWA in the mix was relatively small. The smaller CTE for LWC results in reduced cracking potential from thermal effects and reduced joint movements.
24	Does UHPC (Ultra-High Performance Concrete) cast with lightweight aggregates exist?	I am not aware of any UHPC that has been made with LWA, although as I mentioned in the webinar, there is some potential for using the internal curing effect of LWA to improve the efficiency of mix design for UHPC. I do not expect that enough LWA could be added to the mix to provide a significant reduction in density and still achieve the high compressive strengths required for UHPC.

25	Regarding lightweight concrete aggregate, how much variability can be expected in specific gravity / density / unit weight? Do the variations in specific gravity of the aggregate affect the mix design and ultimately the unit weight of lightweight concrete?	I do not have any data on this. However, since LWA is made by expanding raw materials in a rotary kiln, there is an opportunity for the suppliers to blend the expanded material to reduce the variability of the properties of the LWA, especially the specific gravity and unit weight. There are rather wide tolerances on other parameters in concrete, such as the entrained air content, which, for LWC, can result in significant variability in the measured unit weight even if the unit weight of the LWA does not vary.
26	How much variability in specific gravity could be expected from one supplier over time (let's say, one year)?	I do not have any data on this. I recommend checking with a LWA supplier if the application requires tight control of the unit weight. In most applications, the design will be adequate as long as the maximum density is not exceeded.
27	For lightweight concrete, have there been any fatigue-related tests done to understand the behavior under stress reversals and dynamic effects?	Some limited fatigue studies for lightweight concrete have been conducted. A major study to investigate the use of LWC for offshore oil platforms included fatigue tests of LWC; results were published by Hoff in ACI SP-136 (1992). Gerwick also commented on fatigue of LWC in a paper published in Concrete International (1985). Both of these authors reported favorable fatigue performance of LWC. The performance of LWC under low-cycle fatigue associated with seismic events has been studied by Kowalsky and others at UCSD (2000) and NCSU (2010). LWC was found to provide good seismic performance. This is discussed and references are given in the LWC Primer.
28	How widely is lightweight concrete used outside the U.S.? Is lightweight concrete a suitable alternative for applications in cold/extreme weather conditions?	LWC has been used in other parts of the world, especially in Europe. The three concrete segmental box girders with the longest main spans in the world (all are about 300m or nearly 1000 ft) are in Norway, and all three use LWC for a major portion of the main span. References are provided in the LWC Primer. Part of the study of LWC for offshore oil platforms published by Hoff in ACI SP-136 (1992) included cold weather performance of the LWC. It was found that LWC performed well in arctic environments. Since then, LWC has been used successfully on several off-shore oil platforms in cold climates.