RISK AND BENEFITS INCLUDING SNFRC FOR THE DESIGN AND CONSTRUCTION

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Abstract:

The performance was met, the schedule on time, and the costs were significantly less by using synthetic fiber reinforced concrete in an thin overlay of concrete on asphalt on an average 17% grade residential driveway. Five almost equal lengths of SnFRC were placed in 2 groups 11 months apart. The delay between placements allowed for some experience to better analyze and determine if this was the best solution given the customer's criteria and the difficult construction conditions. The design included a high cementitious content mixture with small aggregate, fibers, air entrainment, and no other admixtures for workability. The resulting driveway was construct-able down hill and has performed well in spite of minimal surface preparations and no jointing or saw cuts in the overlay. Some small cracking has occurred but has been of no consequence because the concrete has been held together by the synthetic fibers.

Keywords: synthetic fiber reinforced concrete, SnFRC, bonded overlay

1 Introduction

A good design for construction has to do with best fit or conformance to the existing conditions, and desired outcome by following a generally understood set of activities to establish some constraints and parameters. For a designer, this begins with determining the customer's needs, wants, and desires. From this then, hard measurable criteria are established to meet the project cost, schedule, and performance. The risks before the project begins are getting enough information about these issues without dictating to the customer the designer's preferences. When the materials have been chosen and the design is complete, the information is transmitted to construction by contract (legal verbiage about relationship conduct) including specifications (criteria generally and specifically about materials and execution issues on pages, copies, cut sheets, etc.) and graphical representations (drawings, sketches, etc.) of the work to be done. By definition, the amount of these documents is the level of quality control the designer wants for the project. Further risks associated with the construction have to do with labor, equipment, materials, weather, and then also incorporating and ensuring the designer's intent.

The benefits associated with this entire process are that the process can be duplicated (i.e. using the same design, materials, techniques, etc.). Further benefits may also include additional customers, making a profit, and self-satisfaction having done that work.

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This case history describes a small sized project for design and construction of a synthetic fiber reinforced concrete (SnFRC) driveway and adds details to the risks and benefits of choosing this

2 Problem Overview

The house was built in 1961. Sometime before 1989, an asphalt driveway was installed. The severely rutted and cracked asphalt driveway received no maintenance since the 1989 purchase by the current owners. Traffic roundtrip on the driveway was at least twice weekly trucks and at least twice daily autos. The amount of rutting and cracking developed some deep potholes that even bent the rim on an alloy wheel getting a 'run at it' to get up the hill.

The sloped hillside driveway is on average 17% and up to 19% in some spots in about a total run of 250-feet (76-meters). This portion of the driveway elevation difference is about 40-feet (12.2-meters). Due to the dense woods surrounding the property and Minnesota location, the hill frequently becomes snow and ice covered regardless of plowing. Numerous times vehicles have slid off the driveway. Further still, burning rubber while trying to mount the hill and get past the no-go slippery spots has shortened tire life. Traction on the new surface is an issue of concern.

2.1 Project issue - performance

With my background, concrete seemed the logical choice for pavement, but there were other details to be worked out (Farney, MacDonald, and Ramakrishnan).

Performance criteria: the pavement needed to work (i.e. cover the ground) and be drive-able, plow-able, textured for minimal slipping, self-defrosting color (if possible due to lower winter sun and heat gain), minimal maintenance, and durable (previous experience indicates it would get no maintenance).

2.2 Project issue – schedule

The schedule criteria for September of 2005 was there were two locations on the hill that were worse or had deeper potholes than other portions of the hill. With the impending winter season and subsequent plowing, these worst spots needed to be repaired during a stretch of 'warmest' weather in October to allow the concrete to gain strength for subsequent service. The FRC pavement placement higher on the hill was designated 1 and lower placement 2.

In September of 2006, concrete was placed again above, between, and below the October 2005 placements and used the same FRC. The order of FRC placements, from the top of the hill, is 3-1-4-2-5 and each placement is almost equal length. Again, placements 1-2 were done October 2005 and placements 3-4-5 were done September 2006. For a detailed description, see Table 1 regarding placement locations.

2.3 Project issue – cost

The general criteria for cost was as minimal expense as possible and still meet the schedule and performance criteria. Both asphalt and concrete were considered. The asphalt solution included complete removal of the old asphalt, rebuild the base and then place a wearing course or replacement surface of asphalt. A local asphalt contractor provided a written estimate of USD 15,000 for this asphalt solution. A decision was made to go with portland cement concrete and not asphalt as the expected costs could be significantly reduced due to familiarity with the materials and alternative construction techniques.

3 Design issues

The driveway is located about 0.6 miles (1 kilometer) from the "Mighty" Mississippi River and the soil is inconsistent and variable but generally a sandy - clay – gravel mixture. This also influences any pavement support conditions and the general erosion and water drainage issues at the pavement edges. The driveway is generally oriented as follows: top is the north end and down is to the south end and it curves (or bows outward) to the west. The east side or inside of the curved driveway is where the rainwater generally runs off the driveway and hillside. This run-off has caused some additional erosion issues that have been repaired with large and mixed gravel and some waste concrete at the flared end of the driveway. Regardless of the pavement type, at and near the pavement edge needs to be addressed as a separate maintenance issue. The varied ground support may have been the primary cause of the initial pavement deterioration.

Design can be characterized as making a choice and then analysis, which is different than design, evaluates the choice. Similarly, risks and benefits are associated with each potential choice. However, this could be endless discussion if we stayed in the design area. Therefore, the biggest decision (choice) so far is to pave with concrete and not asphalt primarily due to my familiarity-benefit and lower cost-risk. Also, the two-stage construction, about a year apart, is of significant benefit as analysis to evaluate the initial design and any other risk-benefit assumptions to determine, frankly, if we want to do this again.

4 Construction sections 1 and 2

Generally, the driveway pavement is a macro synthetic fiber reinforced concrete (SnFRC) overlay on asphalt with varied bonding to the asphalt substrate.

Asphalt surface preparation was minimal and consisted only of using a leaf blower to clean off the surface. There seemed to be enough texture in the asphalt surface due to the severe cracking and exposed aggregate to accomplish a significant amount of bonding though area but decidedly inconsistent bonding. However, the use of fibers to hold broken concrete together did not seem to make this an issue because then there would be no displacement of broken pieces like the previous chunks of broken asphalt. The potholes were roughly leveled off with the readily available existing materials, graded gravel base, and asphalt chunks. The tire ruts were not filled but allowed to add thickness or depth to the overlay at important areas.

Mixture proportions for the FRC are in Table 2 and were not adjusted for yield by volume but prescribed as give me this much cementitious material and air and fill the rest with rock and sand. The fiber dosage was chosen to hold the concrete together or make it tougher and not necessarily for any strength or stiffness in bending or deflection due to the traffic loads. The assumption was the base was stiff enough and had been adequately compacted. The synthetic fibers were small in cross section, approximately square, monofilament, and in bulk presentation twisted together. The fly ash was chosen to increase the interfacial bond with the fibers due to the fly ash particle size smaller than cement. The 0.42 water to cementitious ratio and entrained air was chosen because of the severe freeze thaw conditions of the Minnesota location and the southern exposure of the pavement. The concrete was batched short on water to allow some field addition as needed. Fibers were added at the work site. No other admixtures were needed or used for workability of the mixture, and the water cementitious ratio was not exceeded.

Formwork was minimal again to reduce costs. Wooden stakes were placed just off the old pavement on both sides of the driveway and spaced short of the length of a commercially available plastic pipe length. Plastic pipe was used to set a uniform thickness of the concrete in a wet-screed type of placement. The plastic pipe was chosen for easy clean up, lightweight, and lack of rigidity to conform to the irregular surface compared to a steel pipe. Three pipe were used, on each side or edge and one in the middle or crown of the pavement. Short scrap pieces of wood were used to locate the pipe on both sides of the pavement as off sets from the stakes onto the pavement. Concrete was placed with chute discharge on each side of the driveway middle and pulled and screed by hand using a nominal rectangular cross section (2 by 4, 37 mm by 90 mm) piece of wood about 5.5 feet (1.7 meters) long. The concrete was placed between the crown center pipe and one edge pipe and pulled almost one length of pipe. More concrete was then placed on the other side, between the center crown pipe and the other edge, and pulled again almost one pipe length. The pipe formwork was then pulled down on the sides and out of the middle and reset to the next set of stakes.

With the sloped application, concrete placement was done down hill. This was understood to be the exact opposite of what is recommended for concrete placed on a slope. However, the concrete delivery truck could not be left at the top of the hill while the concrete cured so there was no alternative and no other access to the driveway. The two sections of concrete were about 50 ft. long (15.3 m) and 9.5 ft. wide (2.9 m) and a nominal 1.5 in. thick (37 mm). Each section took about 45 minutes and with the commute to the site, the concrete was a bit stiffer with the second section. Water was added to the mixture for the last 25% of the second placement.

Finishing consisted of using a roller bug on the surface to add texture. A roller bug is a round shaped open metal screen on the end of bull float type handles. A roller bug is normally used to bring paste or “cream” to the surface for finishing by pushing the coarse aggregate down. SnFRC was also later added to fill the void from pulling the pipe out of the center, and the roller bug was used to roughly level and smooth that placement. The finishing by the roller bug for texture was started rather late and the concrete was somewhat stiff in place as evidenced by a few more passes with the roller bug, as the concrete was not as conformable. Transition areas from the asphalt onto or off the FRC were done by a hand trowel and just sloped or made wedge shaped in cross-section.

Curing was done with clear thin plastic sheeting stretched over and pulled down over the side stakes. Water was added by spraying daily under the plastic sheets. The concrete was cured for 5 days. The overnight lows did not go below 40 degrees F (5 degrees C). Daytime highs were about 60 degrees F (15 degrees C).

Construction used 7 cubic yards (5.4 cubic meters) of concrete, and it was all placed within 2 hours of arrival at the job site. Fibers were added at the job. Primarily 2 men did concrete placement with some generous assistance by the truck driver. The neighbor did some roller bug finishing as the concrete was beginning to set too much before this finishing texture. No saw cuts or tooled groove joints were incorporated into the overlay concrete. The concrete was workable for placement and no other admixtures were used.

5 Risk benefit analysis section 1 and 2

The schedule was met because the job was done when the weather was warm enough for the concrete to gain sufficient strength before being driven on and before the first snowfall. The manpower work was essentially completed in three days time, 1 man day preparation, 2 man days for 1 day of construction, and 1 man day curing and clean up. The entire project lasted 7 days from preparation to driving on the pavement.

Approximate construction costs in USD included: 800 concrete, 100 day laborer, and 200 for formwork, leaf blower, plastic sheets, water hoses, and electrical extension cords.

Summer of 2006 the pavement was viewed for how well it had performed through the winter. There was no evidence of any scaling or freeze thaw damage. The surface was extremely textured and overall the ride was a bit bumpy but acceptable. There was evidence especially after moisture was dried off the slab of some small tight crack lines in the pavement. More cracks were evident in the inside of the curve where the ground support was expected to be weaker. The cracks were sufficiently small to be of minimal concern except for 1 crack about 0.020 in. wide (0.50 mm). This crack was located about where the water was added near completion of the second section. The concrete slopes at the concrete asphalt transitions were cracked a bit more due to the thinness of the concrete. However, no FRC had dislodged or been displaced but was held together by the fibers.

Summarizing for these 2 sections would be that the design objectives: performance – schedule – cost, were sufficiently met and especially exceeded regarding the cost. The cracking quantity was disappointing though small in width and not expected to be problematic long term. Further, the general levelness and bumpier ride was also disappointing. However, all things considered the risk was minimal and controllable, and the benefits were outstanding regarding costs so the decision was made to finish the driveway by doing additional sections 3-4-5.

6 Construction section 3, 4, and 5

Generally all things were the same regarding the previously described construction except for these details. The construction was done 1 month earlier in the year so the temperatures were generally warmer. Twice as much concrete was placed using 2 experienced men and 2 inexperienced teenagers instead of 2 men, experienced and not. Further, the concrete was delivered with the maximum allowable water to not exceed the ratio. This concrete was more workable and flowed easier into place and sped construction but did not run down the hill. The concrete went faster and was out of the two trucks within about half the time as the previous sections. The roller bug was started earlier and leveled the concrete better because it was much more workable.

With the unusually warm weather, these sections were viewed 3 months after placement. The roller bug texture is better and generally the concrete surface is better than the other sections. There is also less cracking. The less cracking is attributed to the warmer temperatures and higher strength before driving on the pavement. At the bottom of the hill and the last section, there is a bigger bump than anticipated. This was the end of the job, and it is expected that this is where some of the concrete was least workable and not leveled and caused the bump.

7 Summary conclusion

The overall cost for all the 5 sections of synthetic FRC was about 20% of the asphalt estimate. The difference is attributed to not removing the old materials and mobilization of the asphalt equipment with this small project driveway 250 feet (76.2 meters). The remaining 400 feet (122 meters) of driveway was overlaid with asphalt in 1994 and will soon need some repair. Some additional work is anticipated adjacent and inside the hill portion curve to minimize the rainwater run-off effects at the slab edge and extend the pavement life. Further leveling of the FRC overlay can be considered by topping the existing FRC with more FRC. The surface area and roughness from the roller bug finish would be ideal for bonding a topping slab.

The risk-benefit for performance-schedule-cost using synthetic fiber reinforced concrete was the best-good fit for this project.

References

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