YOU SAY YOUR SLAB IS HOW THICK?

The designer of a ground-supported, industrial floor has to answer many questions. One question is always on the list: How thick must the concrete slab be to support the intended loads? It's an important question, because getting it wrong can bring severe consequences. If the slab is too thin, it may break under load and fail before its time. If the slab is too thick, it costs more than it should. Slab thickness is a major factor in the cost of a concrete floor, so there's often pressure, which can become intense, to make the slab as thin as possible.

Many design methods are available, and superficially they can seem quite different. Some methods call on the designer to solve mathematical equations, while others rely on simplified load tables or nomographs. But those load tables and nomographs are themselves based on equations, often the same equations, so in the end most of the available methods are similar and give similar answers. One way or another, the design process usually consists of these 8 steps:

1. Get details of the proposed loads, and figure out the worst case for which you have to design.
2. Multiply the worst-case load by a safety factor, which usually ranges from 1.3 to 2.0.
3. Guess the slab thickness needed to support the factored worst-case load.

4. Determine the bending stress that the load will induce in the slab, taking into account slab thickness, the area and location of the loading, the subgrade modulus, and several less important factors.

5. Compare the bending stress to the concrete’s expected flexural strength.

6. If the stress is equal to or slightly less than the flexural strength, you are done.

7. If the stress is greater than the flexural strength, the floor is under-designed. Go back to step 3 and increase the slab thickness.

8. If the stress is substantially less than the flexural strength, the floor is overdesigned. Go back to step 3 and decrease the slab thickness.

Where do steel fibers fit in all this? The short answer is: they don’t. The process is exactly the same whether the floor is unreinforced, reinforced with wire mesh or rebar, or reinforced with fibers. Steel fibers play a big role in controlling cracks and curling, but they don’t directly affect slab thickness design.

The long answer is that some designers, on some jobs, do rely on steel fibers to justify thinner slabs. Those designers use several arguments. Some of those arguments are dubious and we at CFS recommend against them. Other arguments are sound and worthy of consideration.

THE DUBIOUS ARGUMENTS

Many claims for reduced slab thickness using fibers involve a property called residual strength or flexural toughness. This is quite different from what is normally thought of as strength, so we need to take a closer look at it.

In the standard test for flexural strength, ASTM C78, you bend a beam till it breaks. (Reference 1) The force needed to break the beam determines the concrete's flexural strength. This test is simple and easy to interpret, and it clearly resembles the way a real slab fails under load.

It's generally assumed that steel fibers don't improve flexural strength as measured by ASTM C78. As we shall see later, that's not completely accurate, but we can accept it as a first approximation.

This means that ASTM C78 is of limited use to people who want to justify thinner slabs. So they look for other tests to tell them what they want to hear, and they find them in ASTM C1399, ASTM C1609, ASTM C1550. (References 2-4) The first two involve a beam like that used in ASTM C78. The third test replaces the beam with a disk 3 inches thick and 31 inches across.
In all three tests, you start out by bending the beam or disk till it cracks. So far, that's a lot like ASTM C78. But then you keep on applying stress after the sample has cracked. As the stress increases, you measure the deflection. Stress and deflection readings are used to calculate the residual strength or flexural toughness. Plain concrete without fibers has zero residual strength; once the beam breaks, it ceases to be a beam. Fibers change that, bridging the crack and providing some resistance to bending after the beam (or disk, in the case of ASTM C1550) has cracked.

Residual strength is real, but there are at least three serious obstacles to using it in slab design. The first obstacle involves the test methods, which are tricky to perform and far more subject to error than the standard ASTM C178 test for flexural strength.

The second obstacle involves relating the test to real life. To rely on residual strength in slab design, you have to assume that the floor will crack under load and that the user's sole concern is how wide the crack gets. This is not how most building users judge their floors. Users hate cracks, and prefer to see none at all. They don't go around with gauges measuring crack width.

The third and greatest obstacle involves fatigue failure. When a slab fails under load, that failure seldom occurs the first time the load is applied. Repeated loadings increase the likelihood of failure, and this is called fatigue. Fatigue is the main reason the standard design methods always include a load safety factor, and this factor is adjusted for the number of load cycles expected. Using the standard methods, you can design a floor for any number of load cycles, from one to infinity. In contrast, residual strength gives you no tools with which to allow for fatigue. Once a slab has cracked, residual strength goes down dramatically with every load cycle. And if the slab never cracks, then you are back to relying on straight ASTM C78 flexural strength and residual strength is irrelevant.

Mainly because of the fatigue issue, anyone promoting a thinner slab based on residual strength with fibers is playing a game. The math may seem to work out, but the floor will lack the ability to withstand repeated load cycles.

A second dubious argument for thinner slabs with fibers also involves fatigue, but in a different way. Several researchers have reported that steel fibers increase concrete’s fatigue resistance. Since the standard design methods rely on a load safety factor to resist fatigue, and since those methods are based on plain concrete, some people argue that we can lower the safety factor when using steel fibers. A lower safety factor will always make the slab thinner if everything else stays the same, so this can be a simple, powerful argument.

But when you look at the published research behind it, the argument for lower safety factors loses much of its strength. The researchers who showed improved fatigue resistance looked at steel fiber dosages higher than those normally used in concrete floors. Batson et al. (Reference 5) looked at fiber concentrations of 264 and 393 pcy -- so far above the usual rates as to make their conclusions useless in floor design. Nanni (Reference 6) performed his experiments at 60 pcy. That's more realistic, but it still lies near the upper end of the dosage range. At least in North America, steel fiber dosages are usually below 60 pcy and are often as low as 30 pcy. Does a 30-pcy dosage increase fatigue
resistance as much as a 60-pcy dosage? Half as much? Not at all? No one knows.

Even if we accept that steel fibers improve fatigue resistance, as seems likely, it's a big leap from there to using the information effectively in floor design. As Nanni said at the end of his article, "the lack of a standard test method and insufficient experimental data make the rational fatigue design of SFRC [steel-fiber-reinforced concrete] a difficult task." The day may come when we can safely and conservatively take advantage of steel fibers to improve fatigue resistance, but that day has not yet arrived.

The defenders of residual-strength design and reduced safety factors sometimes point to floors they designed that have not failed. But that proves little, unless their examples have supported their full design loads for decades. Under-designed slabs seldom fail right away. They may last for years. But in the long run, under repeated cycling of their full design loads, they will not match the lifespan of a properly designed floor.

THE SOUND ARGUMENTS

Fortunately, you don't have to resort to dubious arguments. There are at least two safe, conservative ways to reduce slab thickness with steel fibers. They involve flexural strength and the elimination of corner and edge loading.

Anything that raises concrete's flexural strength will increase a floor's load capacity, and can potentially allow a thinner slab. We are talking here about real flexural strength as measured by ASTM C78.

It is sometimes assumed that steel fibers don't affect flexural strength, but that's not completely true. At low dosage rates the effect is insignificant. At high dosage rates it can be dramatic. Alas, the dosage rates needed for a big increase in flexural strength are higher than those normally used in floor slabs. But at the dosages used in wide-slab construction -- 55 to 75 pcy -- the effect is sometimes enough to matter. In his research into fatigue resistance, Nanni (Reference 6) also measured the normal, first-crack flexural strength of his concrete mixes, and the results are interesting. Steel fibers at 60 pcy raised flexural strength by 2.4%, 5.0%, and 17.7%, depending on fiber type and size. The greatest increase, 17.7%, came from a Type II fiber 1.1 inches long with an aspect ratio of 45. That's almost identical to the CFS 100-2 fiber, which is 1 inch long and has an aspect ratio of 43.

Some steel-fiber mixes test amazingly high for flexural strength. On one recent job, a concrete mix containing CFS 100-2 fibers at 70 pcy was designed for 750-psi flexural strength. But when tested to ASTM C78, it proved to be far stronger, with a mean of 1290 psi and a standard deviation of 50 psi.

Of course, not every concrete mix with steel fibers will attain a 1290-psi flexural strength. But clearly the potential is there for high strength that will allow a thinner slab. To take advantage of that potential, though, you have to measure your concrete's flexural strength with the fibers included. It's no good estimating flexural strength from compressive strength, or guessing how fibers will affect the results.
You have to cast beams and perform the ASTM C78 test. Once you know the flexural strength, you just plug that number into the design formulas and determine slab thickness in the usual way. This is safe and simple, and you need not bend or break any standard design rules to do it.

The second way to get a thinner slab with steel fibers involves the location of floor joints relative to the applied loads. When analyzing the effect of a load, location matters. There are three possible load positions: near a slab corner; near a slab edge, and internal (away from corners and edges). For any given load, the internal position always produces less stress than the other two positions.

A conventional floor with closely-spaced joints is full of corners and edges, so loading in all three positions is unavoidable. Corner or edge loading controls the design, and the floor ends up overdesigned for the internal loading condition. In theory you could thicken each slab at its edges, strengthening it only where necessary. But with joints spaced 10 to 15 feet apart that's hardly practical.

Steel fibers let us eliminate most of those joints, resulting in wide slabs as big as 125 feet square. With joints few and far between, eliminating critical loads at corners and edges becomes easier. This is especially true where the critical loads come from fixed equipment such as racks, shelving, and mezzanines. Where the critical loads come from moving vehicles, eliminating edge loading is harder. But with only few edges to deal with, thickening the slab there can be a practical option.

IT’S NOT ALL ABOUT FIBERS

Then there are ways to minimize slab thickness that are unrelated to steel fibers, but still worth trying. One way is to take a hard look at the proposed loads. Often they have been rounded up, or already include generous safety factors. Floors should be designed for the loads they will actually have to support, not for some arbitrary value that has little to do with reality.

Another way to economize on slab thickness is to make sure the load safety factor is no higher than it needs to be. Since the main job of the safety factor is to protect against fatigue failure the value should
vary according to the expected number of load cycles. For vehicles such as forklift trucks, the number of load cycles is likely to be high, you may need a safety factor as high as 2.0. For fixed equipment such as racks and shelving, the number of load cycles will be much lower and the typical cycle will only rarely involve a full swing from zero to maximum load, so the safety factor can be lower. Where one-time loading controls the design -- for example, where a heavy machine tool must be moved across the floor but will stay in place indefinitely -- a safety factor only slightly above 1.0 may be justified.

It’s important to get slab thickness right. Steel fibers can help you do that, as long as you use them the right way.

References:

1. ASTM 78, Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading).


