Something about Continuous Beams

Continuous beams are among the most basic and common components in structural mechanics. But do we truly understand what we are talking about when we discuss continuous beams?

Years ago, the concept of continuous beams took up little space in my mind, as did the field of structural mechanics as a whole. It was merely a tool to me; philosophical expressions were just for show. With convenient and user-friendly software at my fingertips, my role was simply to input the parameters correctly. Moreover, with the advancement of such software, It's getting harder and harder to input the wrong parameters ;-)

I buy software, I use software, and if there's a problem, that's the software's problem, not mine.

> If you truly understand the program,
> the program is your best servant;
> if you truly do not understand the program,
> then it becomes your most terrifying master.
>
> —A genuine programmer

Software will never have a problem; if there is a problem with the software, it's your problem because you did not use it correctly. You cannot use it correctly because you do not understand it.

Structural engineering is such an art:
We use materials
whose properties can only be estimated,
to build real structures
that can only be approximated in analysis,
to withstand external forces
whose exact magnitudes are unknown,
all to meet our responsibilities for public safety.
—Adapted from an unknown structural engineer

Professor Edward L. Wilson, the father of SAP, wrote these words on the title page of his seminal work "Structural Statics and Dynamics Analysis—Emphasizing Seismic Engineering Materials Methods." The first sentence in the preface of the book reads, "In my freshman year, my physics teacher dogmatically warned the students: 'Never use an equation you cannot derive yourself.'" I used to think this statement was odd, but now I see there might be some truth to it. Professor Wilson further elaborates in the preface, "Never use any structural analysis program unless you fully comprehend the theories and approximation methods it employs."

After reading this book, I developed a strong desire to dismantle the entire black box of finite elements, to see exactly what goes on inside, and to become a true structural engineer. Not long ago, I actually fulfilled this wish.

At first, I thought it was going to be simple. After all, finite element analysis for the elastic part should be well-developed by now, as these theories have been around for decades. I thought all I needed to do was copy and modify. But later I realized it was not that simple. I wrote a program for frame beams and then verified it with SAP2000, ANSYS, and Abaqus. Surprisingly, some of the internal force values didn’t match. If such simple components can't be calculated correctly, how can I continue, or is there even a need to continue? Fortunately, when I used PKPM and YJK (software), the results matched perfectly. Moreover, these programs did not agree on the internal forces in certain areas. Interestingly, regardless of how the elements were divided in SAP2000 and ANSYS, the results did not change, while in Abaqus, the results kept changing. This left me completely puzzled. How could this be? It was only when I started studying space beams, or three-dimensional beams, that I understood the entire issue. I was able to figure out the results for SAP2000, ANSYS, and Abaqus. Readers who are interested in the specific principles can refer to Chapter 9 of "Finite Element Method" by Wang Xucheng on the mechanics of rod structures. But that was not the end of it. I wrote a program for a three-dimensional truss and verified it with SAP2000, ANSYS, and Abaqus, and the results did not match again, especially at the supports. SAP2000's calculations differed significantly from the other two software. At this point, I somewhat understood why the "Space Standards" defined the components at the supports as critical components; at least the experts who compiled the standards must have been clear about it. Speaking of standards, nowadays, everyone unhesitatingly treats the standards as law. By following the standards, if there is a problem, it is not my responsibility. Is that really the case? Structural master Lin Tongyan once said—standards should be used cautiously and only as a reference. Further, if a problem arises even when you have designed strictly according to the standards, it is still your problem because you did not truly understand the standards. Then why is the licensing exam focused on standards?Because those taking the exam usually have not yet gained a profound understanding of structural design, it is necessary to ensure their familiarity with the standards to maintain the safety of structural design. The standards are the summary of long-term experience of experts, and within the parameters they set, this approach should be problem-free. It's like Sun Wukong from "Journey to the West" using his Ruyi Jingu Bang to draw a safe circle—I guarantee your safety within the circle, but beyond it, I can't help you. However, it's possible to "step out of the circle" in daily work, which is why Master Lin Tongyan said to use caution. Actually, some people today, especially those in review institutions, have turned the standards into a set of formulaic responses, which is laughable. While the standards appear very strict, behind them are also many issues. Take the minimum reinforcement ratio as an example. Why do we use the full section height to calculate the minimum reinforcement ratio, but the effective height to calculate the tensile reinforcement ratio? If you have attended a licensing coaching class, the teacher definitely explained this issue clearly. However, I remember a different version. When I attended a licensing coaching class, the instructor was Shi Lanqing (a senior professor from Tsinghua University), and he explained it this way: During the Cultural Revolution, they were required to save steel at all costs, so they could only sneak in some adjustments in the codes. When calculating, they used h0, and when verifying, they used h, which is effectively a multiplier for the tensile reinforcement of the beams. Today, it's the same, if not worse. Clients and owners also relentlessly pressure engineers to save steel while demanding architects to create bizarre buildings, which are inherently more steel-intensive. Engineers feel unable to do anything but believe that as long as they meet the codes and use software to calculate, or even use a bit of craftiness, they will be fine. From the above narrative, we already know that sometimes software and even standards are not entirely reliable, so you might now find the oversight of this "master" terrifying. Moreover, this is an international issue. Recently, I watched a video about a high-rise residential building near Central Park in New York City; the structural plan looked problematic, and sure enough, the video's host later explained that the building had indeed encountered issues. It's truly a global phenomenon! Capital is inherently the same wherever it goes. Additionally, it is important to note that if you define yourself merely as an operator of software or a verifier of standards, then your job could be done by a high school student.

What then justifies your demand for a high salary? When the market is good, you desperately compete with others, but when the market is poor, you risk being eliminated, After all, it's the software doing the designing, not you, so the master is also cruel. When the licensure exams were first introduced, many engineers were resentful. They argued, "I have been working for so many years, why do I need your certification? I am too busy with work to have time to read and study." In response to this, a chief engineer said, "Nowadays, some engineers rely too much on software, they can't even correctly calculate a continuous beam. How can that be acceptable?" Furthermore, the difficulty of the registration exams was so high that it wasn’t just about resentment anymore; many engineers were almost cursing. Another chief engineer said, "If you're not qualified, passing you would not only harm you but also the project." Complaints have subsided now, but many who have passed still cannot accurately calculate a continuous beam. In fact, the initial registration exams did focus heavily on fundamental mechanics. I attended Shi Lanqing’s classes, initially taught by his wife, which covered structural mechanics and materials mechanics. There are two solutions I can think of to address these issues: one is to gradually incorporate examinations on mechanical theories into the registration exams, not only structural and materials mechanics but also theoretical mechanics (those who haven’t passed can start complaining now). Studying theoretical mechanics can enhance the ability to flexibly apply mechanics. Another solution is to increase the decision-making power of registered architects and structural engineers in projects to ensure that those who are ultimately responsible have the greatest authority and benefit the most. After passing my registration exam, I attended continuing education training that highly valued everyone's creativity. The distinction between operators and verifiers is not my own invention; it was a term used at that time.

Now, let's return to the issue at hand. The calculation of continuous beams is not as simple as everyone might think. I first encountered Hamilton when conducting finite element analysis on beams (using Hamiltonian elements). Cao Zexian once remarked that Hamilton was greater than Newton, and I think he was right (although his attempt to explain quantum entanglement with a pair of socks on a TV show was an oversimplification, so much so that it was incorrect). The real difficulty with beams lies in their application to thin-walled components, which requires introducing a seventh degree of freedom, the warping freedom. This changes the rules for integrating the overall stiffness matrix, something I understood while studying spatial beams. Moreover, the problem does not end there. Some researchers repeatedly use the Hamiltonian function to derive elements with 8, 9, 10, or 11 degrees of freedom, which really complicates matters.

Therefore, returning to the original question, what exactly are we discussing when we talk about continuous beams?