As indicated in my profile, I worked at JR East for two years after graduating university in 1988. While my time at JR East was short, the experiences of riding on “Dr. Yellow” Shinkansen inspection trains and on tunnel patrol vehicles during training and learning sleeper and overhead contact line replacement left an impression on me. My superiors and senior coworkers at the section I was assigned taught me how interesting engineering is and the rewards of being an engineer. Even today, I feel a sense of pride when hearing of the achievements of those who joined the company in 1988 with me.

After leaving JR East, I went back to university where I have been constantly studying maintenance and management of steel structures. I hear that JR East has established a Structural Engineering Center under the direct supervision of the head office and is putting even more effort into maintenance and management, and this is very reassuring to me as a user.

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Technologies for Resilient Steel Structures

Introduction

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Maintenance and Management

It goes without saying that steel bridges have been in use as railway bridges from long ago. Many have been in use for more than 100 years, and some are historical assets of the regions where they are located (Fig. 1). The greatest reason that steel bridges have lasted so long is that the material properties of the steel itself do not deteriorate over time. Appropriate maintenance and management are also important points to their having lasted. The material properties of steel do not change, but paint can deteriorate and corrosion can occur if left untouched (Fig. 2). And on lines with much train traffic, fatigue cracking can occur due to the repeated loads of passing trains (Fig. 3). If such corrosion and fatigue deterioration can be prevented by appropriate maintenance and management, steel bridges can continue to be sound over long periods of time.

According to the professor emeritus who wrote a prominent textbook on steel structures I used when a student, the textbook contains no section on corrosion in the table of contents because it was not envisioned at the time that steel structures would become useless due to corrosion. It was a given that they would be repainted and that water drainage measures would be taken. So, from that perspective, it is convincing that textbooks would not cover the subject of corrosion. Many railway bridges are open-floor type, so it is difficult for moisture to build up on them and the effects of being washed by rain can be expected, so they can be said to be in an environment more resistant to corrosion.
would often reoccur soon after repainting. If rust reaches the base metal, surface preparation by blasting will be required. Blasting is treatment by blowing particles (abrasive) of a few millimeters or smaller by compressed air against the material surface, allowing paint, rust, and the like to be removed almost completely. However, blasting involves scattering of abrasive and fine particles, making it difficult, dirty, and dangerous (3D) work (Fig. 5). Vacuum blast methods where abrasive and particles are sucked up and recovered during work have been developed recently, but there are issues with those in terms of applicability to narrow spaces and work efficiency. Small blast nozzles and the like have been developed to improve the scope of applicability to narrow spaces. While it may not be exciting, such technical development affecting the lifespan of steel bridges is important, and I look forward to seeing future advances.

New phenomena in the area of steel structures will probably not be discovered in the future, something that likely can be said for civil engineering in general. The situation is different than with things like the blue light-emitting diodes discovered by Nobel Laureates and Nagoya University professors Isamu Akasaki and Hiroshi Amano. We already know the phenomena

![Fig. 2 Example of Corrosion](image1.png)

![Fig. 3 Example of Fatigue Cracking](image2.png)

![Fig. 4 Steel Bridge on Discontinued Line (Kamiyamada Line, Discontinued in 1988)](image3.png)

![Fig. 5 Blasting Work](image4.png)
that can happen with steel structures. How much we understand about those individual phenomena, however, increases over time. Deeper understanding the phenomena is constantly demanded, and measurement technologies are important in doing that. Even if the issues handled are the same as 30 years ago, our understanding naturally deepens if measuring technologies advance and we are able to observe the phenomena in more detail.

A familiar but old example measurement of strain in steel tubing by digital image measurement is that which I conducted in the past together with people from the Railway Technical Research Institute (RTRI). With image measurement, we were able to identify strain around buckling areas that could not be measured with strain gauges. I remember being very excited about that. The digital cameras we used back then in 1999 had a resolution of 1.3 megapixels. Mobile phones today have cameras in excess of 10 megapixels, putting them in a class far above what was available at the time. The resolution increasing over time was an expected technical advance, and I have started to think that there may be new ways to use that.

We also had to put together our own software at the time. Coding was done while worrying about each individual element, such as what to do about lens distortion compensation and what would be an efficient way to recognize patterns, but today software to do that can easily be acquired. A few days after talking in the lab recently about not being able to measure weld joint deformation by image measurement, a student found an application to do that. It creates a 3D model by simply recording images from a few locations and inputting those; and to top it off, the software is free. I was amazed after trying it out that it had precision of a level that we can be satisfied with.

I believe advances in measuring technologies hold the potential to greatly change structures. Whether or not monitoring proves to be useful depends on this. In addition to images, various technologies are already coming into use, such as lasers, optical fiber, and thermography. I am really looking forward to the advances in this field.

4 Analysis Environment

The advance of computers in the past few decades has brought about benefits in all sorts of areas of our lives. In structural engineering, finite-element analysis having become easy to perform is a prime example of the benefit of computers. Highly refined software has become available, allowing students to do things like modeling and analysis in just two or three weeks after being assigned to the lab.

While not yet at a practical level, there is movement towards 3D modeling of bridges, conducting 3D finite-element analysis, and using that data in design. While I don’t think that directionality is wrong, there are many issues that come up in actual application. Modeling and analyzing a structure in a form close to reality means shaving off to some extent the excess (flab) included up to now, so careful judgment is required. On the other hand, partial safety factors have been introduced in current railway bridge design, so I believe that such an idea is easier to introduce than road bridges using allowable stress.

Frankly, today’s railway bridge design standards seem to simply be allowable stress methods adapted to sectional force display, so it may be worth considering going forward with even more advanced design methods.

The aforementioned is an attempt to refine models; but separate from that, there is a new design method that has come up because large-scale analysis has become possible. Here I would like to introduce an example of that a fatigue design method by effective notch stress.

In order to conduct fatigue design, we need to find the stress at the points where fatigue cracks are generated. However, fatigue cracks occur from locations with relatively sharp shape (stress concentration locations), such as at the borders of welds and plates, so it is not easy to accurately find stress at those points. Thus, the idea came about of deciding that the point of cracking is a curve with a 1 mm radius of curvature. As shown in Fig. 6, effective notches are holes and arcs virtually set at the start point of fatigue cracks, and effective notch stress (ENS) is the maximum elastic stress generated on those arcs. Conducting fatigue checks using this stress is the effective notch stress method. Such a method is needed because it is a general-purpose method applicable even to weld joints of unprecedentedly complex shape and stress situation. If fatigue checks can be done for all kinds of parts, fatigue-free bridges could be achieved at least in design. At the International Institute of Welding (IIW), research on this method has been a major point of discussion in the past few years.

As you can imagine, effective notch stress needs to be found analytically using the finite-element method and the like. The holes are not perfectly round, needing to be approximated by hexagons, pentagon, and the like; so 0.1 mm order fine element breakdown is necessary to model a 1 mm radius hole. This is an idea that will not prove valid unless assuming large-scale analysis. Fig. 7 shows the results of fatigue tests for full penetration.

![Figure 6 Example of Effective Notches](image)

![Figure 7 Organization of Results of Fatigue Testing by ENS](image)
Special feature article

cruciform weld joints with linear misalignment, organized by nominal stress (stress used in ordinary design) and effective notch stress. Optimal test results are confined in a narrow zone proceeding downward to the right, but we found in the figure that using effective notch stress gives smaller variation of data than when organized by nominal stress. The straight line in the figure is the FAT 225 fatigue design curve proposed by the IIW, and fatigue checks can be done on the safe side by using effective notch stress and this fatigue design curve. Such a new approach becomes possible if assuming large-scales analysis.

5 Improvement on Current Technologies

Finally, I would like to cover old technologies that I would like to see undergo revival.

Rivet joints are a type of joint used in the mainstream until about 1970. Today, steel bridges made with rivet joints are still in use for both railway and road bridges. Rivet joints are extremely high-performance joints, even compared to high-strength bolt joints and weld joints. Use of rivet joints is said to have been cut back due to their low construction efficiency and the noise from rivet hammers at construction. However, they have higher dynamic performance than high-strength bolt friction jointing in small-scale worksites such as for repair and reinforcement where construction efficiency is not demanded, and there is still need for rivets with their good water stopping performance. Moreover, noise in construction probably can be overcome with modern technologies.

Another technology is welding repair. This involves removing cracks and damage by grinding, gouging, and the like and re-welding to restore damaged parts to their original state. Weld cracking can sometimes occur at construction with welding repair. While I do not know the situation recently, I have heard of cases of weld cracking due to welding repair being performed without much thought. The trend recently is to avoid welding repair, but there will probably still be many worksites that want to use that. So, we need to create an environment where the conditions in which weld cracking does not occur can be properly identified so it can be used with peace of mind.

6 Conclusion

I titled this article “technology improvement, development, and innovation,” but there is no clear separation between those tasks. To tell the truth, I can’t think of many examples of technical innovation. In other words, if something comes to mind easily, it can’t be true innovation.

There are various other technologies required for making steel bridges more resilient, not covered in this article. Down-to-earth technologies found all around, instead of spectacular ones, can likely play a major role with a bit of improvement, so I would like to keep that in mind at all times.

Reference: