Preface

As we live on Earth, it is necessary to build structures that can resist gravity, as well as the demands imposed by natural phenomena such as earthquakes, strong winds and heavy snowfall. Structural engineers are charged with designing efficient and elegant buildings or bridges, while ensuring that the structure can safely withstand these demands. It takes great ingenuity to achieve these competing objectives.

Although major structures are composed of timber, reinforced concrete or steel, all of which are economic materials with good structural properties, steel has proved to be uniquely useful. The unit weights of timber, reinforced concrete and steel are 0.5, 2.4 and 7.85 t/m^3, respectively. However, timber has low stiffness and is relatively weak, particularly at the connections. While concrete has proven to be economic, the compressive strength is only 10~30% of steel, and the tensile strength is almost negligible. To overcome these limitations, steel is used in the connections or to provide the tensile capacity. Steel is an elegant resource, providing 10 times the stiffness of concrete, equal tensile and compressive strengths, and large ductility.

For timber or reinforced concrete structures, solid sections such as rectangular or circular shapes are generally required. However, steel members can be easily fabricated in all types of shapes including I/H sections, angles, channels, pipes, and boxes. This results in a more efficient use of material and produces lighter structures.

To take full advantage of steel as a structural material, it is necessary to consider several important design criteria, summarized as follows.

1. Details

Steel is first produced as plates or hot rolled section in steel mills, and then cut, spliced and bent by fabricators to achieve the desired member geometry. Modern frames are assembled either by bolting or welding, which leads to short construction periods, particularly relative to concrete structures. Therefore, a well detailed structure and due consideration of the construction process is necessary to achieve a good design.

2. Deflection

Although the material properties of steel, such as stiffness and strength are relatively large, the required area and moment of inertia are generally smaller compared to timber or reinforced concrete structures. Therefore, steel members are often slender, with performance determined by member deflection, overall structural deformations or vibration. Additionally, flexural and lateral torsional buckling are critical issues, and attention must be paid to local buckling when a plate is thin relative to its width.

3. Stress

Introductory structural engineering classes frequently focus on the stress distribution due to axial force or bending moments. Although strength is essential, many other checks are required to avoid instabilities or unexpected large deflections.

Buckling of slender steel members subject to compression has intrigued engineers since at least 1799 when the Iron Bridge was completed in England. One of the most famous theories of buckling behavior is the Shanley model, considering the inelastic buckling capacity of column members.

Pure axial compression imposes uniform stresses, but to ensure lateral stability, flexural stiffness is also required. However, members of moderate slenderness ratios will buckle below the Euler's elastic buckling strength. This is due to destabilizing Pδ moments introduced by geometric imperfections, as well as early yielding due to compressive residual stresses at the cross section extremities. As a result, the compressive resistance of non-compact members deteriorates prior to the nominal axial yield force.

The buckling behavior of structural members is complicated even under monotonic uniaxial loading. Braces used to resist seismic forces are subjected to cyclic loads, which further complicates the buckling behavior. Plastic ductility demands can be limited by enlarging or shortening the braces to increase the buckling load, but this imposes larger demands on the columns, beams and foundations. Particularly in chevron configurations, the unbalanced tension and compression strengths create large demands on the beams.

The coupled relationship between the axial capacity and lateral stiffness complicates the brace performance. When these two functions are isolated, the hysteretic behavior is greatly simplified and repeatable stable behavior can be obtained. This is the fundamental concept of the buckling restrained brace. An important distinction is that buckling is restrained, but not completely eliminated. A small debonding gap is still required to accommodate transverse Poisson expansion of the core member, permitting small amplitude higher mode buckling waves to form.

Buckling-restrained braces provide uniquely efficient hysteretic behavior and have a wide range of uses, limited only by the engineer's ingenuity. Modern buckling restrained braces are used not only for buildings, but also for long span bridges and other spatial structures. While buckling-restrained braces were developed in Japan, they are now widely used throughout the world. To use the buckling-restrained brace properly, I truly expect structural engineers and researchers to read and study the contents of this book deeply.

Akira Wada
Professor Emeritus
Tokyo Institute of Technology