BS5950-1:2000 – A Designer's Practical View

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Introduction

The long awaited version of BS5950-1:2000, Structural use of steelwork in building – Part 1: Code of practice for design – Rolled and welded sections, arrived finally in May 2001 with an effective date of 15th August 2001.

The standard was previously amended in 1990. Since it is the main source of guidance in the UK when designing structural steelwork, it is subject to on going care and maintenance. Over the last three years, it has been amended to ensure that its provisions remain safe and appropriate for use in the light of new advances in understanding.

Due to EU agreements, all changes in national standards have to be related to the need to ensure safety in use. In the case of BS5950, this was taken to include lack of clarity, situations in which rules were known to be over-conservative and direct safety issues.

To designers familiar with the 1990 version, the amended standard looks like a brand new publication with almost double the number of pages and a completely new format. In this article, I wish to focus on two of the more major changes, one relating to clarity and the other to safety:-

- Clarity – imperfections and sway sensitivity
- Safety – in-plane stability of Portal Frame buildings

Imperfections and Sway Sensitivity

Many of the additional words have been added to clarify intention, which was there in the 1990 version but perhaps not explicitly worded to convey the content unambiguously. As a result, some designers were overlooking some of the intended issues.

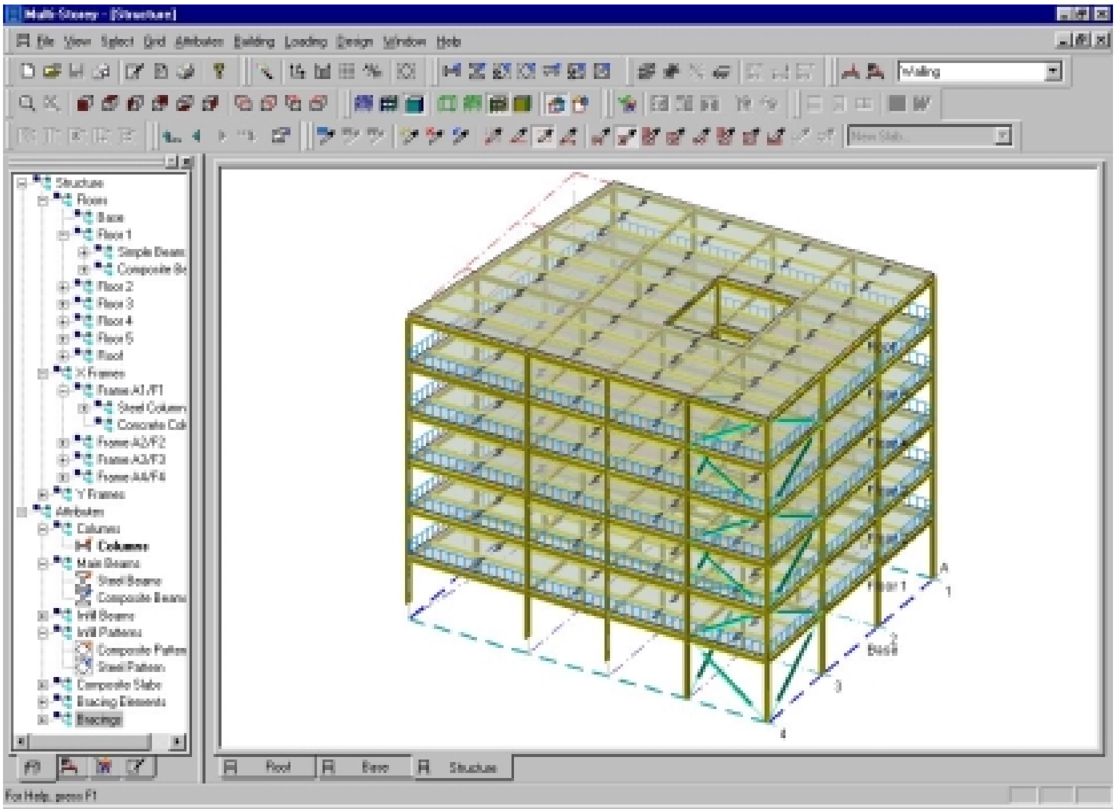
One such item in the 1990 code was the treatment of the Stability Limit State when considering both imperfection and sway sensitivity.

The 1990 code used notional horizontal forces for two purposes:-

- practical imperfections - notional horizontal forces are applied to the structure in order to mimic such effects as lack of verticality
- sway sensitivity – in the absence of more rigorous approaches, notional horizontal forces are applied to the structure in order to classify the structure as non sway or sway sensitive

Notional horizontal forces, representing the effects of imperfections, were typically ignored in portal frame design. Although sway sensitivity was dealt with in detail when considering continuous structures, such requirements for braced frames were not explicit.

This resulted in the assumption that bracing a simple multi-storey structure ensured that the frame would not be susceptible to sway. Situations can arise where a simple braced frame should be classed as a sway frame according to the real intention of the 1990 code. As an accentuated example, the frame depicted has a braced core at one corner of the building. This bracing system does not provide torsional stiffness and the structure will twist on plan. As a result, the building could be sway sensitive.



Practical Design 1.jpg – A "simple" braced sway frame

Notional Horizontal Forces

The 2000 code clarifies the dual use for Notional Horizontal Forces

- To act simultaneously with factored vertical dead and imposed load in the absence of other horizontal loading in order to simulate the effects of practical imperfections. The notional horizontal loading increases the axial and bending in the structure to simulate the lack of verticality in real steel members.
- To be applied to the frame to develop notional horizontal deflections for each storey in a building. From these it is possible to determine an approximate minimum sway mode elastic critical load factor (λ_{cr}) for the structure. If λ_{cr} is greater than 10, the frame is "non sway", otherwise the frame is considered to be "sway sensitive".

Sway Sensitivity

In addition to clarifying the use of the notional horizontal load, the new code also combines all the disparate clauses on sway into a single section within the Stability Limit States clause. This section clearly states that "All structures should have sufficient sway stiffness, so that the vertical loads, acting with the lateral displacement of the structure, do not induce excessive secondary forces or moments in members or connections."

Under the term "all Structures", the new code clearly defines the steps required to assess and allow for second order effects due to sway in Simple Multi Storey structures:-

Step 1 – determine λ_{cr}

- **either** accurately using 2^{nd} order analysis
- **or** approximately using the notional horizontal load.

Step 2 – account for sway sensitivity if appropriate

- $\lambda_{cr} \geq 10$ – the frame is "non-sway". No further action required
- $\lambda_{cr} < 10$ – the frame is "sway sensitive".
    - $10 > \lambda_{cr} \geq 4.0$
        - **either** using the sway mode in-plane effective lengths for columns and designing the beams elastically
        - **or** by multiplying the sway effects by the amplification factor k_{amp}
        - **or** by carrying out a second order elastic analysis to directly determine the design forces and moments
    - $\lambda_{cr} < 4.0$ elastic second order analysis must be used in the determination of design forces and moments

To put the above into context, under the application of notional horizontal loading

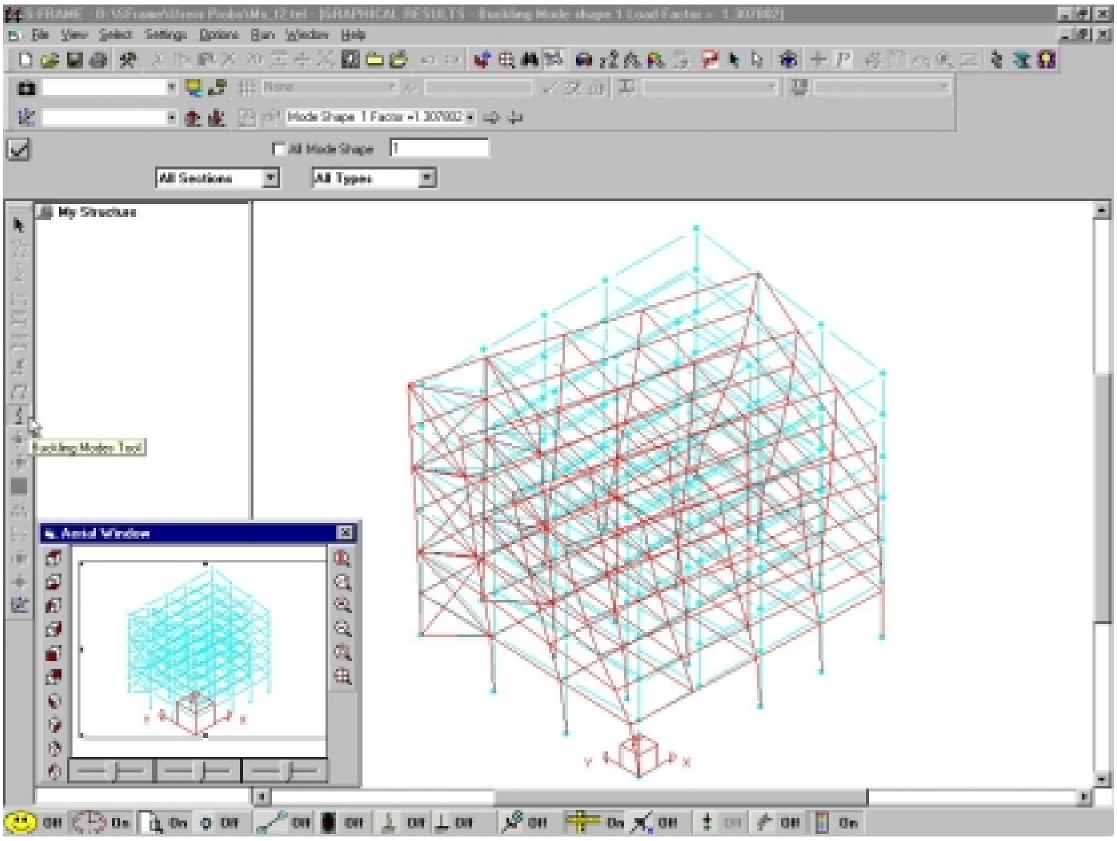
- $\lambda_{cr} = 10$ limit is equivalent to a storey deflection to storey height ratio of 1:2000, this would be 1.6mm deflection under notional horizontal loads for a 3.2m storey
- $\lambda_{cr} = 4.0$ limit is equivalent to a storey deflection to storey height ratio of 1:800, this would be 4mm deflection under notional horizontal loads for a 3.2m storey.

In general, for an average building, notional horizontal loads are in the same order of magnitude to wind loads. This is obviously dependent the ratio of floor area to façade area. If the ratio of wind deflection to storey height is close to the 1:300 limit, sway sensitivity needs to be seriously assessed.

In essence, the methodology and the intent of the code have had two significant clarifications:-

- All structures, including Simple Multi-Storey buildings, have to be assessed for sway sensitivity. There are now design tools on the market such as CSC's FASTRAK Multi-Storey that will handle this assessment automatically.
- Any frame which has a sway mode elastic critical load factor $\lambda_{cr} < 4.0$ has to use second order elastic analysis to account for secondary forces and moments. There are a number of software tools available today for this purpose, for example CSC's S-Frame product.

As an aside, rather than approximating the assessment of "sway sensitive" frames, it is possible to use second order buckling analysis to calculate λ_{cr} directly. When using software tools of this type, it is essential that the model is fit for purpose and that the buckling mode found is the first sway mode, otherwise an incorrect value of λ_{cr} could be determined.



Practical Design 2.jpg – A sway buckling mode (an accentuated example)

In-Plane Stability of Portal Framed Buildings

In the early 1990's, studies of the in-plane stability of single-storey pitched roof portal frames, by Professor J.M.Davies, indicated that modern frame configurations are more sensitive to reductions in strength due to second order effects than the 1990 code rules indicated.

Moreover, the methodology used to check pitched roof portal frames was not considering one critical issue – the in-plane stability of the sloping rafters.

In order to accommodate the issues raised by Professor Davies, the amended code has three approaches to the checking of in-plane stability of portal frames.

Method 1 – the sway check method is essentially the method that was available in the 1990 version of the code. The change here is that the method can only be used within certain geometric limits. This ensures that the check will provide a safe prediction, despite the shortcomings identified by Professor Davies.

One additional check has been included in this method for situations where significant horizontal loads are applied to the frame. Provided certain sway criteria are satisfied for the gravity situation, the required load factor (λ_r) for frame stability under horizontal loads should also be determined.

From a practical viewpoint, now that column height/1000 is a fixed limit within the sway check method and can no longer be reduced for the stiffening effects of the cladding, more economic designs may be determined by using the λ_{cr} and P 292 methods. Therefore, for the economic design of portal frames, designers need to be able to use any of the three methods now available – the sway check method, the λ_{cr} method or the P292 method.

Method 2 – the amplified moments method (λ_{cr} method) provides a good solution for some frames, particularly those frames for which sway collapse is the primary mode of failure. This method was originally proposed to be the only alternative solution to the sway check method. Studies undertaken by CSC (UK) Ltd with the assistance of a number of well known fabricators, indicated that in many instances it produces an overly conservative solution, with a consequent increase in frame weight.

Based upon the lowest elastic critical load factor accounting for all members in the frame, the method calculates the required load factor λ_r. Some strain hardening and other effects are taken into account in the approach.

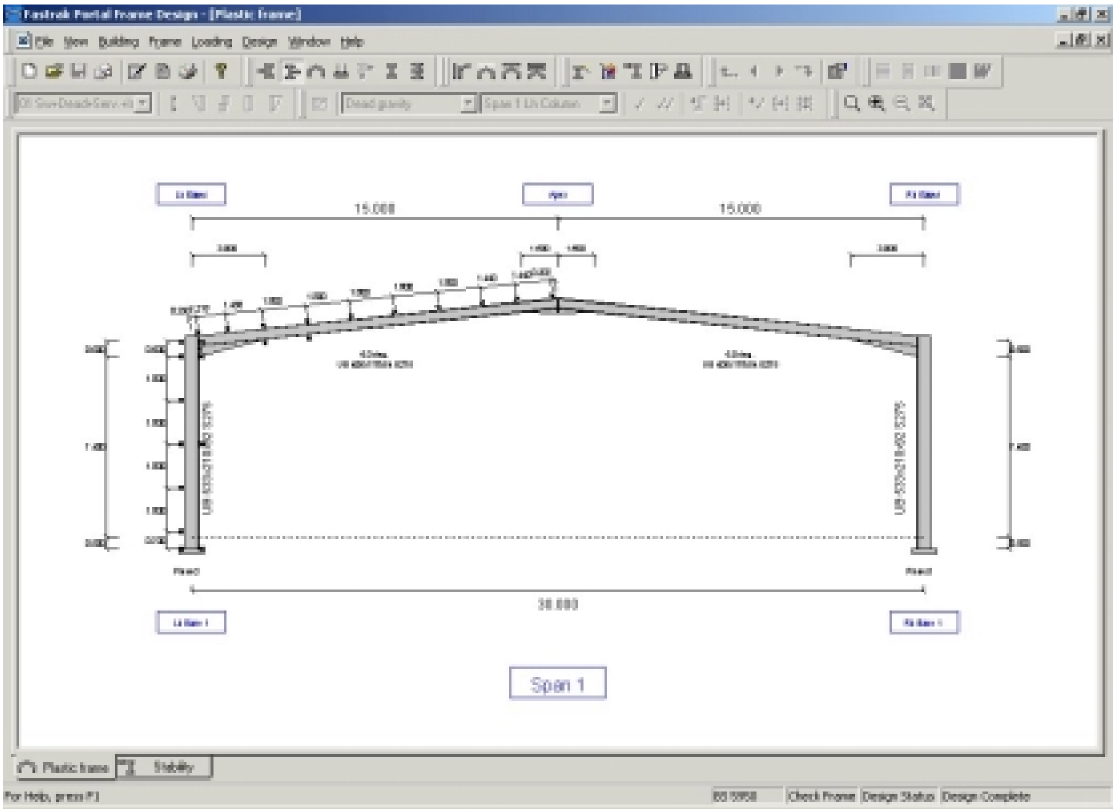
The method is not applicable when $\lambda_{cr} < 4.6$, in which case alternative methods must be used (see below).

Method 3 – second order analysis (P292). Bearing in mind the limitations associated with the other methods, it became necessary to find a generic approach without restriction. To do so, it was essential that the method considered second order effects in the elastic-plastic collapse of the portal frame. The SCI, in close association with CSC (UK) Ltd., has developed what has become known as the “P292” method.

The method uses the principle of conservation of energy, equating the strain energy in the structure under load with the potential energy given up by the structure as it deflects. The critical issue in the method is that the solution accommodates both the overall frame behaviour ($P\Delta$) and the member effects ($p\delta$).

The SCI and CSC (UK) Ltd have undertaken a large number of comparative studies to prove and to benchmark the method. The outcome is the current approach detailed in the SCI’s publication “In-Plane Stability of Portal Frames”, Publication P292.

The inclusion of 2^{nd} order effects generally results in a reduction in the failure load factor. Thus frames with a first order load factor close to unity are likely to see an increase in frame weight using this new method. In addition, there are likely to be more hinges within a frame prior to ultimate limit state. This could result in a small increase in the number of cold rolled sections acting as restraint.



Practical Design 3.jpg – P292 in action in FASTRAK Portal Frame

Conclusion

I have touched on two important areas, which have changed in the new code. With the march of technology, the theory is becoming more sophisticated with the aim of more accurate mathematical prediction of the real world.

As we become more sophisticated, structures become more predictable. This can be looked at in two ways. Either the result will be the same structure with a greater known and reliable factor of safety or alternatively, solutions will be more efficient and cost effective whilst maintaining the current level of known safety factor.

Inevitably, as accuracy increases, the solution becomes more complex and the development of software tools to match new methods is essential. Software suppliers are working hard to meet these needs.