Restraint forces to long-span roof truss systems

Dr. Yigit Ozcelik of the Steel Construction Institute (SCI) presents findings from a recent SCI research project sponsored by BCSA, investigating the adequacy of orthodox purlins and sheeting to restrain multiple long span roof trusses.

BS 5950 provides guidance on lateral restraints through its definition of "normal" arrangements, which have served standard practice well; however, long-span truss systems may fall outside the scope of these "normal" arrangements, and the stiffness and strength of the restraint system may require explicit verification to ensure the lateral stability of truss chords. The research found that discrete bracings were necessary to provide reliable restraint to roof truss chords, as ordinary purlins alone were insufficient for long-span systems. As part of the project, a refined design method was developed to quantify the required stiffness and strength of lateral restraints for such systems. The article outlines this design approach.

Introduction

Designers of portal frames and roof truss systems typically rely on guidance notes and rule-of-thumb checks for lateral restraints of rafters and truss chords. In the UK, Clause 4.3.2.2.2 of BS 5950-1[1] constitutes the backbone of the common practice: purlins that are adequately restrained need not be "normally" checked for forces from restraining rafters, provided that there is either in-plane bracing or a stressed-skin diaphragm. That pragmatic approach works well for short- and moderate-span systems where axial forces in truss chords or in the compression flange of rafters are modest. However, the "normal" arrangements may not apply to long-span roof systems, and it may be unsafe to assume "normal" arrangements without verification.

The following two points explain why BS 5950's practical shortcut might be unsuitable for long-span roof truss systems: (1) Axial forces in truss chords increase with span, so the corresponding restraining forces transferred to lateral restraints can be substantial; (2) The implied stressed-skin behaviour of the roof cladding might be assumed at design stage but is hard to guarantee in practice. In UK construction, sheeting, fixings, and the construction sequence introduce several uncertainties: (1) the cladding type is frequently undecided when the primary steelwork is designed; (2) the insulation and interface create offsets and discontinuities; and (3) the performance of connections and screw fixings varies with workmanship and construction quality. For stressed skin design, fixings must be designed and installed in orthogonal directions around cladding panels. When forces are large, many fixings will be required, with significant concerns at the points where forces accumulate. For these reasons, relying on roof sheeting as a primary stability mechanism is often optimistic. The research therefore focused on a more robust and verifiable design approach for long-span roof systems.

This article summarises the findings of a numerical research study[2] (funded by BCSA) that investigated the stiffness and strength requirements of lateral restraints for long-span roof truss systems. It compares the findings with the recommendations in SCI P360[3] and outlines a design procedure that engineers can apply for the structural design.

Current guidance, SCI P360

SCI P360 is a widely-used reference for stability checks of steel members and frames and provides valuable guidance, including suggestions for the stiffness and strength of lateral restraints. Looking into the behaviour of an isolated column for the case of distributed or multiple point lateral restraints, P360 gives expressions for the restraint stiffness required to achieve an elastic critical buckling load and suggests simple rules for the design force in each restraint when multiple lateral restraints are present. Similarly, P360 covers

Figure 1: Roof trusses – National Composites Centre, Bristol (image courtesy of Billington Structures Ltd.)

the familiar rule-of-thumb that designers have historically used – 1% of the member axial force as the restraint force.

Designers need to pay attention to two critical points in the P360 guidance, especially when applying it to long-span roof trusses:

- P360's minimum stiffness requirements are derived from single-member elastic buckling models and do not explicitly account for systems in which several parallel truss chords are restrained by multiple lateral restraints. When multiple truss chords act in parallel, the accumulated restraint forces and associated lateral deformations increase the required stiffness for each lateral restraint point when the goal is to force individual truss chord members to buckle between lateral restraints. On the other hand, the stiffness expressions in P360 do not account for the inelastic response of truss chords, which may lead to overly conservative stiffness requirements in some cases.
- The restraint forces proposed in P360 do not account for a deliberate restriction of the design axial load relative to the member buckling capacity. As will be explained later, if the design axial force in a truss chord is limited to a certain fraction of its buckling resistance, the required restraint force can be significantly reduced. P360 does not exploit that opportunity.

It should be noted that these aspects were outside the scope of P360, rather than indicating a shortcoming of the publication. The study expands the scope to address long-span effects and interaction between multiple chords and the in-plane bracing system.

Numerical study

A parametric study was undertaken to assess the required stiffness and strength requirements of lateral restraints for long-span roof truss systems. The main parameters considered in the study were truss span, lateral restraint spacing, number of trusses in parallel, the amplitude of initial imperfection of truss chords, and the ratio of provided lateral restraint stiffness to its ideal stiffness.

In the numerical study, three-dimensional roof truss systems were reduced ▸26

▸24 to simplified two-dimensional models: a continuous top chord (treated as a column in compression) with equally spaced point restraints representing lateral restraints, i.e., purlins or discrete bracings. Lateral restraints were modelled as springs to capture axial flexibility of these elements and the in-plane flexibility of the in-plane roof bracing. Both elastic and inelastic behaviours were examined using elastic or inelastic buckling analyses and second-order nonlinear analyses, with an initial imperfection introduced to simulate initial out-of-straightness of truss chords.

Key modelling assumptions were kept explicit and conservative where possible – for example that the axial compression is taken as constant along the chord (a conservative simplification) and that the contribution of sheeting to lateral stiffness is negligible. Where the study had to adopt assumptions about the amplitude of initial imperfections, these are made transparent in the design equations presented below.

The key findings of the study are as follows:

- **Stiffness requirement:** The ideal lateral restraint stiffness given in P360 for an isolated column restrained by distributed lateral restraints is insufficient for long-span truss chords. Based on the results of the parametric study, a new stiffness requirement that accounts for the number of parallel trusses and the in-plane roof bracing stiffness was proposed.
- **Lateral restraint force:** If the design axial load in truss chords is limited to 95% of its buckling resistance ($N_{Ed} \leq 0.95\ N_{b,Rd}$), the design axial force acting on each lateral restraint (i.e., discrete bracing or purlin) reduces to about 40% of the value implied by the traditional 1% rule. In other words, restricting member utilisation leaves a modest reserve stiffness that dramatically relaxes the required restraint force without compromising stability.
- **Practical implications:** Using purlins as lateral restraints can reduce truss chord weight noticeably; however, achieving the required stiffness demands purlin sections that are impractically large or unavailable in standard supply. Discrete bracings, on the other hand, typically offer more practical solutions as they can meet both stiffness and strength requirements.

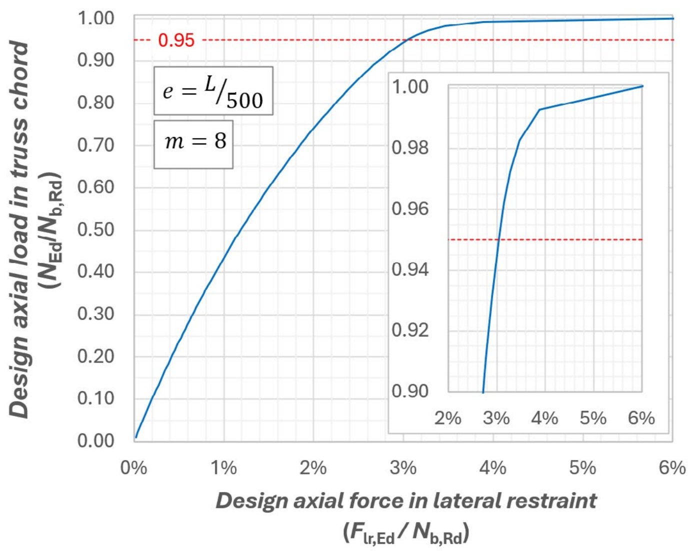

Figure 2: Relationship between axial force in truss chord and axial force in lateral restraint

Design procedure

The step-by-step procedure for the design of lateral restraints is presented below. It should be noted that this design procedure can be applied to systems using either purlins or discrete bracings as lateral restraints.

1. Design truss chords to satisfy:

$$N_{Ed} \leq 0.95\ N_{b,Rd} \qquad (1)$$

where N_{Ed} and $N_{b,Rd}$ are the design axial load of truss chord and its buckling resistance between the lateral restraint positions in the roof plane, respectively.

2. Design lateral restraints to resist the axial force, $F_{\mathrm{lr,Ed}}$:

$$F_{\mathrm{lr,Ed}} = 2\frac{e}{L} m N_{\mathrm{Ed}} \quad (2)$$

where e, L, and m are the amplitude of initial imperfection in truss chords, lateral restraint spacing, and number of truss chords in parallel per an in-plane roof bracing, respectively. For lateral restraint-to-truss connections susceptible to significant slip, the lateral displacements resulting from slip should be added to e. Similarly, for load combinations including lateral loads such as wind and earthquake, the lateral displacement of the in-plane roof bracing should be added to e.

3. Determine the required "system-level" lateral stiffness, $\beta_{\mathrm{t,Ed}}$, that can be calculated by Equation (3):

$$\beta_{\mathrm{t,Ed}} = \frac{6N_{\mathrm{b,Rd}}}{L} \quad (3)$$

4. Determine the required stiffnesses of an individual lateral restraint (i.e., purlins or discrete bracings) and an in-plane roof bracing ($\beta_{\mathrm{lr,Ed}}$ and $\beta_{\mathrm{ir,Ed}}$, respectively).

   The general expressions for the stiffness requirements of both individual lateral restraint and in-plane roof bracing are available; however, for the sake of brevity, only Equation (4) is presented here, which can be used to calculate the required axial stiffness of an individual lateral restraint when the in-plane stiffness of the in-plane roof bracing is significantly larger than its required stiffness.

$$\beta_{\mathrm{lr,Ed}} = (0.4m^2 + 0.4m + 0.2)\,\beta_{\mathrm{t,Ed}} \quad (4)$$

5. Check if the stiffnesses of an individual lateral restraint and an in-plane roof bracing ($\beta_{\mathrm{lr,Ed}}$ and $\beta_{\mathrm{ir,Rd}}$, respectively) are adequate.

$$\beta_{\mathrm{lr,Ed}} \le \beta_{\mathrm{lr,Rd}} \quad (5a)$$
$$\beta_{\mathrm{ir,Ed}} \le \beta_{\mathrm{ir,Rd}} \quad (5b)$$

Conclusion

The study supports the concern: the simple reliance on BS 5950's "normal arrangements" for long-span roof trusses may be insufficient without verification. By combining a system-level stiffness requirement with a modest utilisation limit for truss chords, designers can both reduce the required lateral restraint forces and achieve reliable buckling behaviour between restraints. The key practical outcomes are as follows:

- Verify lateral restraint stiffness explicitly – do not rely on "normal" arrangements.
- Limit the design axial loads of truss chords to 95% of their buckling resistance to benefit from the reduced lateral restraint forces.
- Use discrete bracing for long-span roof truss systems since purlins are likely to be impractical due to the stiffness requirement.

The proposed design procedure will allow engineers to design lighter and more economical long-span roof truss systems without compromising stability – provided that the assumptions of the design procedure are respected.

References

1. British Standards Institution. (2000). BS 5950-1:2000: Structural use of steelwork in building – Part 1: Code of practice for design in simple and continuous construction: Hot-rolled sections. British Standards Institution.
2. SCI. (2025). RT2029 v01 - Restraint forces to long-span roof truss systems
3 SCI. (2011). Stability of steel beams and columns (SCI P360)Unpublished