Engineering reports

Adapted from: Braham M, Jaspart JP. Is it safe to design a building structure with simple joints, when they are known to exhibit a semi-rigid behaviour? *Journal of Constructional Steel Research,* 60, 2004, 713-723.

Annotated model

Purpose **Method** **Results** **Conclusion** **Recommendations**	**Executive Summary** This report evaluates the assumption that joints which display semi-rigid behaviour can be modelled as frictionless pinned joints in building design calculations. The idealisation is evaluated by comparing computer simulations incorporating this assumption with experimental test data for the actual structure. The results show that the idealisation is safe and is usually conservative in estimating the structural strength; however these conclusions are limited to cases where the joints display large deformations before rupture of the bolts or welds. Only in few, probably unrealistic cases will this assumption lead to unsafe results which overestimate strength. It is recommended that three conditions are necessary for the safety of semi-rigid joints: joints must show enough ductility, welds must be well designed in order to avoid premature fracture and the design of the joint must be such that the rotation is practically possible.

Background **Context** **Problem / issue**	**1. Introduction** In building design, joints are classified as pinned, semi-rigid or rigid depending on their stiffness relative to the framing in which they are used. Engineers consider some joints as pinned in their structural analysis, even though it is common knowledge that all joints exhibit some rotational constraint. For example beam-to-column joints made with a thin and non-extended end plate are actually semi-rigid but are modelled as frictionless pinned connections. Until recently there has been no reliable evidence that the idealisation of such joints is a safe building design practice. Even in the absence of definite proof the above assumption continues to be used. Only recently have extensive studies been performed and design rules established for the modelling of structural joints; these are published in the European regulatory document Annex J of Eurocode 3 [1]. This raises the question of safety for existing buildings whose designs are based on the assumption of pinned joints. Another important question is whether building practitioners can continue to safely use the pinned joint assumption or adopt a more accurate

Framework / model for research	(and complex) modelling technique. These questions are important for the building industry and will strongly influence the complexity, time and cost of structural analysis and design of buildings. This research compares the computer numerical simulations based on Euro code 3 for the behaviour of an existing building with experimental test results. Therefore, a ‘‘Eurocode 3 model-test’’ comparison is used to evaluate the level of accuracy of the of the Eurocode modelling guidelines.

Purpose / aim	**2. Objectives** The objectives of the research are to determine whether: • building designs based on idealised joints exhibit similar strength characteristics to a building containing real joints; • existing buildings have been designed using safe modelling practices; • the current modelling techniques must be changed for future building designs

Materials **Testing procedures**	**3.Materials and testing procedures** The frame considered is a braced structure made of two types of steel and is schematically represented in Figure 1. The joints of beams B1 to the central column are bolted connections with thin, non-extended end-plates of 10mm thickness. Joint EP2 has been submitted to test and the results are reported in Aribert *et al* [2]. The moment–rotation curve characterising EP2 has been recalculated based on the rules of Eurocode 3 Annex J and compared with the test results [2].
Extent of testing	The calculations were performed using the CoP computer program [3] with symmetrical loading identical to the loading applied during experimental testing. The loading consisted of two transverse loads acting at the end of the beams, applied at a distance of 1730 mm from the axis of the column. The calculations of the frames are performed with the full non-linear FINELG computer program [4], both fully pinned beam-to-column joints and semi-rigid joints were analysed. The M–*I* response calculations are performed step by step up to the collapse of the structure. Instability and plasticity are taken into account but are limited to in-plane behaviour because the ‘‘pinned’’ or ‘‘semi-rigid’’ character of the joints mainly influences this behaviour.

	4. Results and Discussion
Research compared with theory	Figure 2 shows the experimental and theoretical moment–rotation curves for the joint EP2. It can be seen that the initial stiffness and the ‘‘plastic’’ resistance are in perfect agreement with the test results. The failure mode obtained from the calculation is also confirmed by the test [2]. The models disregard the effect of the steel strain-hardening: this is why a plastic plateau indicates the theoretical failure of the joint.
Evaluation of results	The model incorporating pinned joints exhibits failure with one plastic hinge in the middle of all four floor beams and a maximum load factor (ULS) of 1.12. The model using semi-rigid joints exhibits a plastic failure mechanism in the two right floor beams with three plastic hinges: one in the middle of the beams and one in the two end joints. The load factor at collapse is 1.28. For the pinned joint model the beam deflections and collapse loads are smaller than those obtained with semi-rigid joints and will therefore lead to a more conservative design.

	5. Conclusion
Summary of findings	It has been shown that the assumption of pinned joints is more conservative than the semi-rigid model and can safely be used in building design and analysis under the following conditions:
Identifies problem / issue for further research	It must be emphasised that the pinned joint assumption is not economical and could possibly lead to a reduction of the beam profiles. This however requires further analyses and is recommended as a topic for further research.

	6. Recommendations
Outlines in point form actions, conditions or solutions to the issue / problem	It is recommended that three conditions should be met to ensure the ongoing safety of semi-rigid joints. These are: • joints must show enough ductility, • welds must be well designed in order to avoid premature fracture, • design of the joint must be such that the rotation is practically possible.

References

[1] Revised Annex J of Eurocode 3. Joints in building frames. European Prestandard ENV 1993-1-1:1992/A2. Bruxelles (Belgium): CEN; 1998.

[2] Aribert JM, Braham M, Lachal A, Richard C. Testing of ‘‘simple’’ joints and their characterisation for structural analysis. Proceedings of the Third European Conference Eurosteel on Steel Structures, Coimbra, September 19–20, 2002, Portugal. 2002, p. 1079–90.

[3] CoP, The Joint Program. Computer program for the calculation of joints, developed by JP Jaspart, University of Liège, MSM department, and K Weynand, RWTH Aachen (D). Version 2000R19, 2000. Commercialised by ICCS bv (NL).

[4] FINELG, Finite Elements Computer Program for non linear Analysis. MSM Department of the University of Liège (B). *Journal of Constructional Steel*, Research 60 (2004) 713–723