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Comparison of stiffness reduction method, effective length method and geometrically non-linear analysis with imperfections for in-plane design of steel frames

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INTRODUCTION

Currently, effective lengths are used to determine the buckling resistance of columns in accordance with Eurocode 3 (EC3). However, the use of effective lengths can be overly conservative and uneconomical. Alternatively, geometrically non-linear analysis with imperfections (GNIA) is another codified method by EC3. Kucukler et al. (2014) proposed an alternative method, the stiffness reduction method (SR) to account for the non-linear buckling effects in order to avoid the use of effective lengths. This study will evaluate the accuracy and effectiveness of SR for in-plane design of steel frames, relative to the traditional effective length method (ELM) and the theoretically accurate GNIA.

IMPERFECTIONS AND NON-LINEAR EFFECTS

The properties and behaviours of real columns inevitably deviate from an elastic and geometrically perfect one. One of the challenges to design and anlaysis is the modelling of geometric imperfections and non-linear effects, and they are accounted as follows.

	Effective length method	GNIA	Stiffness reduction method
P-δ effect	Use of imperfection factor α	P-δ moment in geometric non-linear analysis	Use of imperfection factor α in stiffness reduction factor
P-Δ effect	Evaluated by critical buckling factor α_{cr} and corresponding procedures	P-Δ moment in geometric non-linear analysis	P-Δ moment in geometric non-linear analysis
Member imperfection	Use of imperfection factor α	Explicit modelling	Use of imperfection factor α in stiffness reduction factor
Frame imperfection	Equivalent horizontal forces	Explicit modelling	Equivalent horizontal forces
Residual stresses	Use of imperfection factor α	Use of imperfection factor α	Use of imperfection factor α in stiffness reduction factor
Plasticity	Use of imperfection factor α	Use of imperfection factor α	Stiffness reduction factor

DESIGN PHILOSOPHY

A structure is deemed to be stable and safe if the effects from loading can be sufficiently resisted by the capacities of member. For instance, for beam-column members,

$$\frac{Design\ axial\ compression}{Axial\ compression\ resistance} + \frac{Design\ moment}{Moment\ resistance} \leq 1$$

The three approaches account for the geometric imperfections and non-linear effects in various ways.

Effective length method

Reduction in axial compression resistance by multiplying buckling reduction factor χ from European buckling curves

Geometrically non-linear analysis with imperfections

Magnification of design moment by explicitly modelling geometric imperfections and considering second-order effects

Stiffness reduction method

Magnification of design moment by reducing the flexural stiffness of members through stiffness reduction factor and considering second-order effects

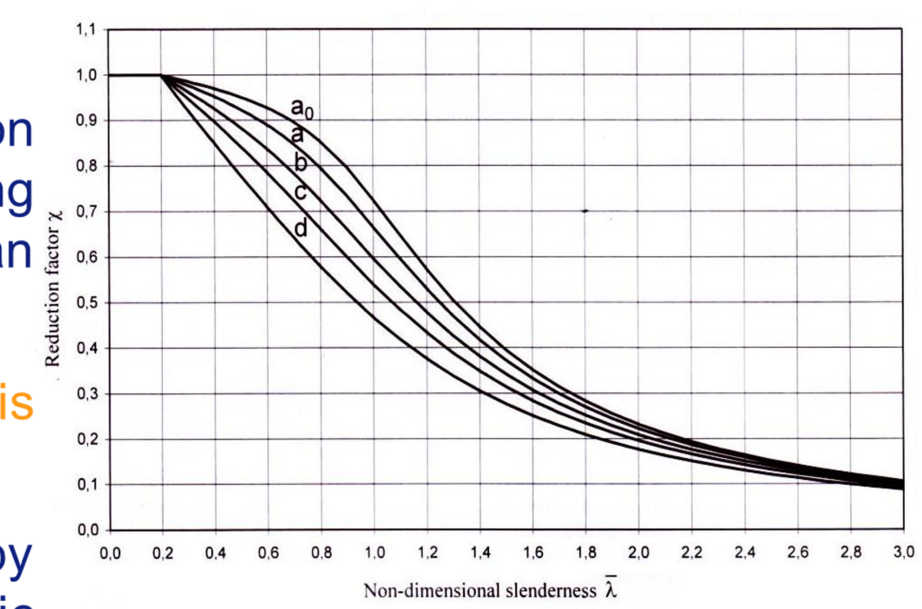

Figure 1: European buckling curves (BSI, 2005)

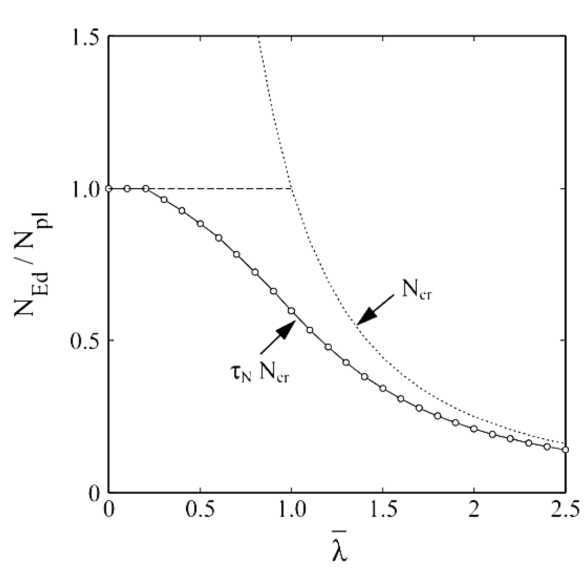

Figure 2: Stiffness reduction factor (Kucukler et al., 2014)

METHODOLOGY

One sway frame (A) and two non-sway frames (B & C) were analysed by the aforementioned methods. The beam stiffness is varied as multiples of column stiffness. The ultimate load factors are obtained and compared. Two GNIA cases with two imperfection values are used – actual and EC3 recommended values. The stiffness reduction method with geometric non-linear analysis (GNA-SR) is used for Frame A and the stiffness reduction method with linear buckling analysis (LBA-SR) is used for Frames B and C.

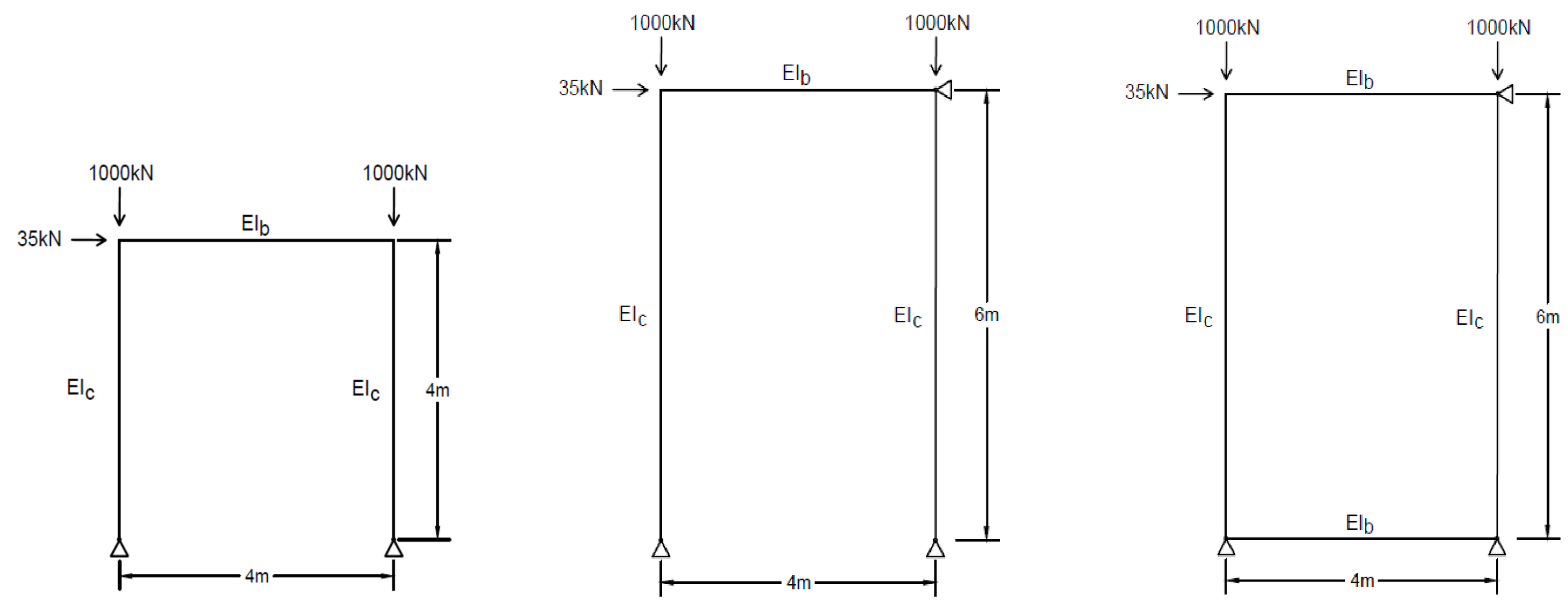

Figure 3: Configurations of Frames A (left), B (middle) and C (right)

RESULTS

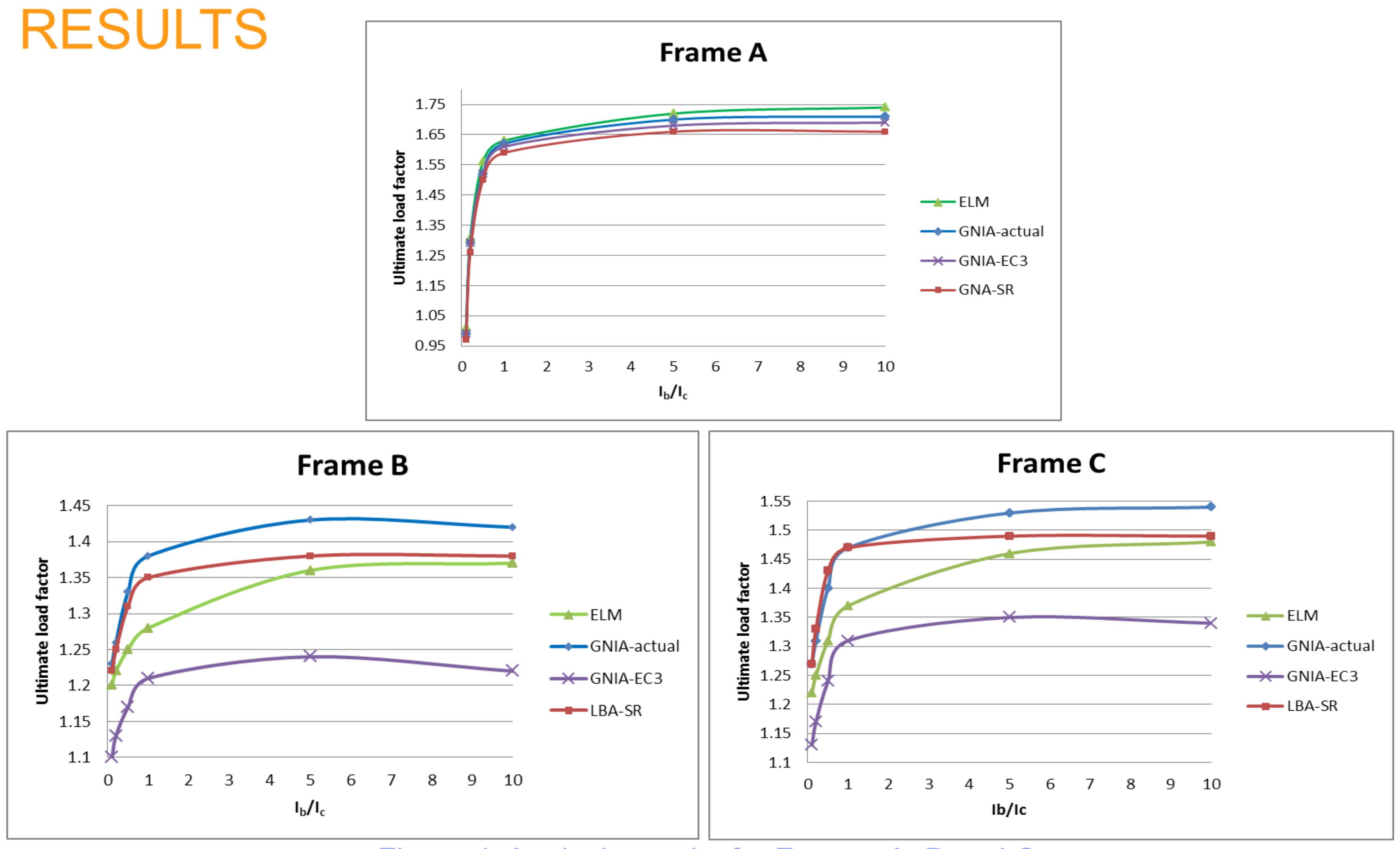

Figure 4: Analysis results for Frames A, B and C

General comments

- GNIA-actual can be used as a benchmark
- GNIA-actual is the better representation among the two GNIA cases

Sway Frame (A)

- High affinity between GNA-SR and GNIA
- GNA-SR more conservative than both ELM and GNIA

Non-sway Frames (B and C)

- High affinity between GNA-SR and GNIA
- GNA-SR more conservative than GNIA but less conservative than ELM

CONCLUSIONS

The stiffness reduction method is an accurate and reliable method for in-plane design of steel frames. It describes the structural behaviour better and provides more economical design than ELM. Compared to GNIA, it is easier to implement as it does not have to determine the critical orientation of geometric imperfections.

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REFERENCES

Kucukler, M., Gardner, L. & Macorini, L. (2014) A stiffness reduction method for the in-plane design of structural steel elements. *Engineering Structures*. 73, 72-84.

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