Dynamic response of HSS floors

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Steel Buildings and Vibration

- Steel building designs generally meet criteria without modification
- Even strictest criteria can be met with careful design
- Always important to assess vibration performance as remedial costs can be substantial

Introduction

- Response of steel floors to floor vibrations
  - RFCS HIVOSS project (Human Induced Vibration of Steel Structures)
  - SCI P354 Design of Floors for Vibrations (updated)
- Two issues to be addressed for HSS floors:
  - lack of availability of analysis tools
  - perception that HSS is worse than S355 floors in vibration response
- STROBE
  - A new analysis tool for floor vibration (FEM based)
  - Study response of HSS floors (vs. S355 floors)

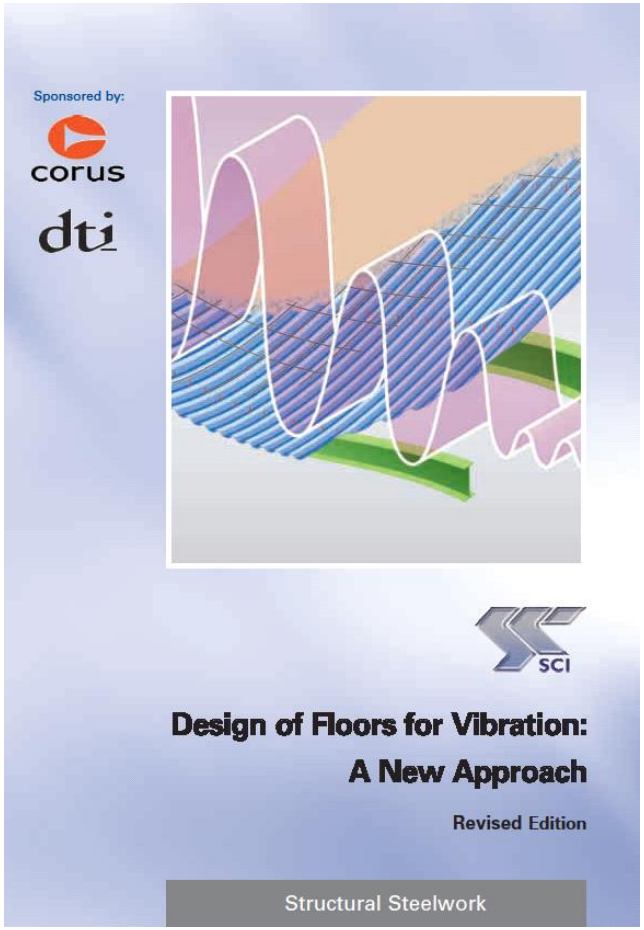
Traditional Practice

- Serviceability criteria
- Primary & Secondary beams checked independently for minimum frequency of 3 Hz
- Analysis typically assumes self-weight and 10% of imposed load

Design of floors for Vibration

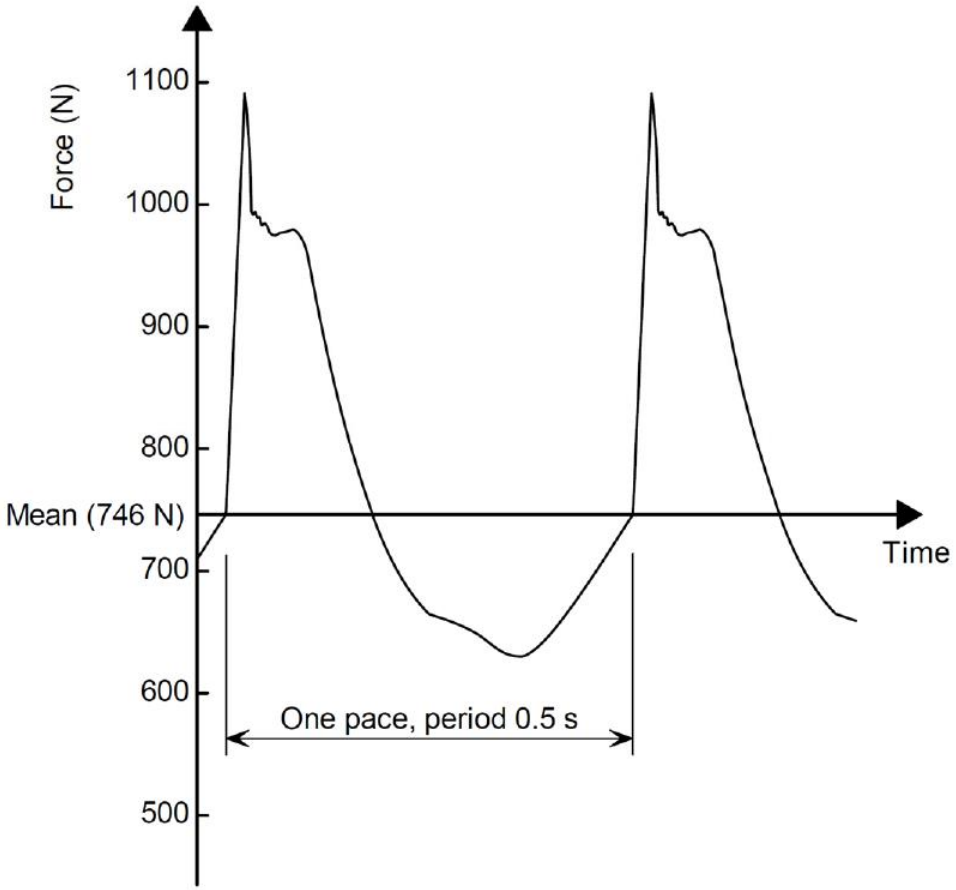
- SCI P354 (2009) www.steelconstruction.info
- Key publication for vibration design of floors in the UK
- Contains guidance for FE modelling, and a simple method

- Arcelor Mittal – Design Guide for Floor Vibrations



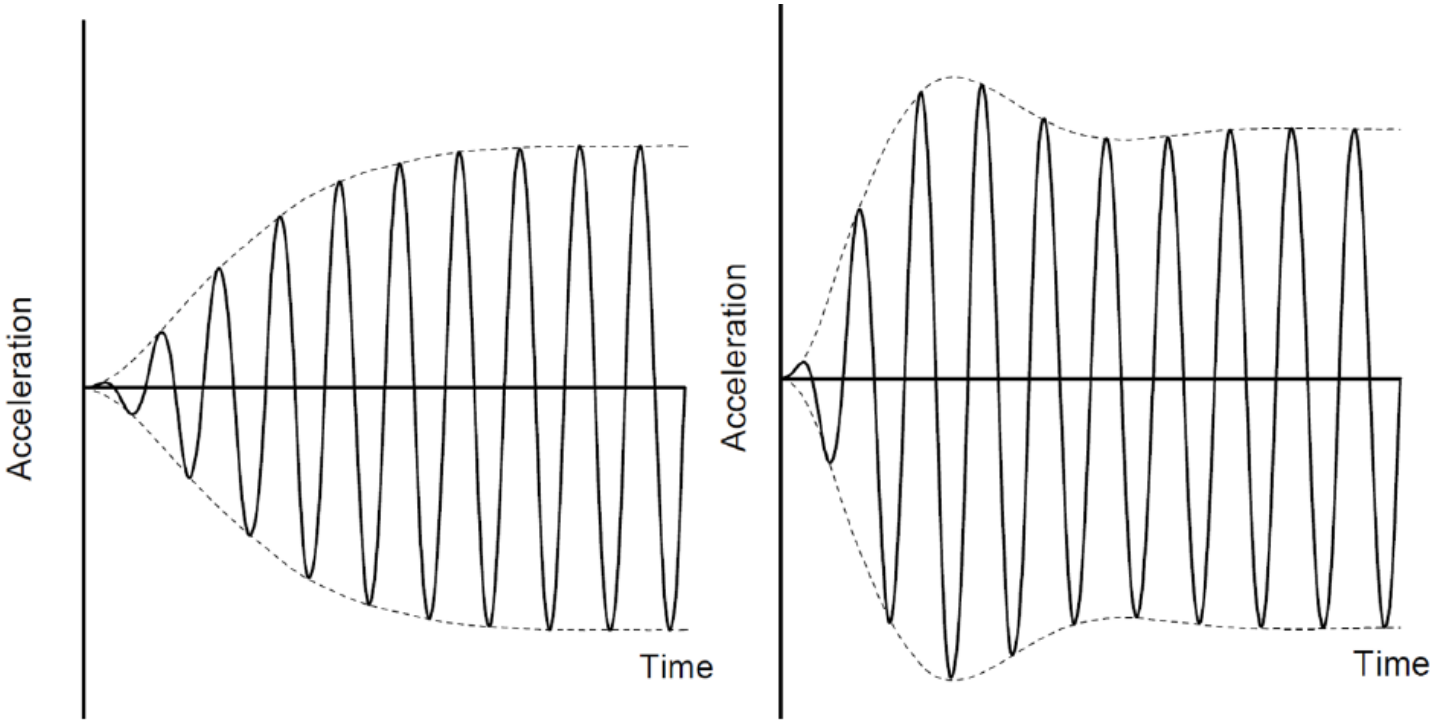
Human Induced Vibration

- Approximated as number of sine waves (harmonics)
- Pace frequency 1.8 Hz to 2.2 Hz



Vibration Response

- Split into 2 parts: steady-state & transient

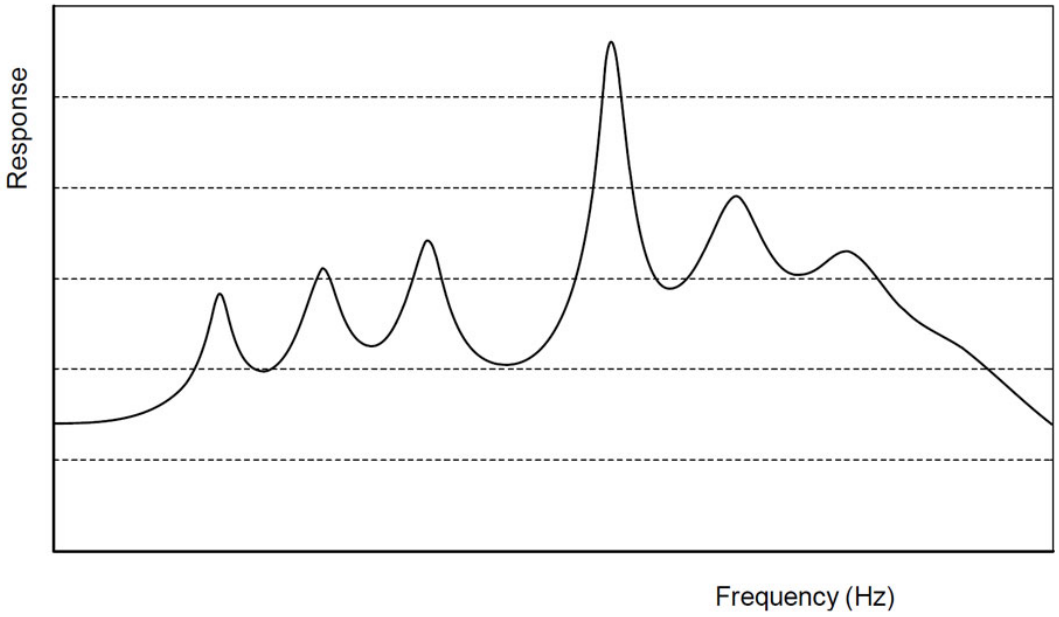


$f \leq 10\ Hz$

$f > 10\ Hz$

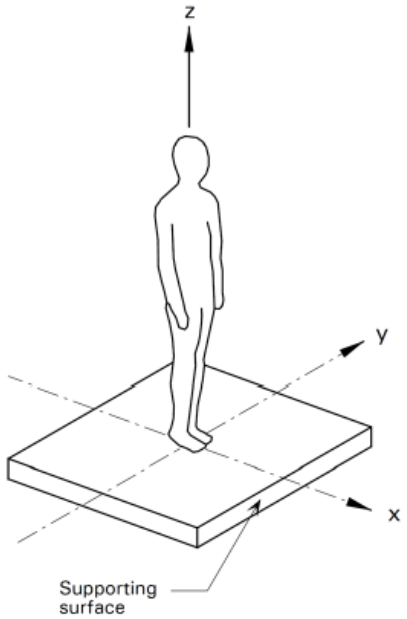
Vibration Response - Resonant

- Lower frequency floors
- Continual force leads to response build-up
- Largest response when excitation frequency matches floor frequencies



Response Factor

- Vibration is an issues of perceptions – varies from person to person
- Depends on:
  - Direction of vibration relative to body
  - Frequency of vibration
  - Activity



$$R = \frac{predicted\ acceleration}{base\ value}$$

⟹ 0.005 m/s^2 for z-axis vibrations – BS 6472

Acceptance criteria

- Typical limiting values for response factors

Office	8
Shopping mall	4
Dealing floor	4
Stairs – Light use (e.g. offices)	32
Stairs – Heavy use (e.g. public buildings, stadia)	24

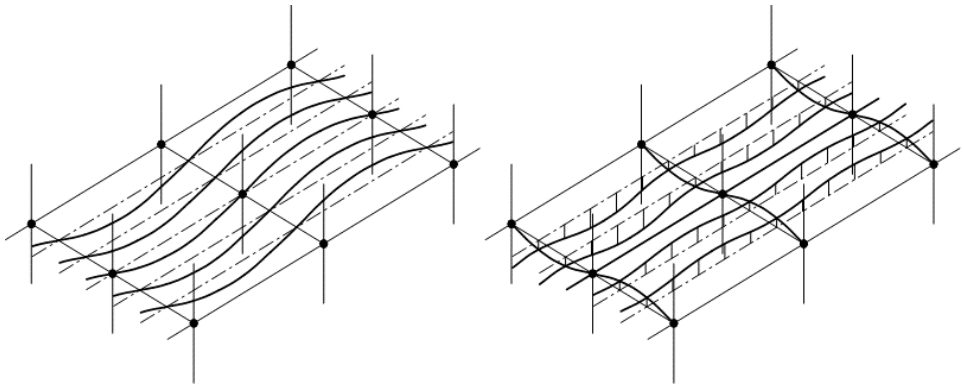
Simple method

- Simple method, allows calculation using a spreadsheet
- Widely used – not every engineer has access to FE software
- Perception that it is extremely conservative for some designs

❑Fundamental frequency

❑Mode shape amplitude

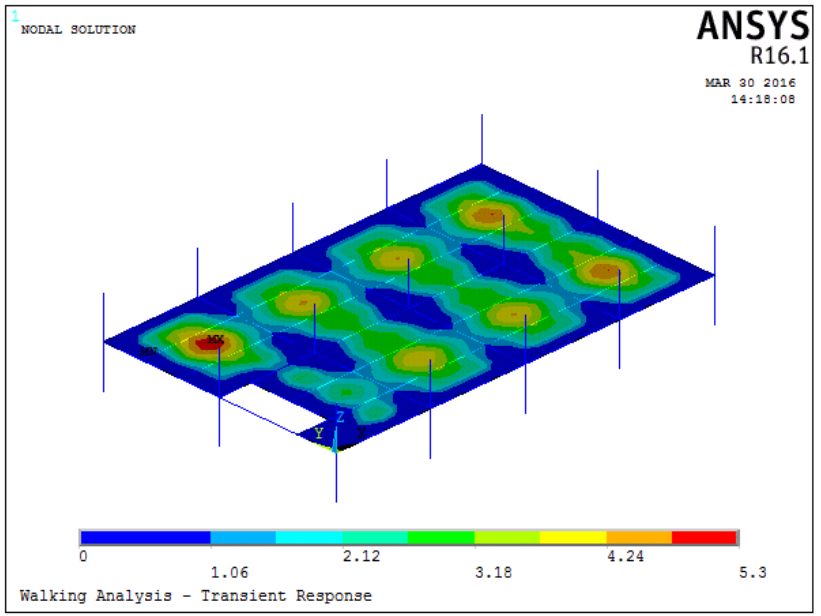
❑Modal mass



(a) Secondary beam mode (b) Primary beam model

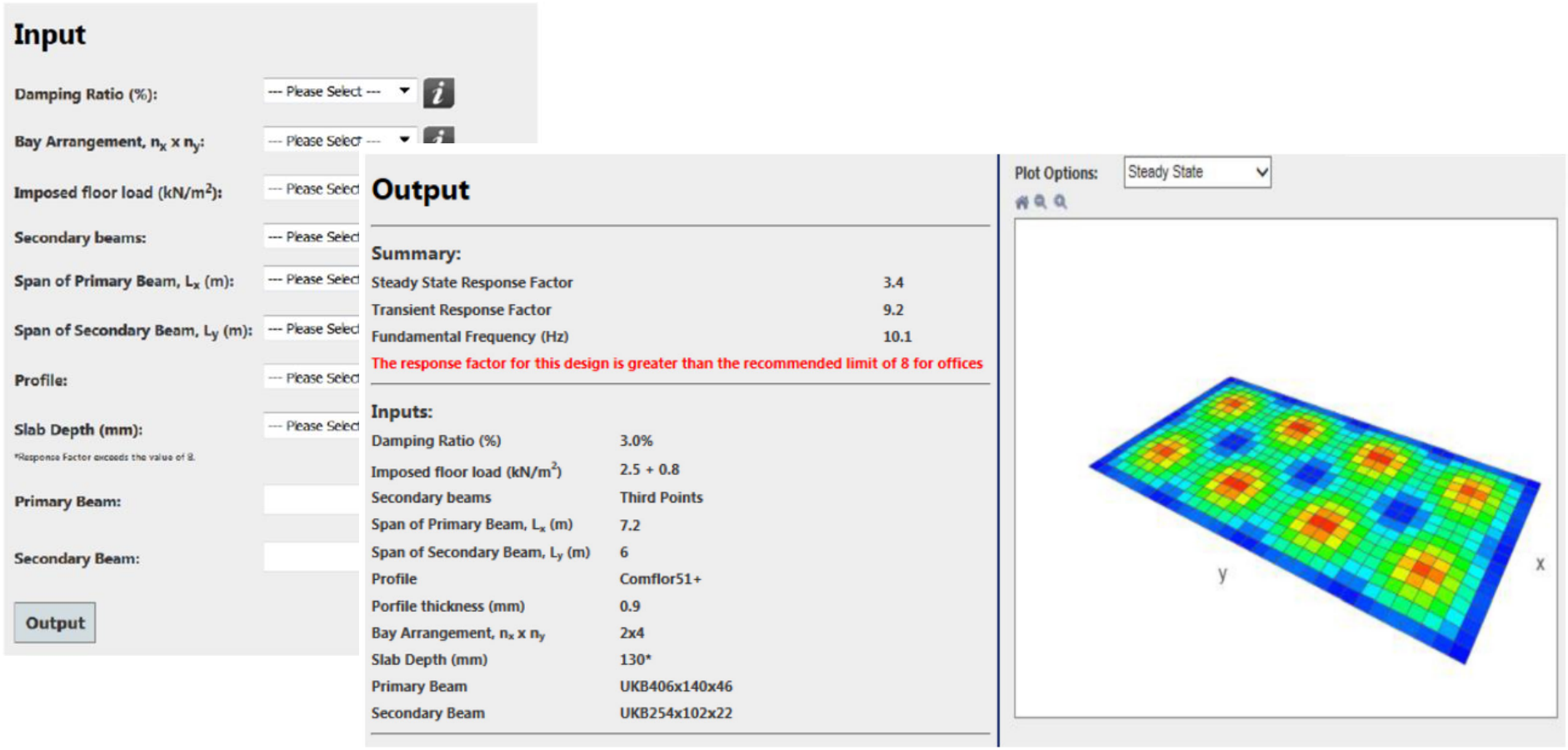
Finite element method

- Rigid connections
- In vibration analysis, strains are not large enough to overcome friction
- Columns pinned at inflexion points
- Located at mid-height between floors for multi-storey construction
- Vertically restrained edge beams
- Cladding provides full vertical restraints, so the edge of clad buildings should be modelled as free in rotation but restrained in translation



SCI office floor (Transient Response Factor)

www.steelconstruction.info Floor response calculator



http://bcsatools.steel-sci.org/FloorResponse/Default

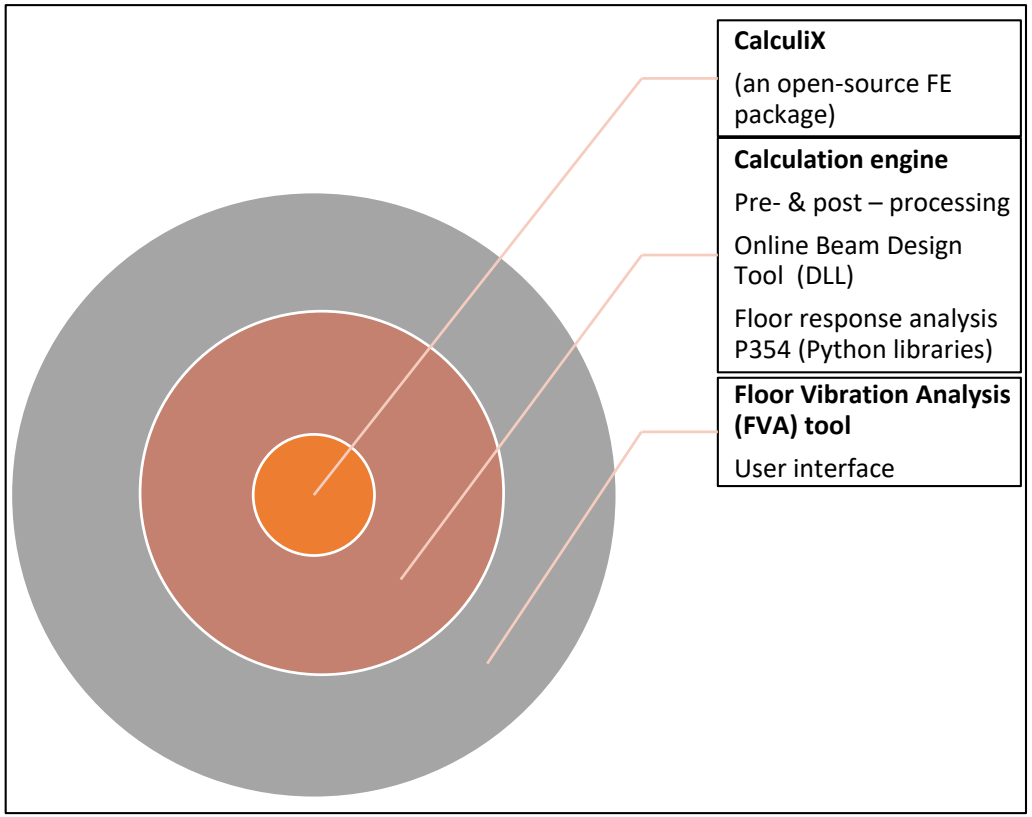
Comparison of methods

Model	Natural Frequency (Hz)	Steady State Response Factor	Transient Response Factor
Manual method	9.3	9.5	-
Floor Response Calculator	10.1	3.4	9.2
FE analysis	11.06	1.67	6.9

- Frequency results close
- Floor response calculator & FE both show transient response is critical and values are close

Floor vibration analysis (FVA) tool

- User defines rectilinear floor system
- FE methods used to calculate the frequency and mode shapes
- SCI P354 used to calculate the response factors



FVA tool

STROBE Floor vibration analysis (FVA) tool - The Steel Construction Institute UK

INPUT Reset

Job ID	STROBE
No. of Bays, nx	2
No. of Bays, ny	4
Span of Primary Beam, Lx (m)	7.2
Span of Secondary Beam, Ly (m)	9.0
Height of Storey, H (m)	3.9
Secondary beams	Mid-span
Dead load (kN/m²)	0.8
Imposed load (kN/m²)	2.5
No. of modes, N	30
Damping ratio, ζ	0.03

Floor slab section

Standard | Custom

Comflor 51+ | 130 | 0.9

Primary beam section

Standard | Auto-select | Custom

UB 457 x 191 x 74 | 460 | Run

Secondary beam section

Standard | Auto-select | Custom

UB 533 x 165 x 66 | 355 | Run

Column section

Standard

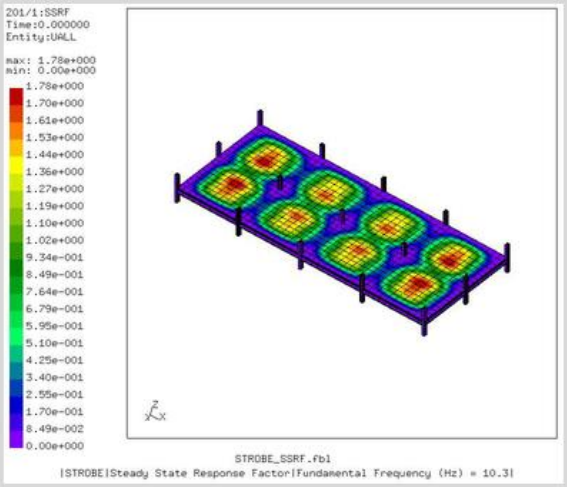
UC 305 x 305 x 283

Generate Input File | Calculate

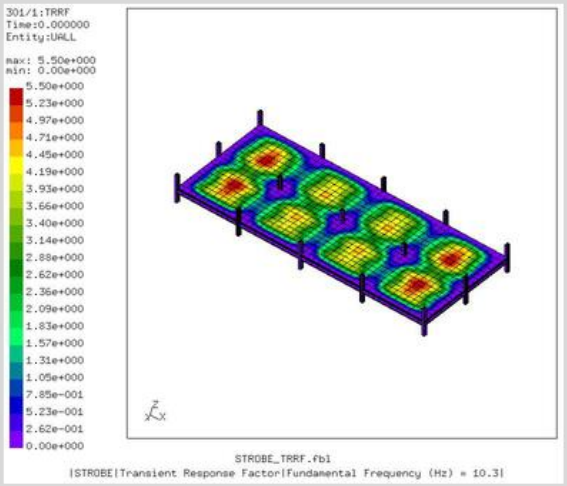
OUTPUT Read Results | Clear Results

Steady State Response Factor	1.78
Transient Response Factor	5.5
Fundemental Frequency (Hz)	10.3

Steady State Plot



Transient Plot



| Beta Version 0.1 | 10 Jan 2020 |

Validation

- 28 test cases
- Compared against SCI floor response calculator

Primary beam span (m): 7.2, 9.0, 9.75, 10.2

Secondary beam span (m): 6, 7.5, 9, 12, 15

Position of secondary beams: mid-span, third points

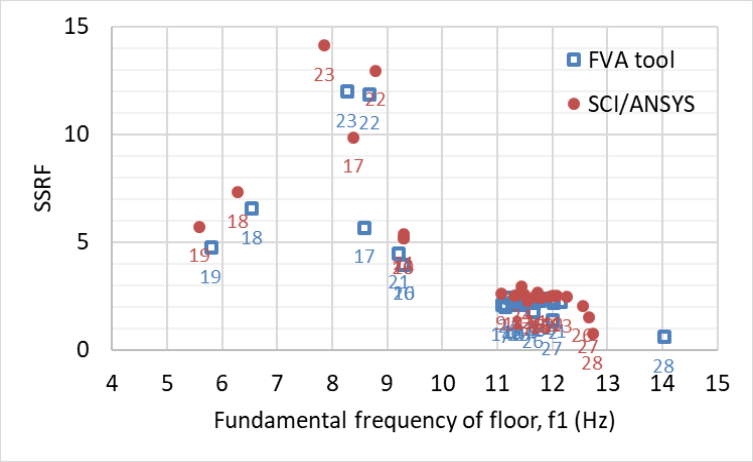
Bay arrangement (nx × ny): 1×2, 1×4, 2×1, 2×2, 2×4, 4×2, 4×4

Decking profile: Comflor 51+ with thickness of 0.9, 1.0 and 1.2

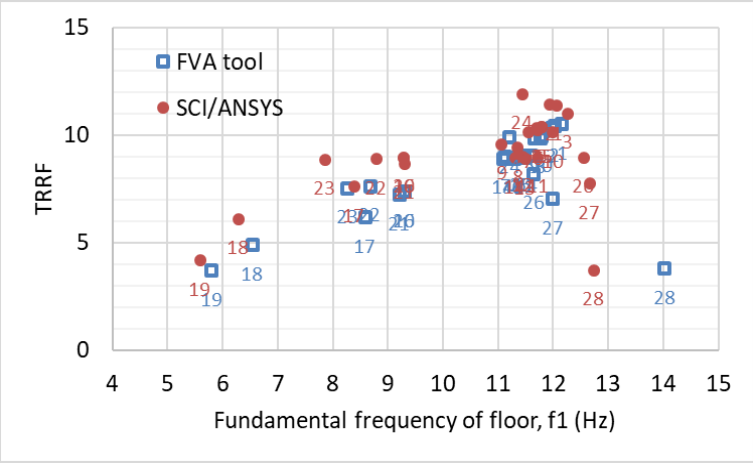
Total slab depth (mm): 120, 130, 140, 150, 200

Floor load: 2.5 kN/m^2 + 0.8 kN/m^2 for normal office

Steady state response factor



Transient state response factor



Comparative study of HSS floors

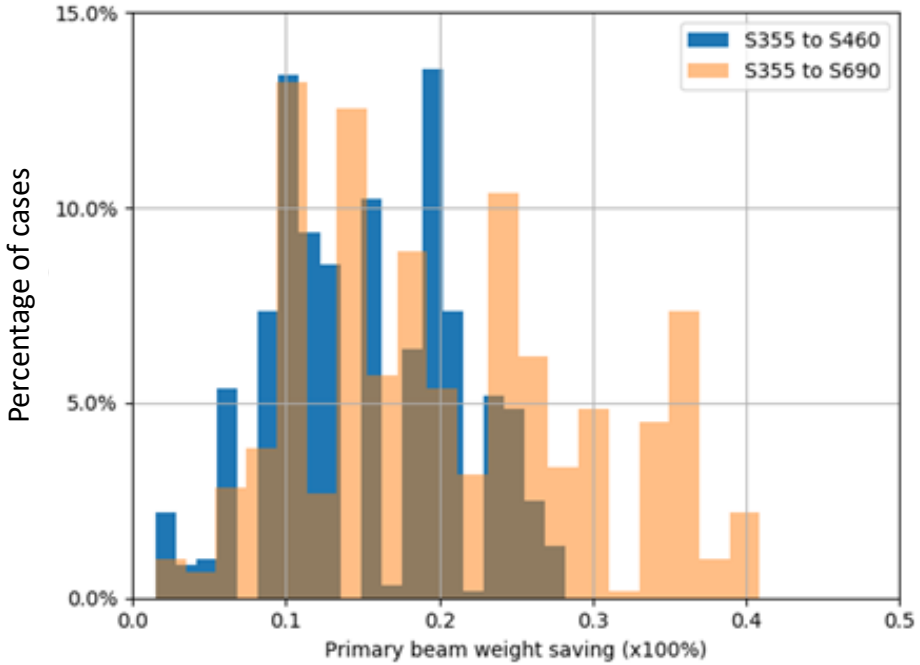
- More than 10000 floor system design cases studied
- Design parameters (using typical values):
  - Steel grades (S355, S460 and S690)
  - Bay arrangement (1x1 to 8x8)
  - Span (primary and secondary beam)
  - Slab (thickness and profile types)
  - Loading
- Serviceability governed by deflection only
- Compare between functionally equivalent HSS and S355 floor systems
- Sensitivity to key parameters

Weight saving

Composite floor

	S355 to S460		S355 to S690	
% of cases with lighter beam section	Primary beam	Secondary beam	Primary beam	Secondary beam
	84%	0%	92%	2%

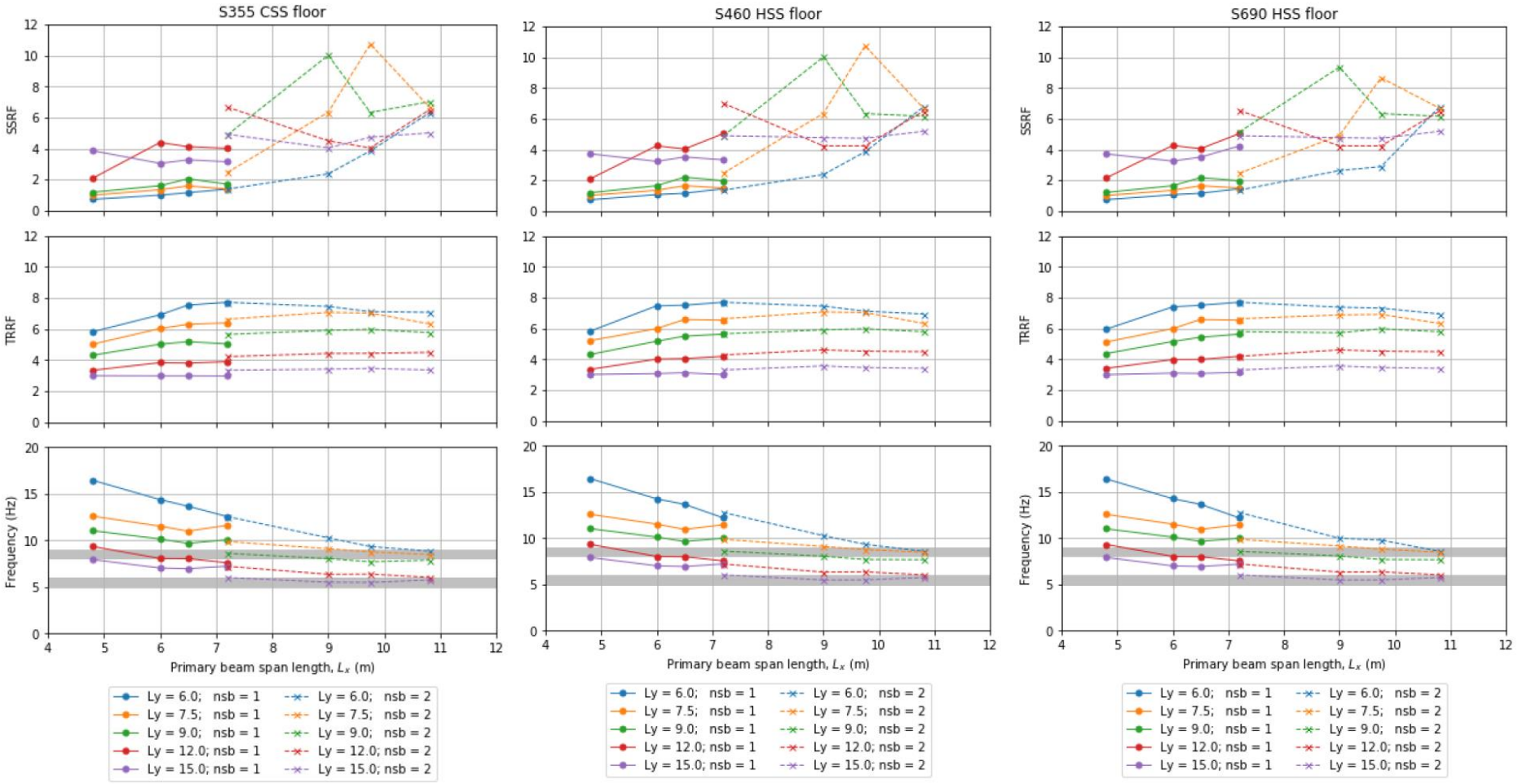
- Max weight saving
  - Long span
  - Heavily loaded floors



Histogram of primary beam weight saving due to steel strength upgrade

Sensitivity study

Example: primary beam span



Sensitivity study

- Vibration response of CSS and HSS floors show same sensitivity to key floor design parameters

❑Fundamental frequency (f_1): SSRF peaks at f_1=8-9 Hz (resonance), TRRF dominates if f_1 > 10 Hz

❑Total floor area↑ - vibration response↓

❑Slab height↑ - vibration response↓

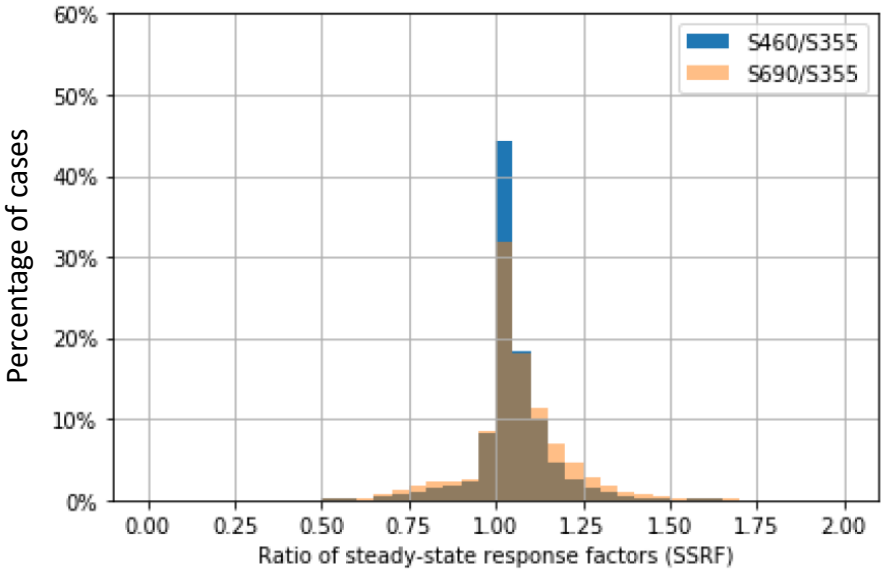
❑Beam span ↑ - vibration response ↑ if in resonance

❑Beam span ratio (pri./sec.) ↑ - vibration response ↑

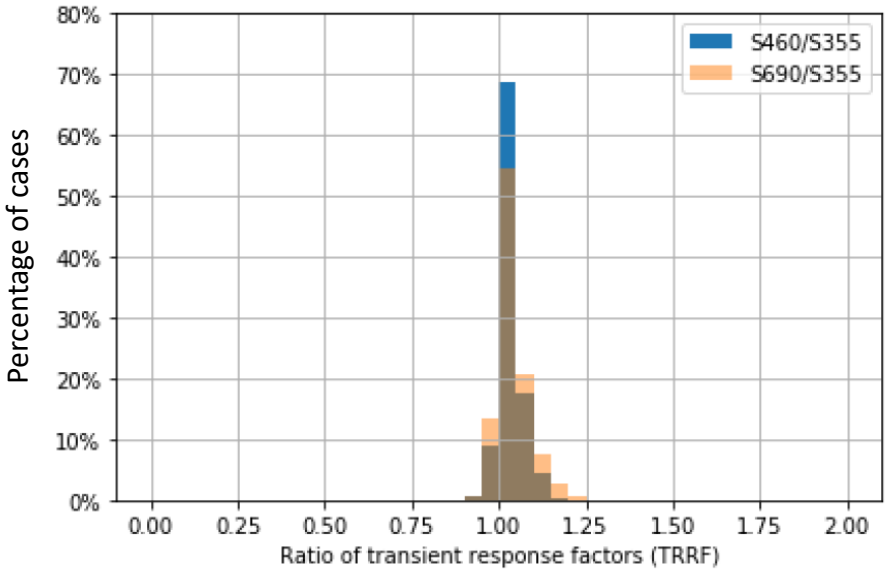
❑Floor load ↑ - vibration response ↓

Comparative study

- Overall comparison of response factors



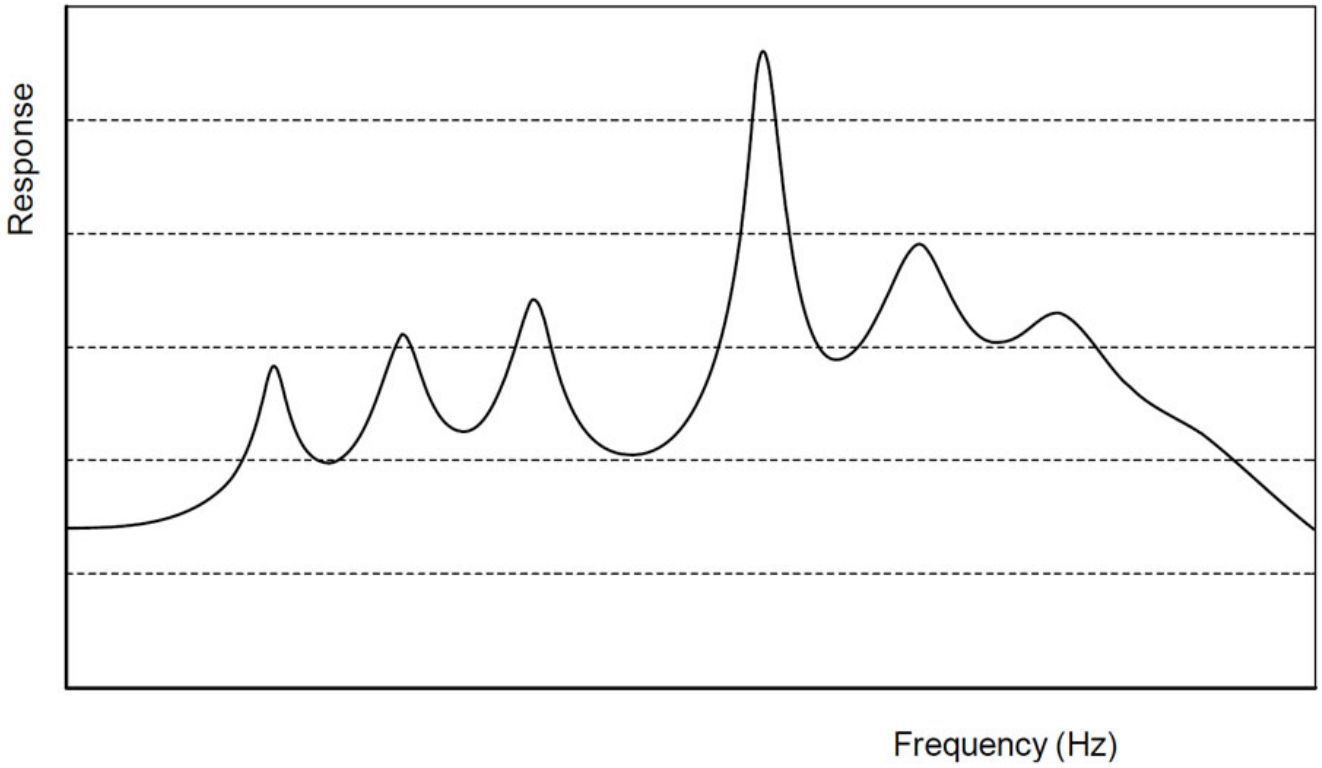
(a) Steady-state



(b) Transient

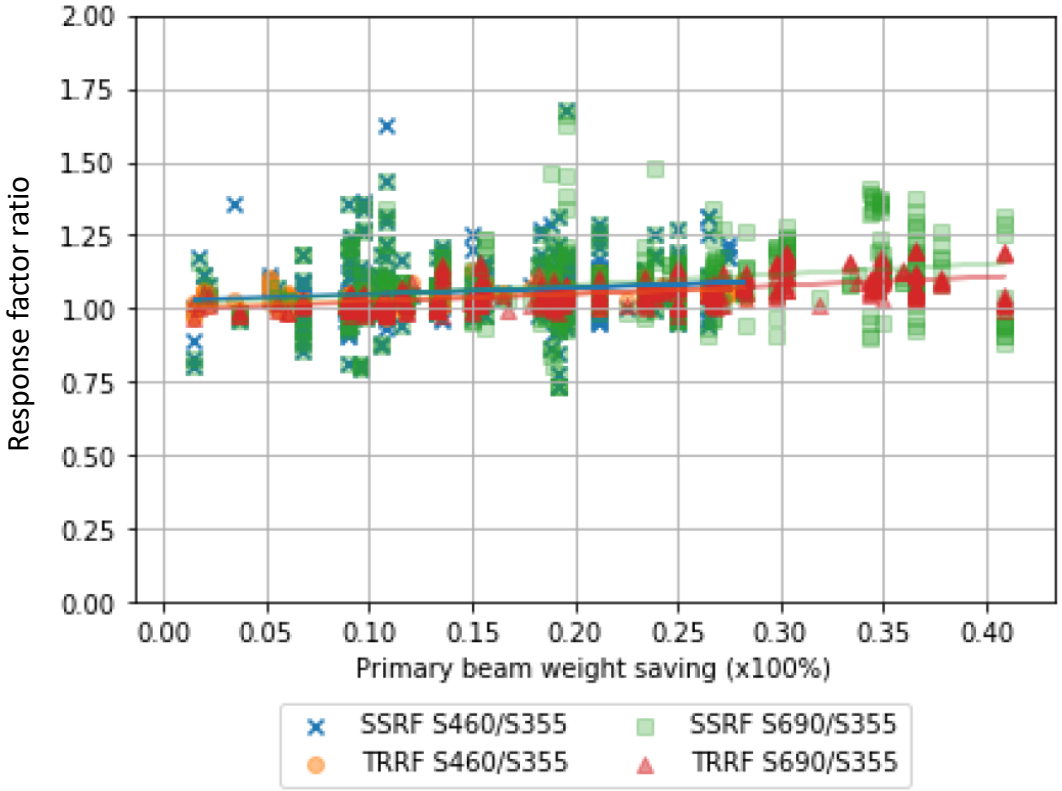
Comparative study

- Fundamental frequency is the key



Comparative study

- Weight saving vs vibration response factor ratio



Conclusion

- Floor vibration analysis (FVA) tool free to use
  - Use more accurate FE method in SCI P354
  - S355, HSS and Hybrid floor systems
- No special consideration for HSS floor system with respect to vibration response
- Using of HSS floor system does not always lead to higher vibration response
- Mitigation
  - Increase mass, stiffness or damping (i.e. deeper slabs)
  - Alter layout (i.e. beam arrangement) during design phase
  - Tie beams