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VERIFYING THE POTENTIAL OF FIBRE OPTIC SENSORS TO MONITOR STRAINS AND CRACKS IN FIBRE COMPOSITES

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Paper content

- The potential of embedded fibre optic sensors to monitor strains and delamination cracks, especially in thick fibre-reinforced composites has been investigated by moulding beams up to 115 mm in thickness and 3 m in length.
- In selected beams, optical fibre sensors with high tensile strength have been moulded within 10 mm of the tensile surface.
- The immediate observation was that the moulding, curing or post curing did not affect the condition of the optical fibres nor did the fibres affect the strength of the beams.

Paper content (continued)

- On loading these beams there was an excellent correlation between the output of the mechanical gauges bonded to the tensile face and the embedded fibre optic sensors, taking into account the difference in strains between the two locations.
- These observations will enable the monitoring in service use of thick GRP beams for which no other non-destructive test method is suitable.

Introduction

- For fibre composites to be used with confidence in primary load bearing structures, methods of monitoring strains in service use are essential.
- For glass reinforced plastic (GRP) beams with thicknesses greater than say 40 mm, no suitable non destructive test technique is available which limits the range of applications for these materials.
- The partners in the Eurobogie project (E!1841) have investigated the potential of fibre optic (FO) strain sensors with high tensile strength, i.e. Draw Tower fibre Bragg Gratings (DTG®s), to monitor strains for components moulded by different methods.

Introduction

- Part of this investigation has been to develop a methodology of inserting the sensors and moulding the beams so that neither the fibre's properties are affected by the moulding process nor the beam's mechanical properties by the insertion of multiple optical fibres and DTG®s.
- The other part was to correlate prediction and measurement making use of mechanical strain gauges. The fibre sensors were manufactured by FOS&S (now FBGS) and are 'draw tower' type gratings, which are fibre Bragg gratings (FBG's) with high tensile strength (~5GPa).

Introduction

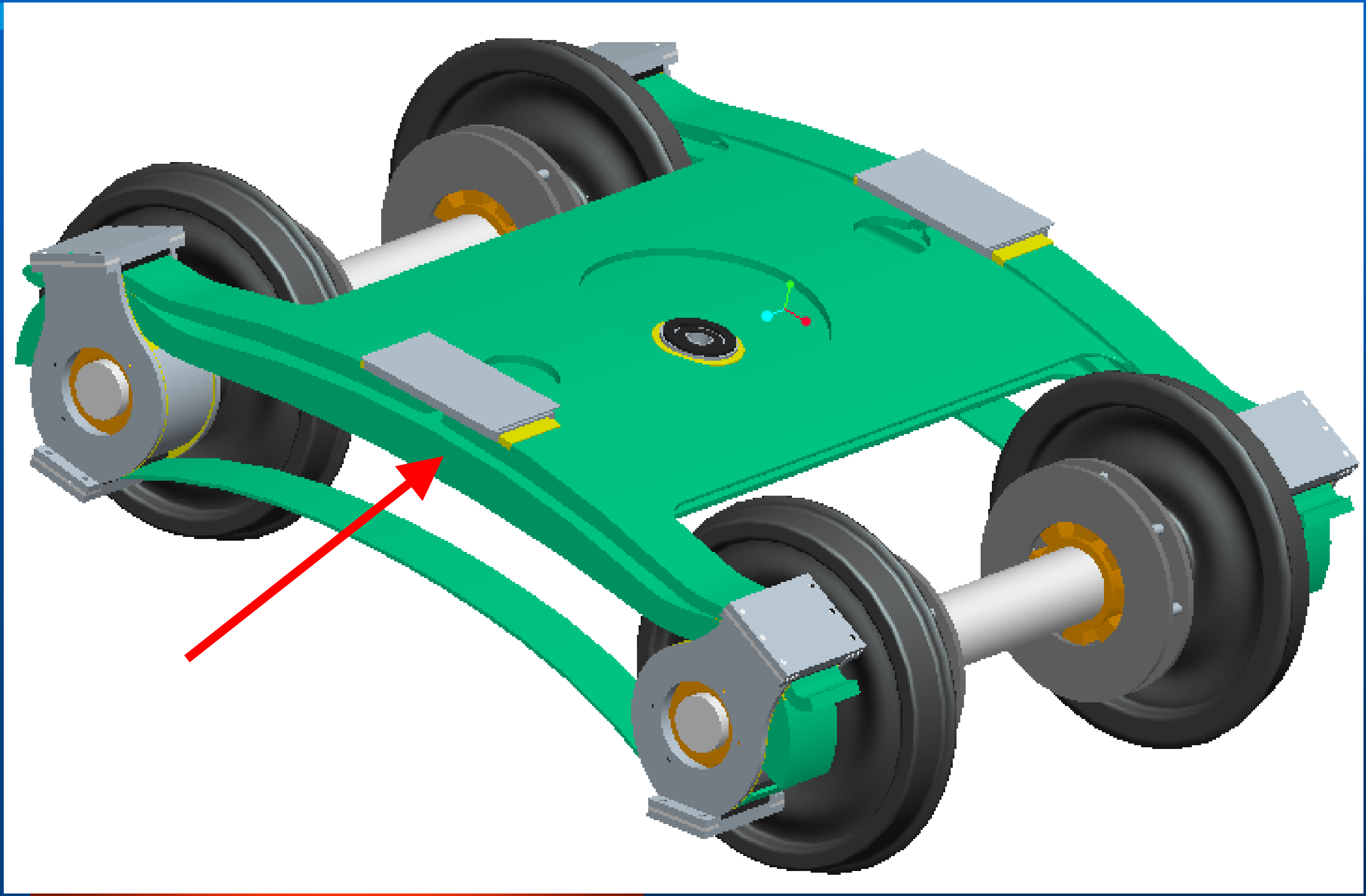
- **Draw Tower Gratings** – DTG®'s - are written during the drawing process of the fibre. This automated process results in very high quality, cost effective Fibre Bragg Gratings making them ideally suited to the following applications:

→ temperature sensing

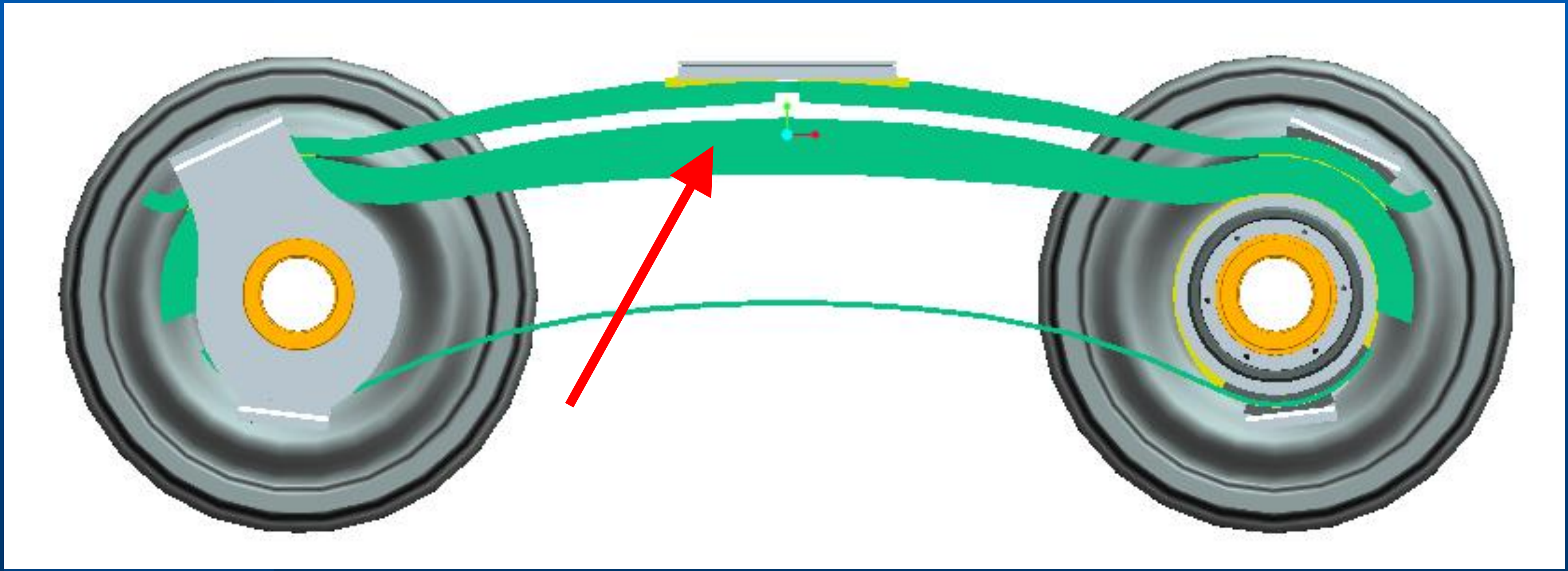
→ strain sensing

→ fibre tagging

Introduction



Introduction



Manufacture

Manufacture

- A series of test plates was manufactured using a leaky mould and laying up each glass fabric layer by hand.
- Finally two beams were moulded 1000 mm long, 100 mm wide and 80 mm thick using 67 layers of a unidirectional glass fabric (OCV Unimat 1136/100) and a high temperature polyester resin (Scott Bader Crystic 199) with Trigonox 44B (Akzo) as catalyst.
- Three optical fibres were embedded and tensioned using a thermoplastic polyester powder on the 8th layer above the tensile face.
- The beams were tested in 3-point bending, one beam without a flaw and the second with a piece of polythene sheet 60mm long in the mid centre of the neutral axis to simulate a delamination crack.

Manufacture

Computations

Computations

- Calculations were carried out at the University of Reading, School of Construction Management and Engineering, using FEM method
- Finite Elements Analysis of the intact and delaminated beams was carried out using Strand 7 FEA Software
- This was done in order to determine the "best position" for the optical fibre sensors and the changes in bending strains in the longitudinal direction "seen" by the optical fibre sensors as a function of delamination length. All simulations have been carried out for a vertical load of 200 kN.

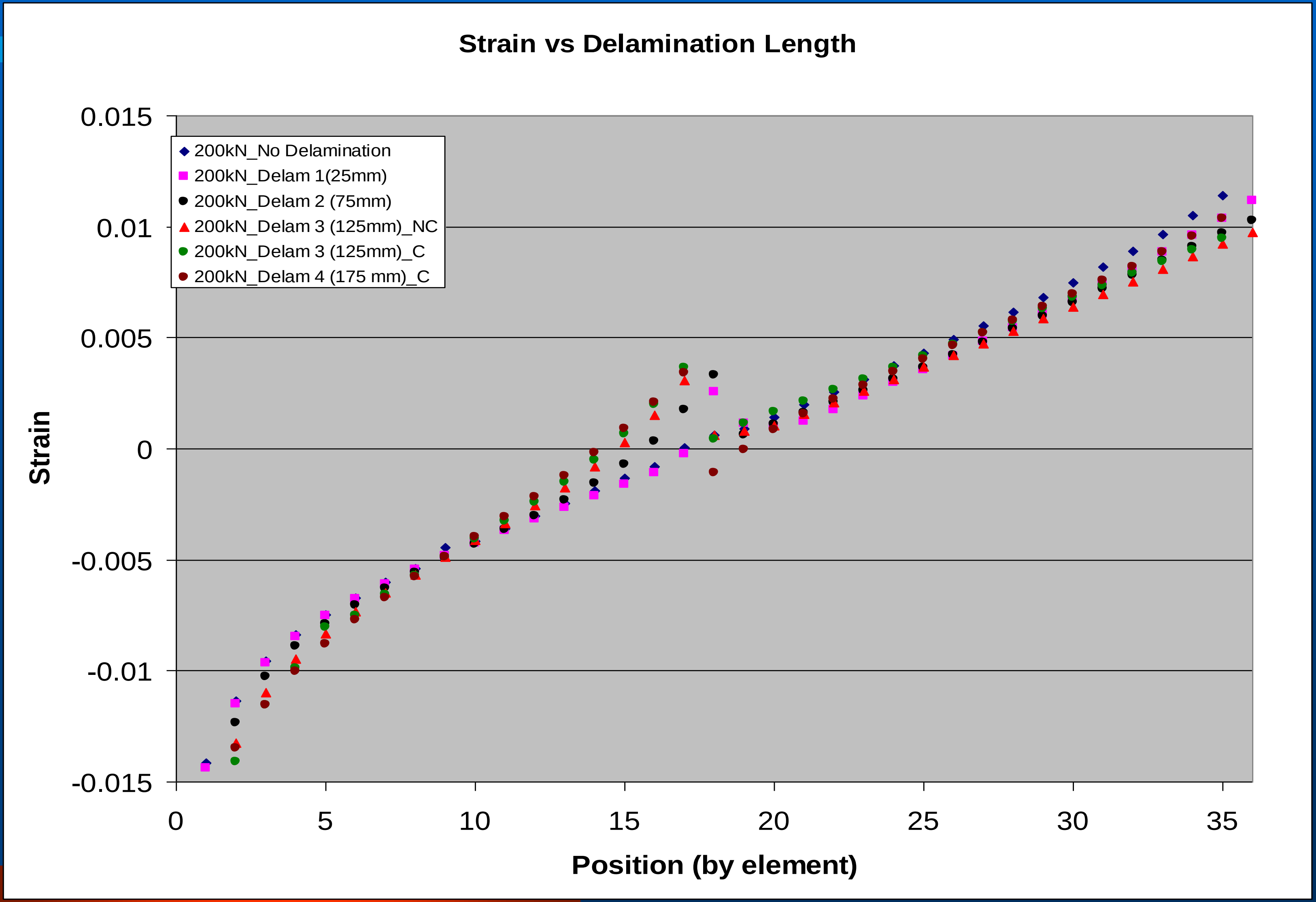
Computations

- **FEA of loaded intact beam** – at 200 kN the predicted central deflection of the beam is 20.97 mm, which is close to the theoretical displacement of 18.8 mm. The difference may be due to additional deformation under the loading points which is not considered in the theory. At this load the maximum bending strain (tensile or compressive) is of the order of 1.25% -1.5%.
- In reality, the bogie maximum allowable strain is limited to 1%. The maximum interlaminar shear stress obtained from the FEA model is about 19 MPa.

Computations

- **FEA of beam with delamination crack** – shows the distribution of bending strains in the beam for delamination lengths at the centre of the beam at mid-thickness of 25, 75, 125 and 175 mm.
- In all cases the delamination is modelled with a separation between the elements of 0.9 mm in the delaminated region. It is clear from Figure 2 that when the delamination "appears" the bending strain across the thickness of the beam changes showing a jump at the delamination discontinuity. The jump increases as a function of delamination length.
- Modelling the delamination with or without contact elements between the delaminated surfaces has a negligible effect.

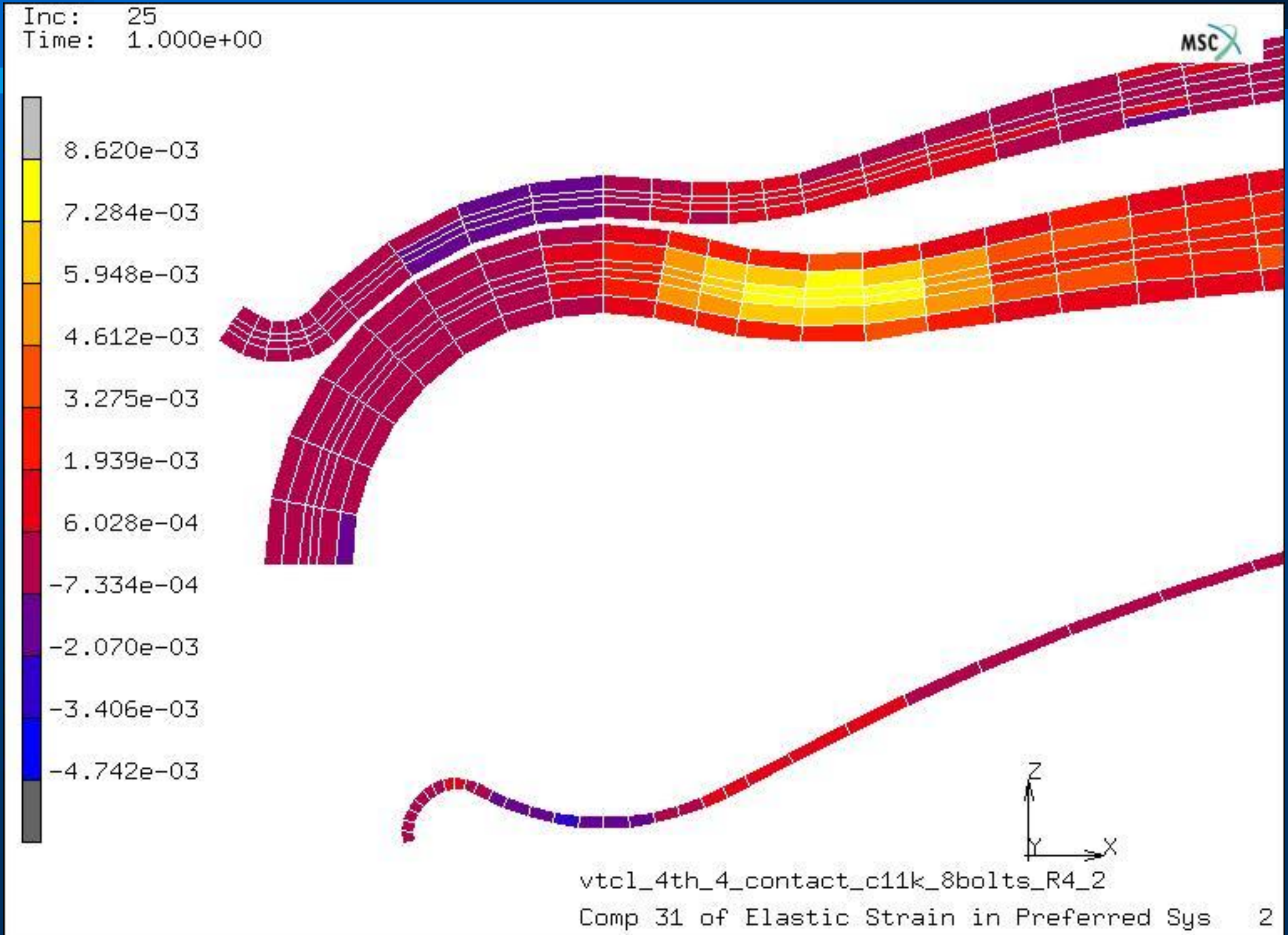
Computations



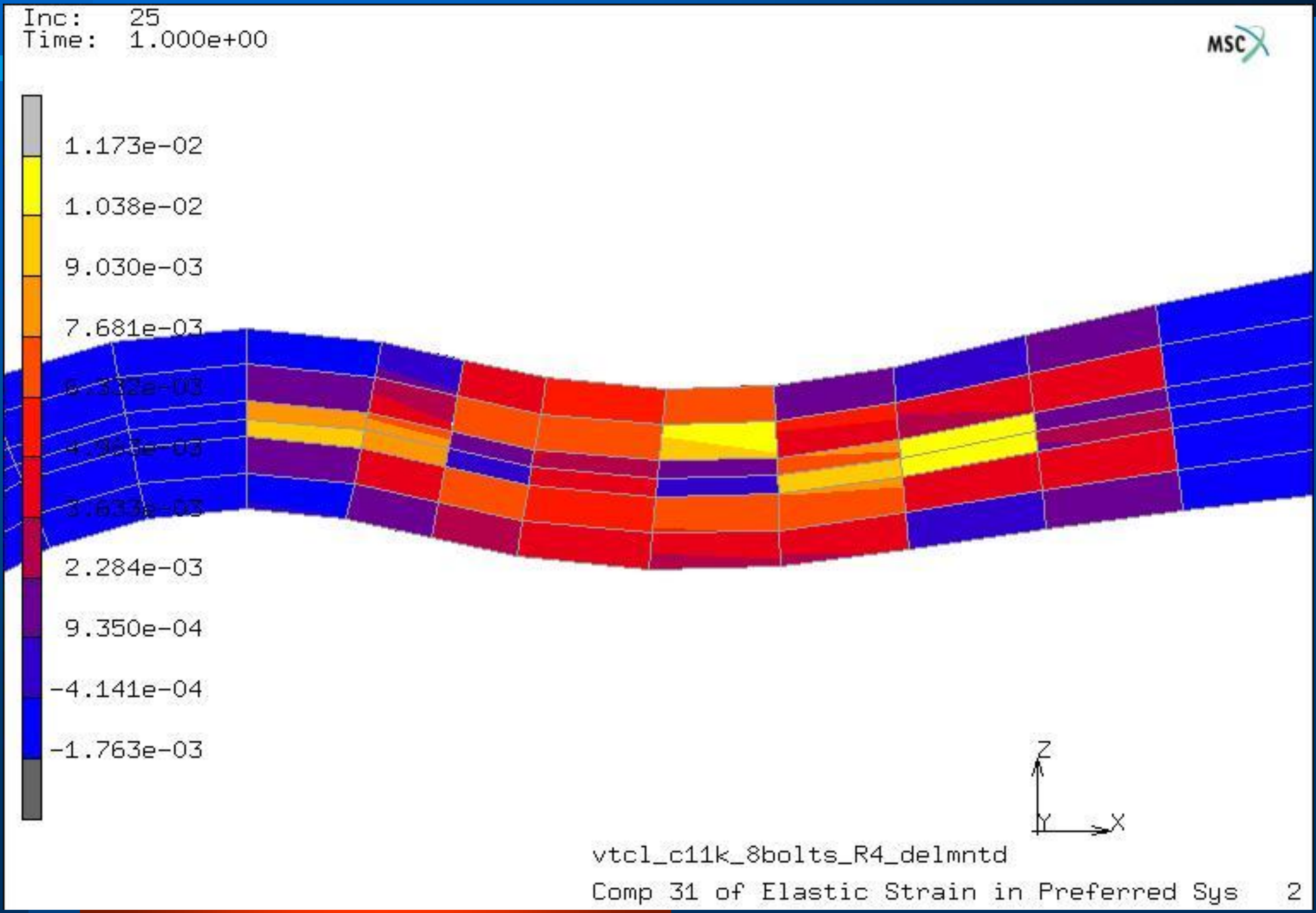
Computations - modelling the side arms of the bogie frame

- MARC/MSC software was used to carry out a similar analysis on the side arms of the lower GRP bogie frame to determine the best location of the optical fibre sensors and to estimate the strain change introduced by a delamination at the centre of the beam.
- Figures 5a and 5b show location of the maximum interlaminar shear strain without and with delamination near the wheel set.

Computations - modelling the side arms of the bogie frame



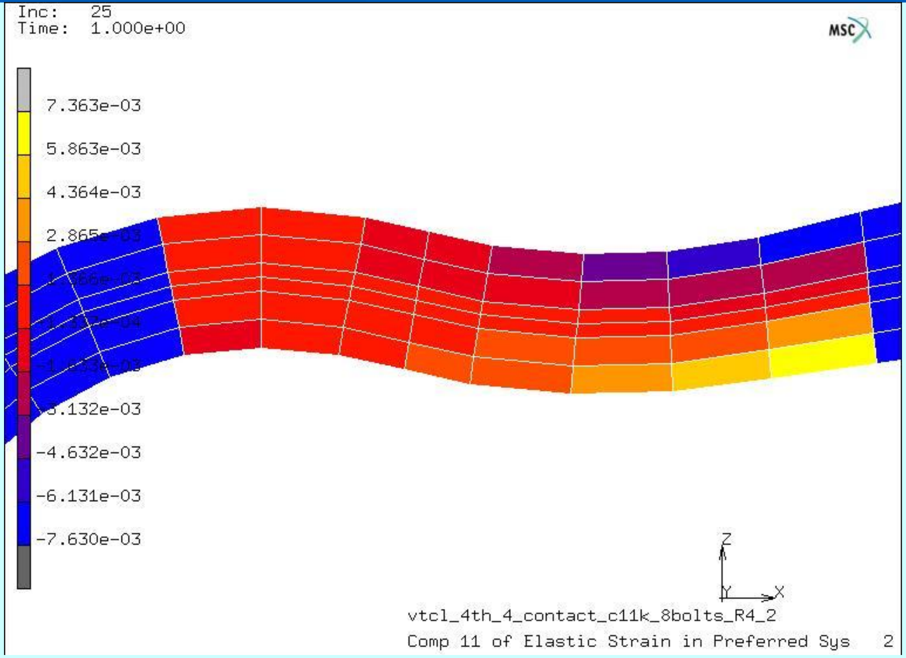
Computations - modelling the side arms of the bogie frame



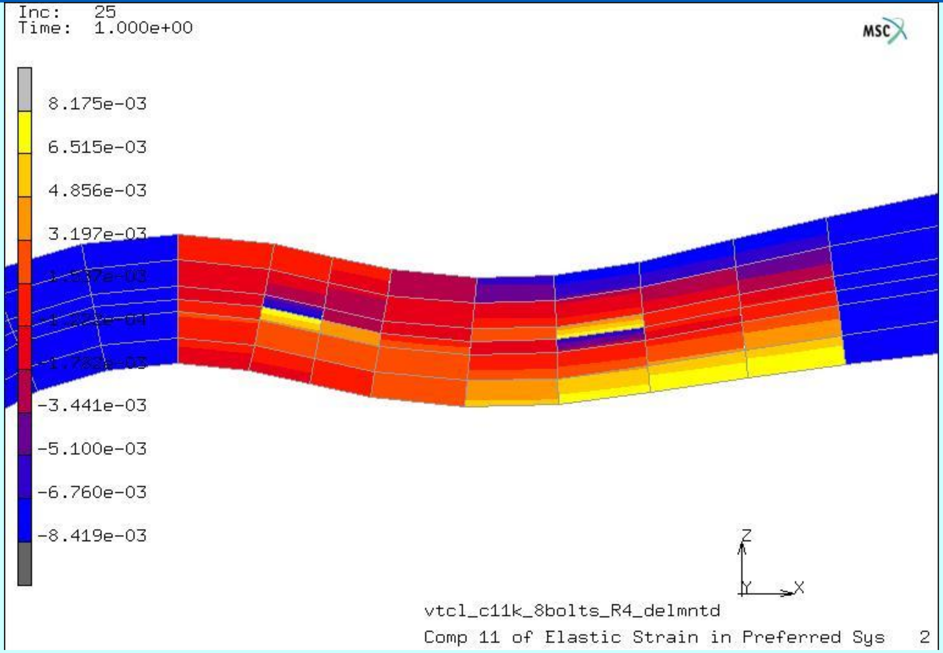
Computations - modelling the side arms of the bogie frame

- Figures 6a and 6b show the distribution of normal strains across the thickness of the bogie side-frame beam without and with delamination, respectively.

Computations - modelling the side arms of the bogie frame



(a)

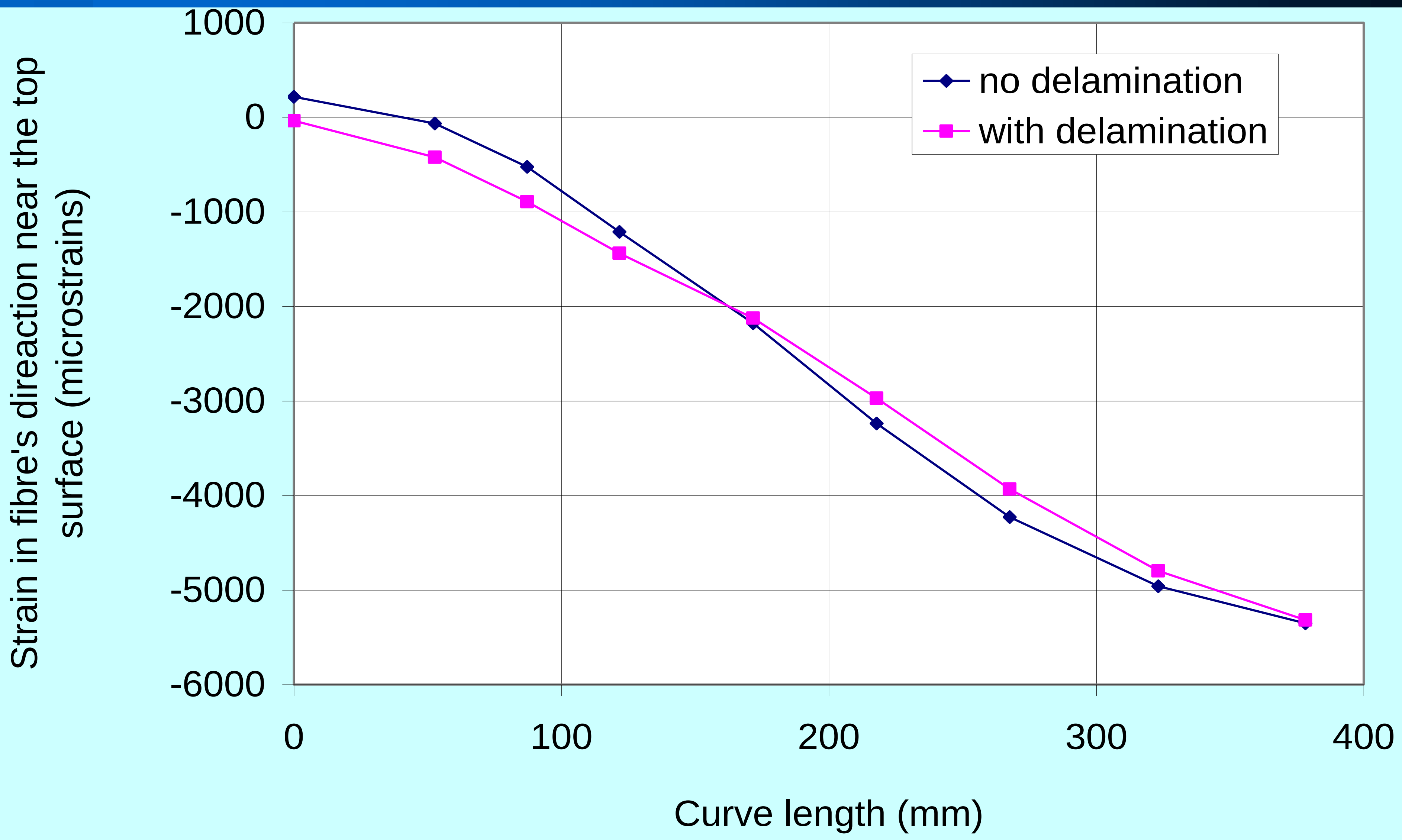


(b)

Computations - modelling the side arms of the bogie frame

- What is important is the change of normal strain due to delamination at the planned location of the optical fibres 10 mm from the tensile surface.
- Figure 7 shows the change in normal strains before and after delamination near the top surface of the bogie frame beam.
- The change in normal strain is of the order of 300-500 microstrains, sufficient for the optical fibres to be able to register

Computations - modelling the side arms of the bogie frame



Moulding and testing the side arm of the lower bogie frame

Static tests

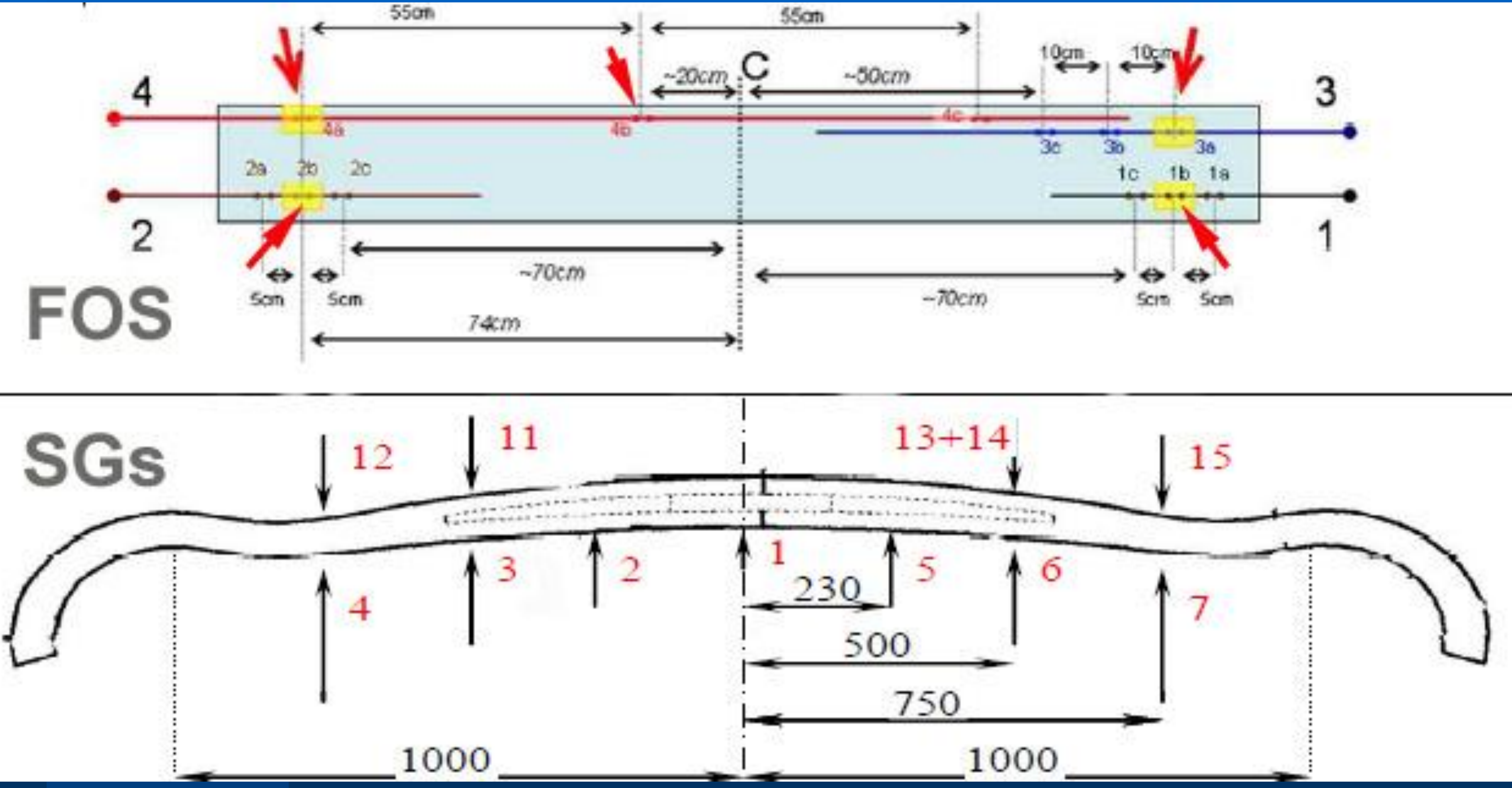
- The side arms of the lower GRP bogie frame are 3.0 m long, 192 mm wide with a thickness tapering from 115 mm in the centre to 75 mm adjacent to the wheel sets.
- Some 104 layers of uni-directional glass fabric were successively laid up laid up inside a dedicated 4 part mould.

Static tests

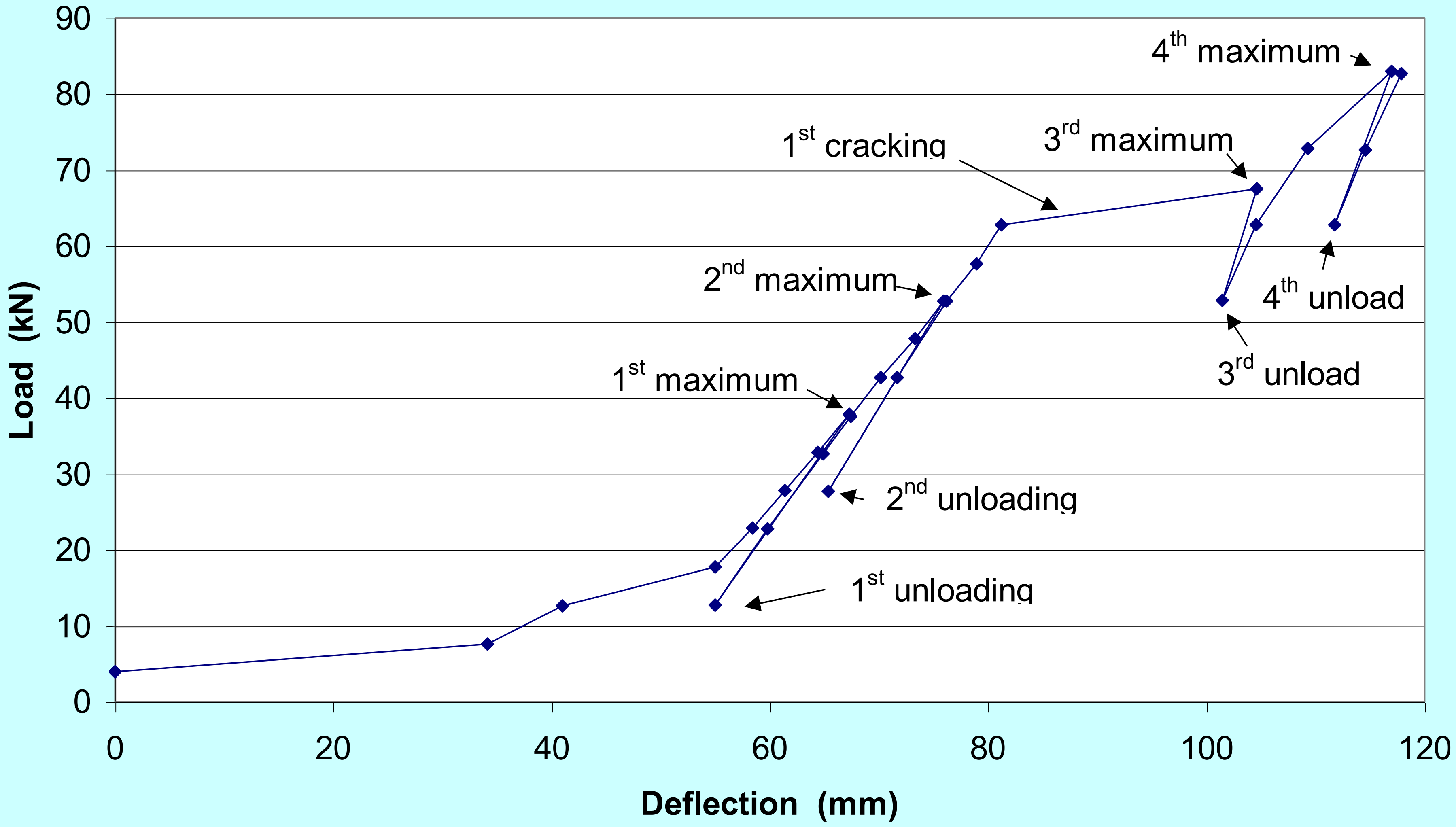
- As with the hand lay up beams, 4 optical fibres were tensioned on the 10th fabric layer from the **tensile surface** and then the remaining 94 glass layers added.
- The out coming FO cables were then wrapped in a protective polystyrene box, the mould closed and catalysed resin injected and cured.
- The 84 kg beam was then demoulded and post cured up to 120 C. After post curing, the FO sensors were checked to ensure that the moulding and subsequent curing had not induced change in the condition of the sensors. No change was detected.

Static tests

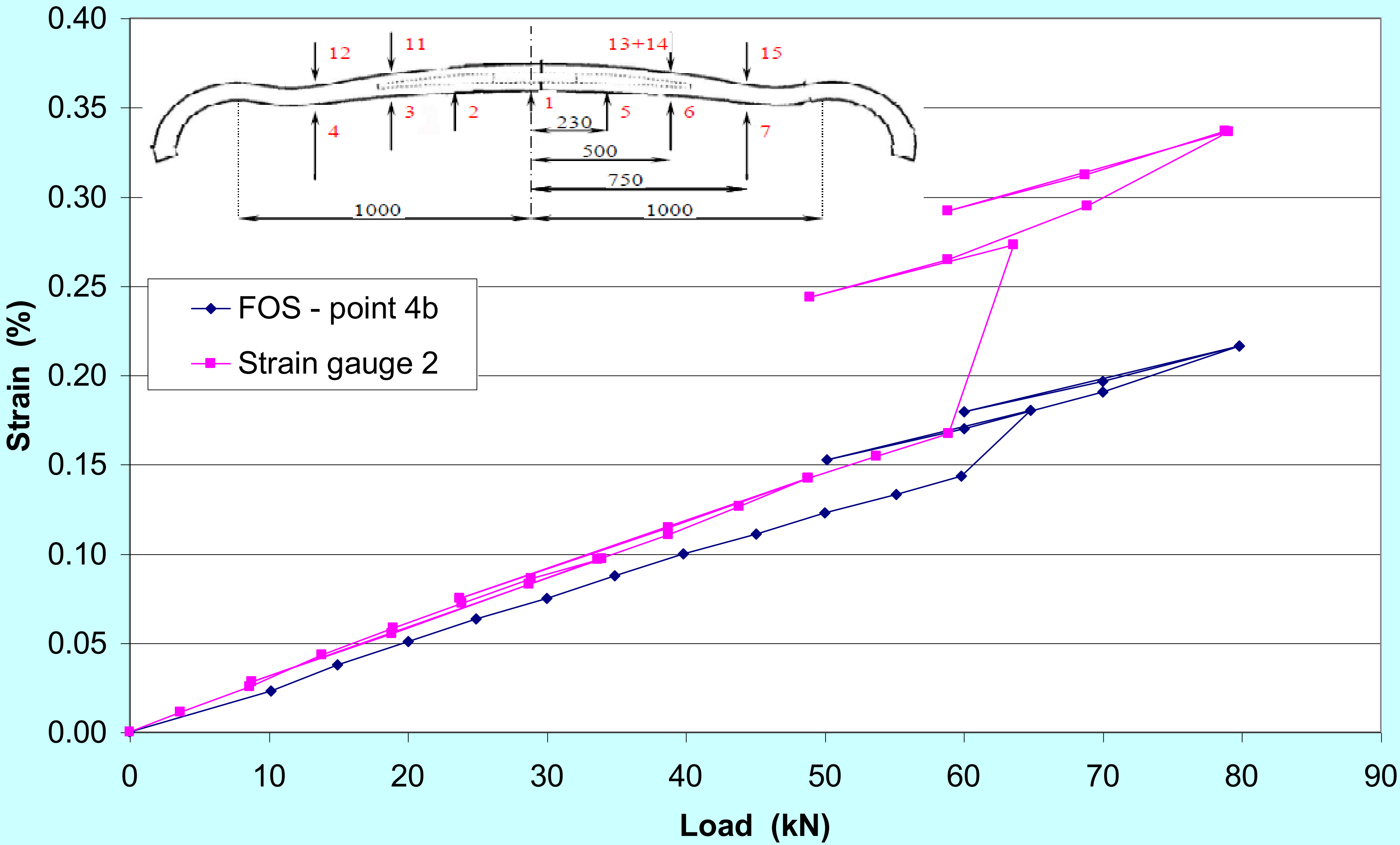
Static tests



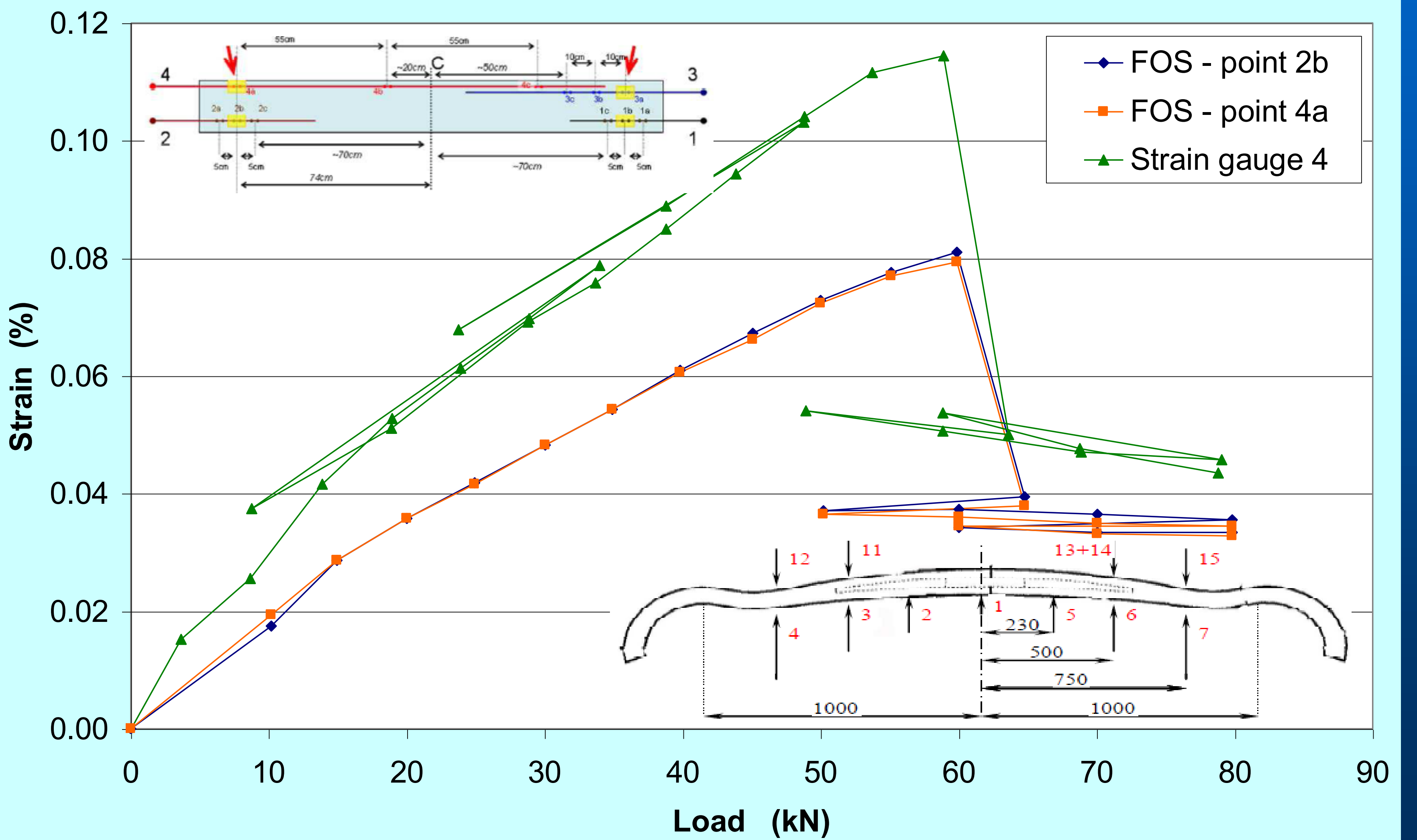
Static tests



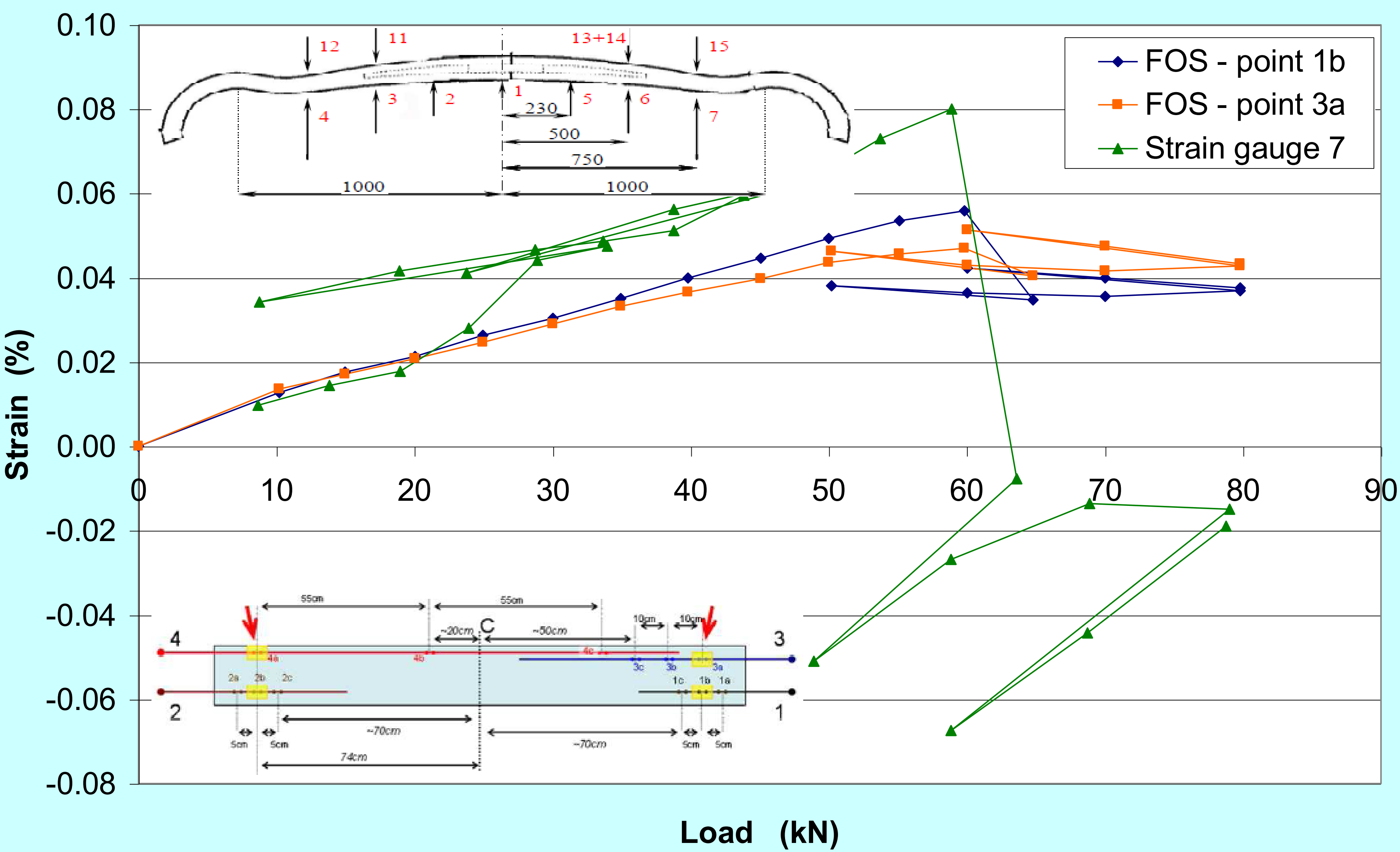
Static tests



Static tests



Static tests



Conclusions

- The presented results demonstrate the potential of fibre optic sensors with high tensile strength to monitor both strains and the growth of delamination cracks in primary load bearing components manufactured from glass reinforced plastics.
- This will enable such materials to be introduced into the railway industry which has lagged behind all the other transport sectors in securing the benefits of reducing mass.
- This potential can only be realized by further demonstrations of the type that are being undertaken within the Eurobogie project and an industry and society willing to invest in introducing new suitable NDT technology.

Acknowledgement

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Thank you for your kind attention