SECTION 7. Mechanics and machine construction.

QR – Issue   QR – Article

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ISOSURFACES OF MECHANICAL STRESSES IN CANTILEVER AND DOUBLY SUPPORTED STEEL I-BEAMS SUBJECT TO BENDING

Abstract: *Comparison of stress condition of cantilever and doubly supported steel I-beams after removing of external forces and moment was performed in the article. Stresses tensors are presented by color contours on a volume of deformed models of the I-beams. The most dangerous sections of the I-beams subject to bending at action of various external active loads were determined.*
Key words: *an I-beam, bending, stress, tensor, deformation, force, moment, a model, a component.*
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Introduction

I-beams are subjected to bending at action of external active forces and moments [1 – 9]. A small value of load on the I-beam causes elastic deformations in material. Plastic deformation occurs with the value increasing of applied load. Plastic deformation of the steel I-beam leads to a shape changing of structural elements (flanges and a web), cracks development and subsequent partial destruction of material. Maximum stress occurs in a material volume at maximum deflection of the I-beam and in a field of supports at different loading schemes. Stress in material can be presented by normal and tangential stresses that occur along three coordinate axes of the Cartesian coordinate system. Thus, complete volumetric presentation of stress condition of material at the calculation of stresses tensors is given. This will reveal the most loaded outer and inner layers of the I-beams material by means of constructed isosurfaces.

Materials and methods

Materials and methods of research of the computer experiments are presented in the work [10]. The research objects were models of the cantilever and doubly supported I-beams, on which external active forces (concentrated and distributed) and moments were applied.

Results and discussion

The models of four cantilever and five doubly supported I-beams were subjected to bending. The isosurfaces of mechanical stresses of the steel I-beams after removing of concentrated moment (A and E), concentrated force (B, C, F and H) and distributed force (D, G and I) are presented in the Fig. 1 – 36. All models of the cantilever I-beams were rigidly fixed to a wall on the left side. All models of the doubly supported I-beams were mounted on the hinged immovable support (left) and the hinged movable support (right).

Stress visualization of the steel I-beam at bending is presented by Gauss-points. Directions of the first, second and third principal stresses of the deformed I-beams material are determined by the x, y and z coordinate axes in accordance with the coordinate system located in the lower left corner of each figure. Principal stresses directions of material of the cantilever I-beams were determined: the volumes of the bottom flange, the web on the right side and on the side of rigid restraint on all axes at action of concentrated moment clockwise; the volumes of the web and the beam flanges on the y and z axes at action of concentrated force on a loose end of the beam; complex stress condition, a right part of the beam has not subjected to stress (the y-axis) at action of concentrated force on $^1/_2$ of the beam length; the volumes of the web and the flange below the neutral axis, the top flange at action of distributed force along the entire length of the beam. Principal stresses directions of material of the doubly supported I-beams were determined: the volumes of the top and bottom flanges, the part of the web at action of concentrated moment clockwise; complex stress condition at action of concentrated and distributed forces on $^1/_2$ of the beam length, distributed force along the entire length of the beam and concentrated force on $^1/_3$ of the beam length.

The first Piola-Kirchhoff stress tensor (asymmetric) is a material measure of stress in the deformed point of a solid. It is defined as the ratio of stress vector to an unit normal. Tensor is presented by the xX – zZ components. The xY and yX, xZ and zX, yZ and zY components are the same by the value and distribution of the isosurfaces of the I-beam material stresses. The calculated stress value in the zZ component is maximum of all nine components.

The deviatoric second Piola-Kirchhoff stress tensor (symmetric) is presented as shear stress tensor. Shear stress at bending of the cantilever and doubly supported I-beams is observed in the volumes of the flanges and the web in direction of the X, Y, Z coordinate axes and the YZ coordinate plane. Stress in direction of the XY and XZ coordinate planes occurs only in the flanges of the I-beams.

Stress tensor is second-rank tensor consisting of nine parameters (written as a matrix) presenting mechanical stresses at the arbitrary point of the loaded solid. Calculated stress tensor of the I-beams material consists of six components. The values and distribution of stresses in the x component are identical to stresses in the xX component of the first Piola-Kirchhoff stress tensor. The values and distribution of stresses in the xy component are identical to stresses in the xY and yX components of the first Piola-Kirchhoff stress tensor and in the XY component of the deviatoric second Piola-Kirchhoff stress tensor. The values and distribution of stresses in the xz component are identical to stresses in the xZ and zX components of the first Piola-Kirchhoff stress tensor and in the XZ component of the deviatoric second Piola-Kirchhoff stress tensor. The values and distribution of stresses in the y component are identical to stresses in the yY component of the first Piola-Kirchhoff stress tensor. The values and distribution of stresses in the yz component are identical to stresses in the yZ and zY components of the first Piola-Kirchhoff stress tensor and in the YZ component of the deviatoric second Piola-Kirchhoff stress tensor. The values and distribution of stresses in the z component are identical to stresses in the zZ component of the first Piola-Kirchhoff stress tensor.
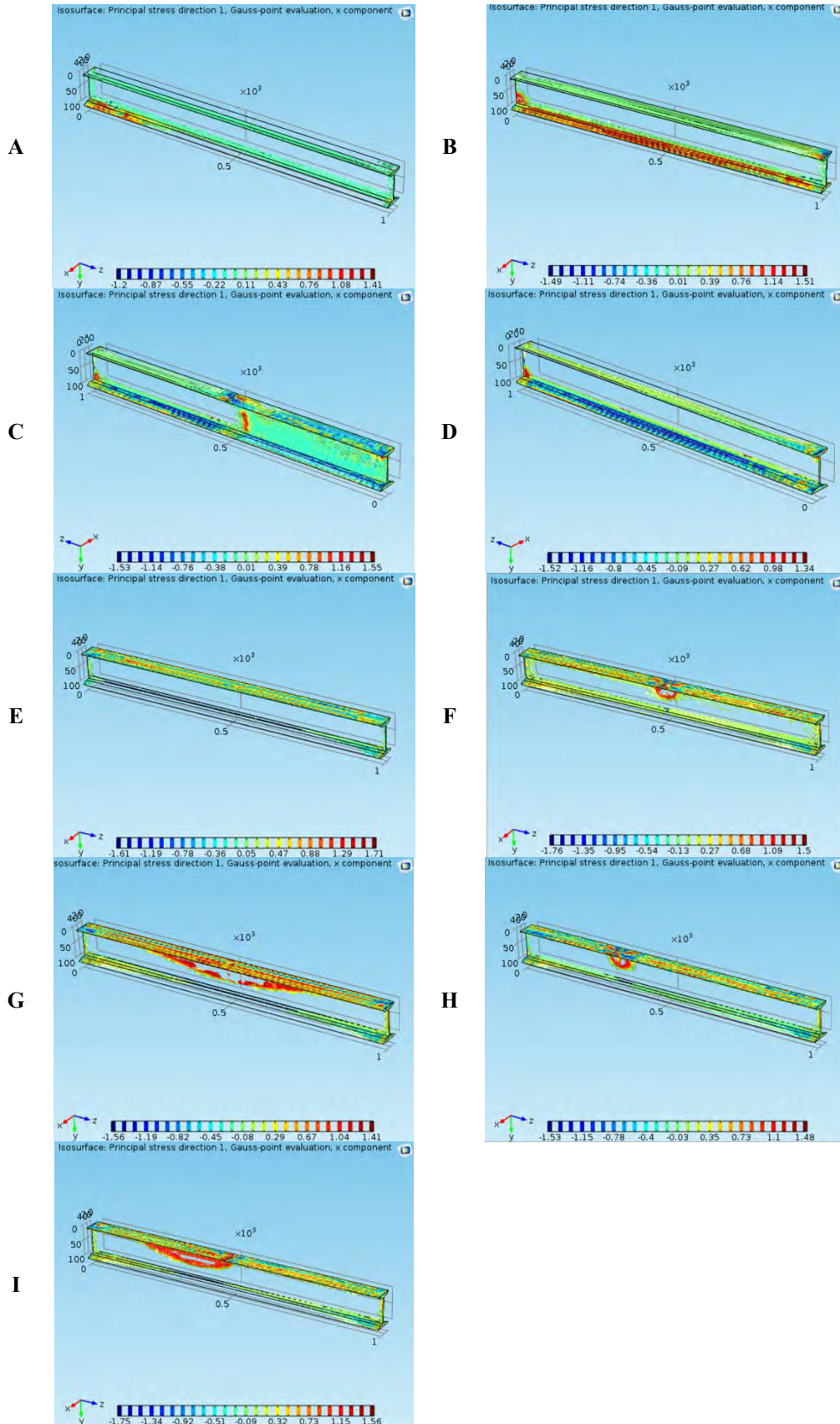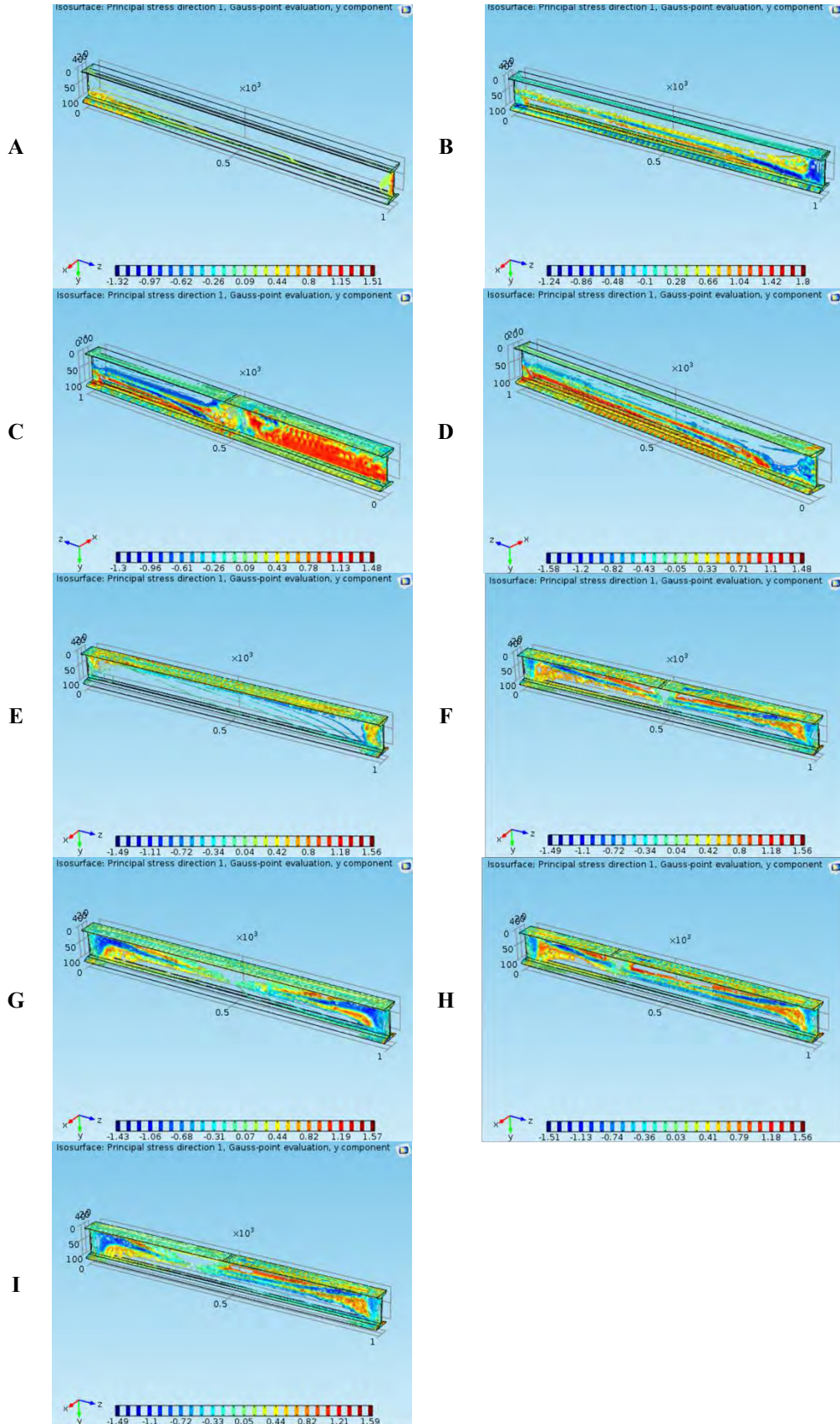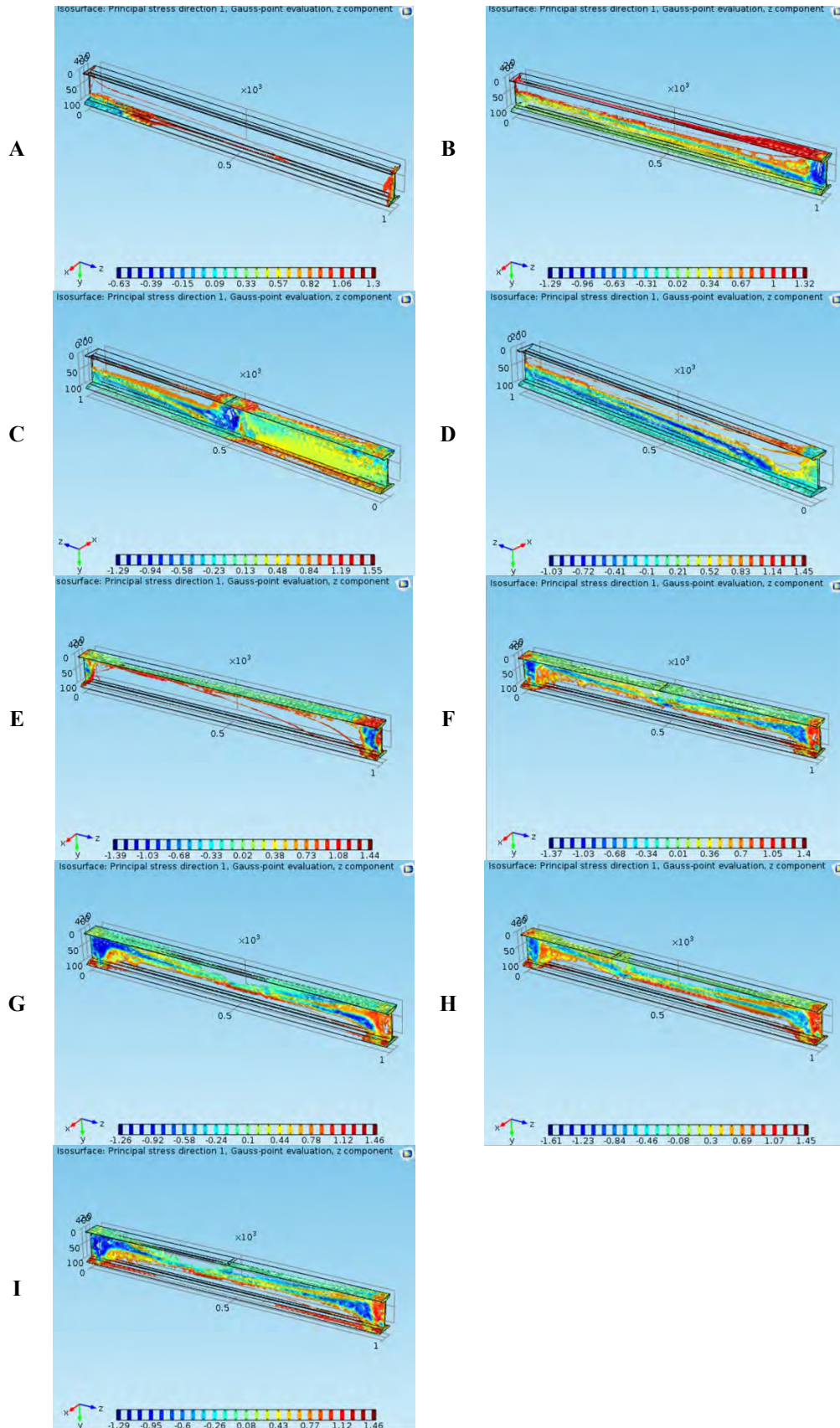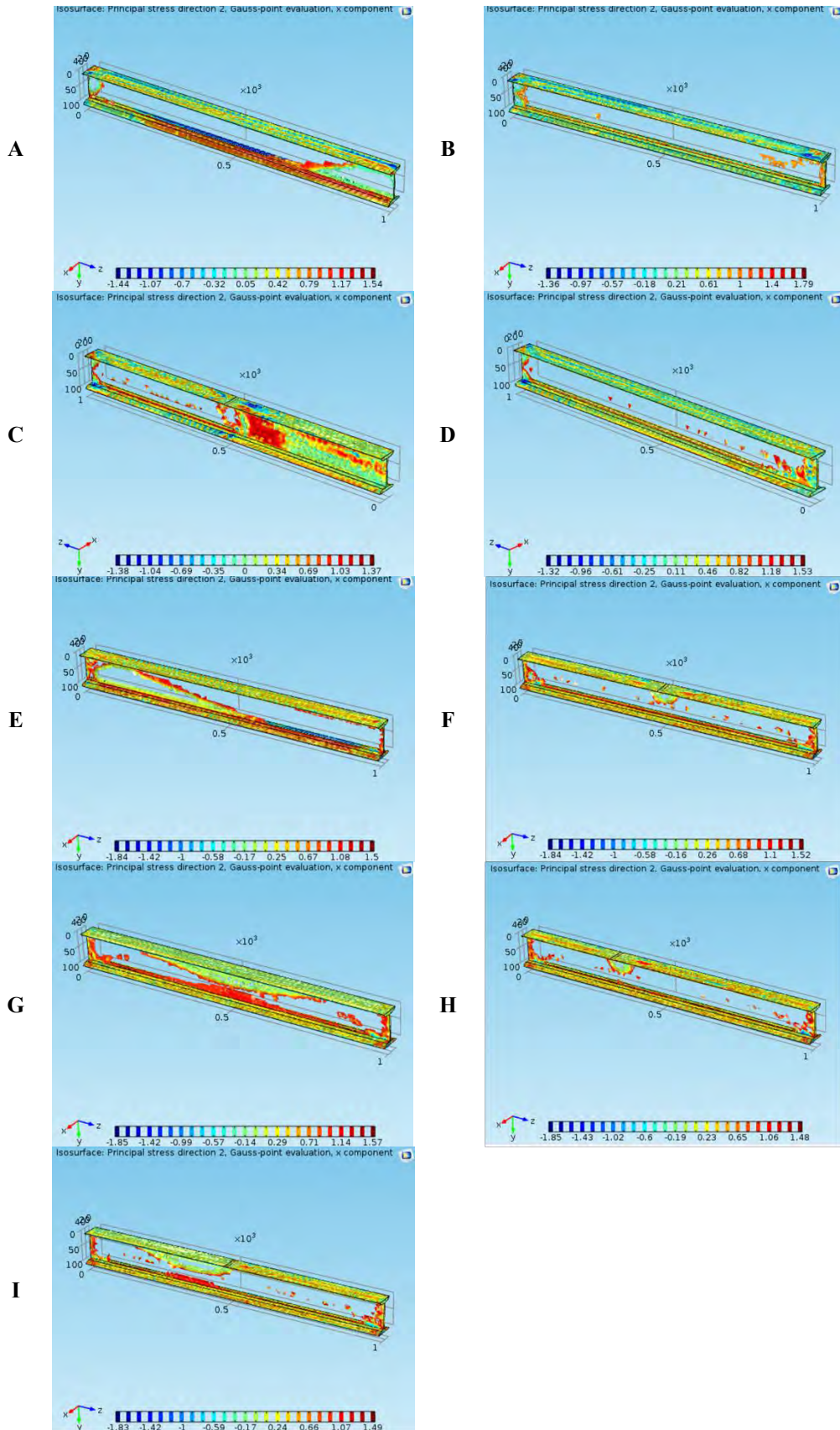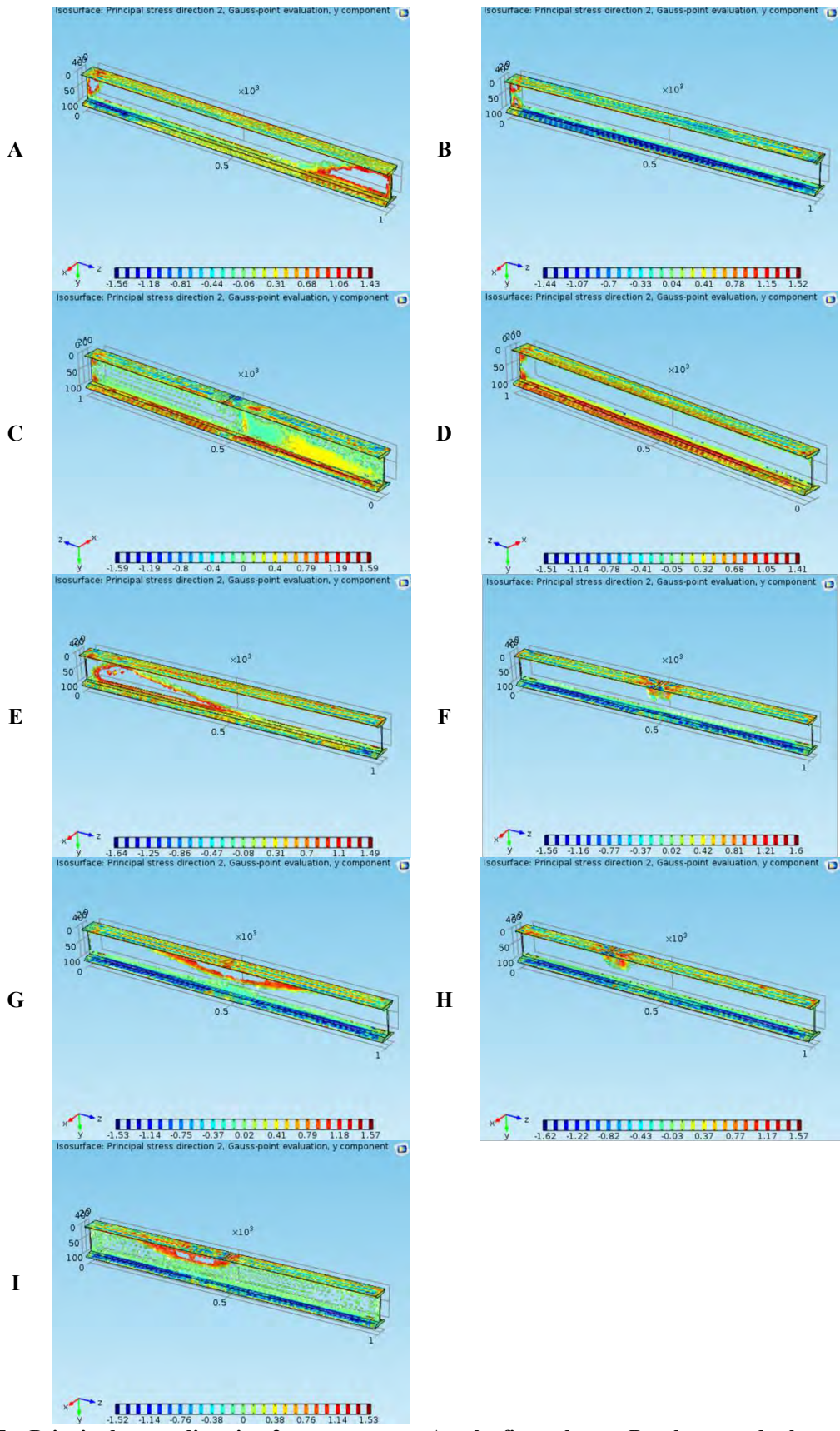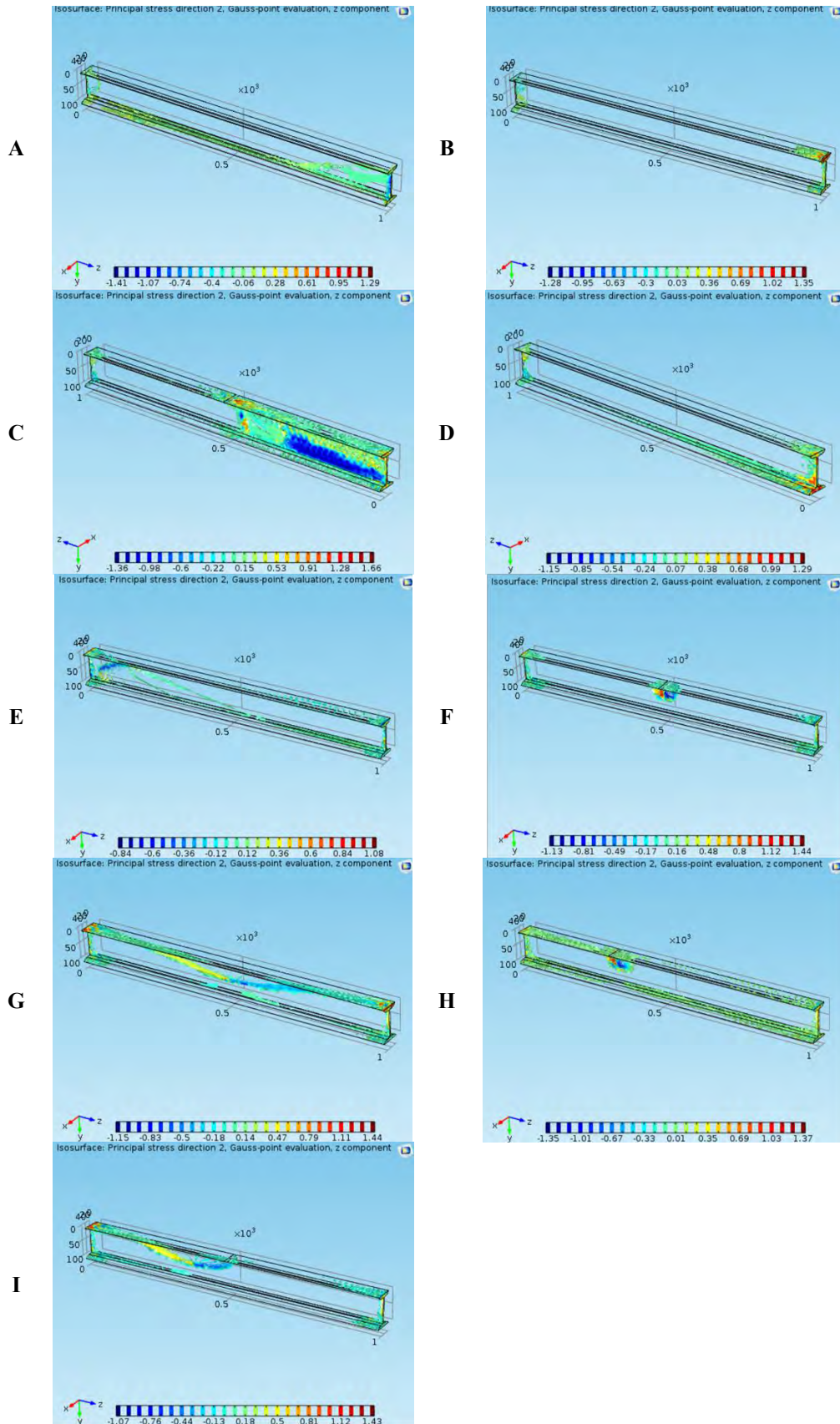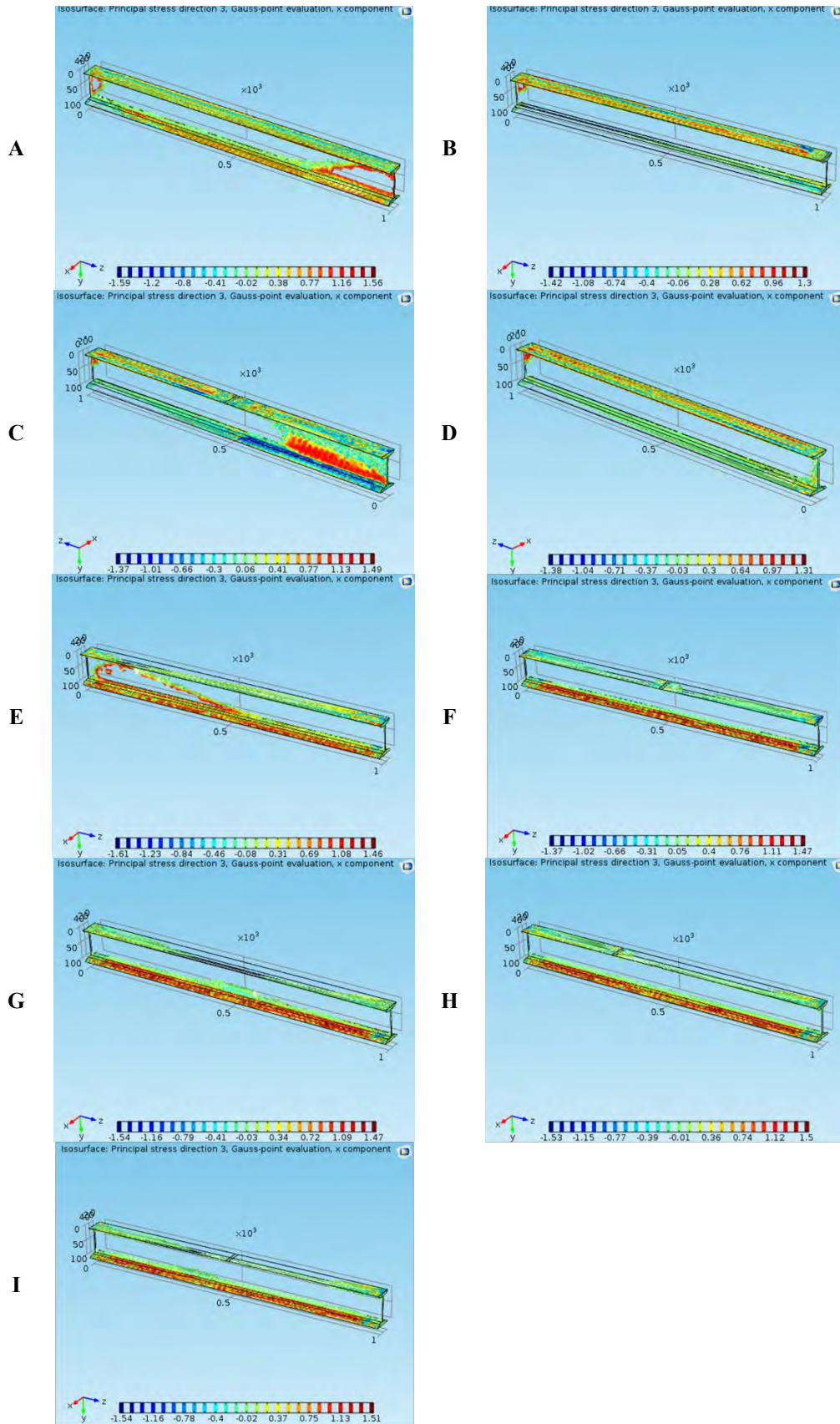
Figure 1 – Principal stress direction 1, x component: A – the first scheme; B – the second scheme; C – the third scheme; D – the fourth scheme; E – the fifth scheme; F – the sixth scheme; G – the seventh scheme; H – the eighth scheme; I – the ninth scheme.

Figure 2 – Principal stress direction 1, y component: A – the first scheme; B – the second scheme; C – the third scheme; D – the fourth scheme; E – the fifth scheme; F – the sixth scheme; G – the seventh scheme; H – the eighth scheme; I – the ninth scheme.
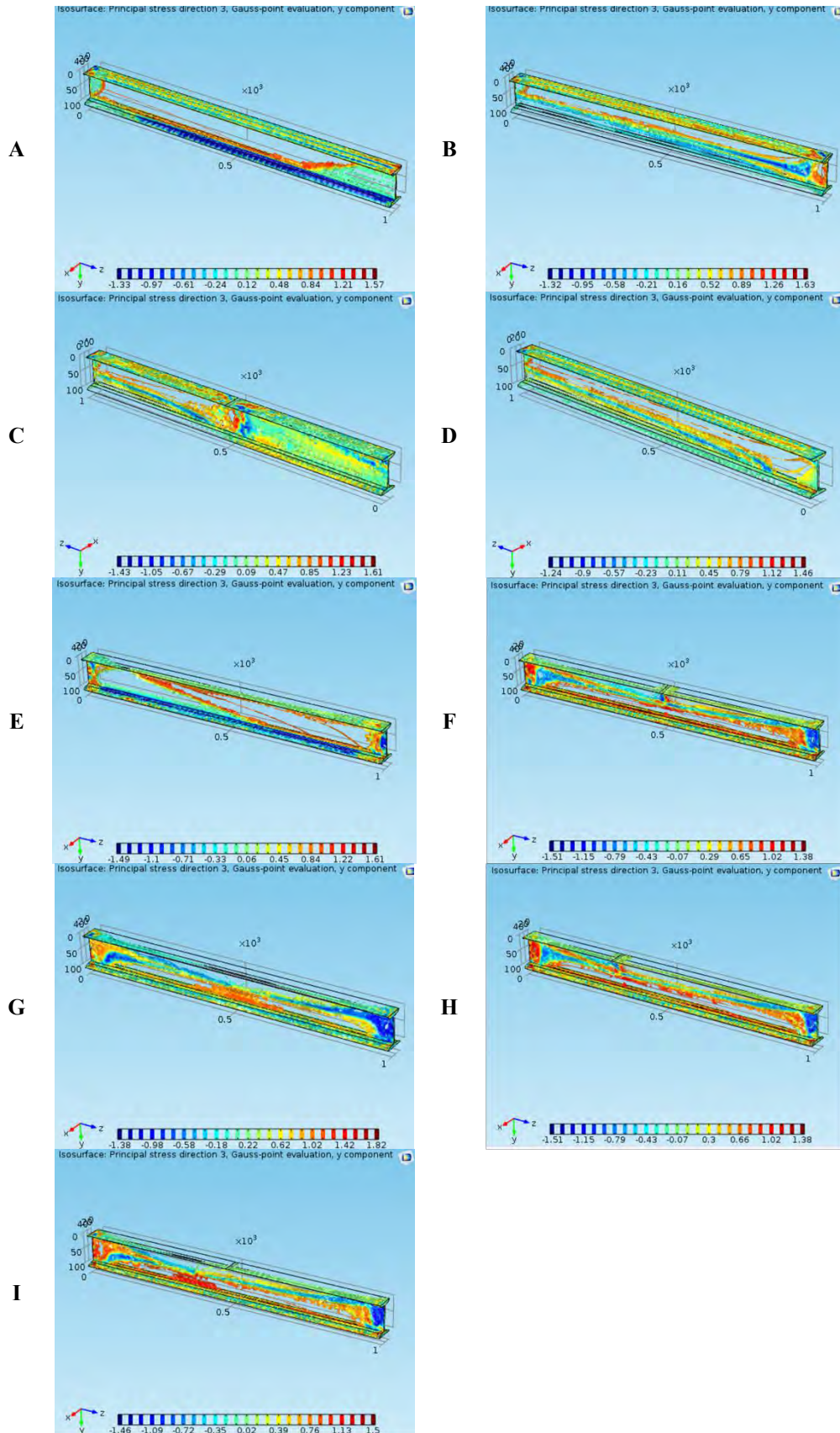
Figure 3 – Principal stress direction 1, z component: A – the first scheme; B – the second scheme; C – the third scheme; D – the fourth scheme; E – the fifth scheme; F – the sixth scheme; G – the seventh scheme; H – the eighth scheme; I – the ninth scheme.
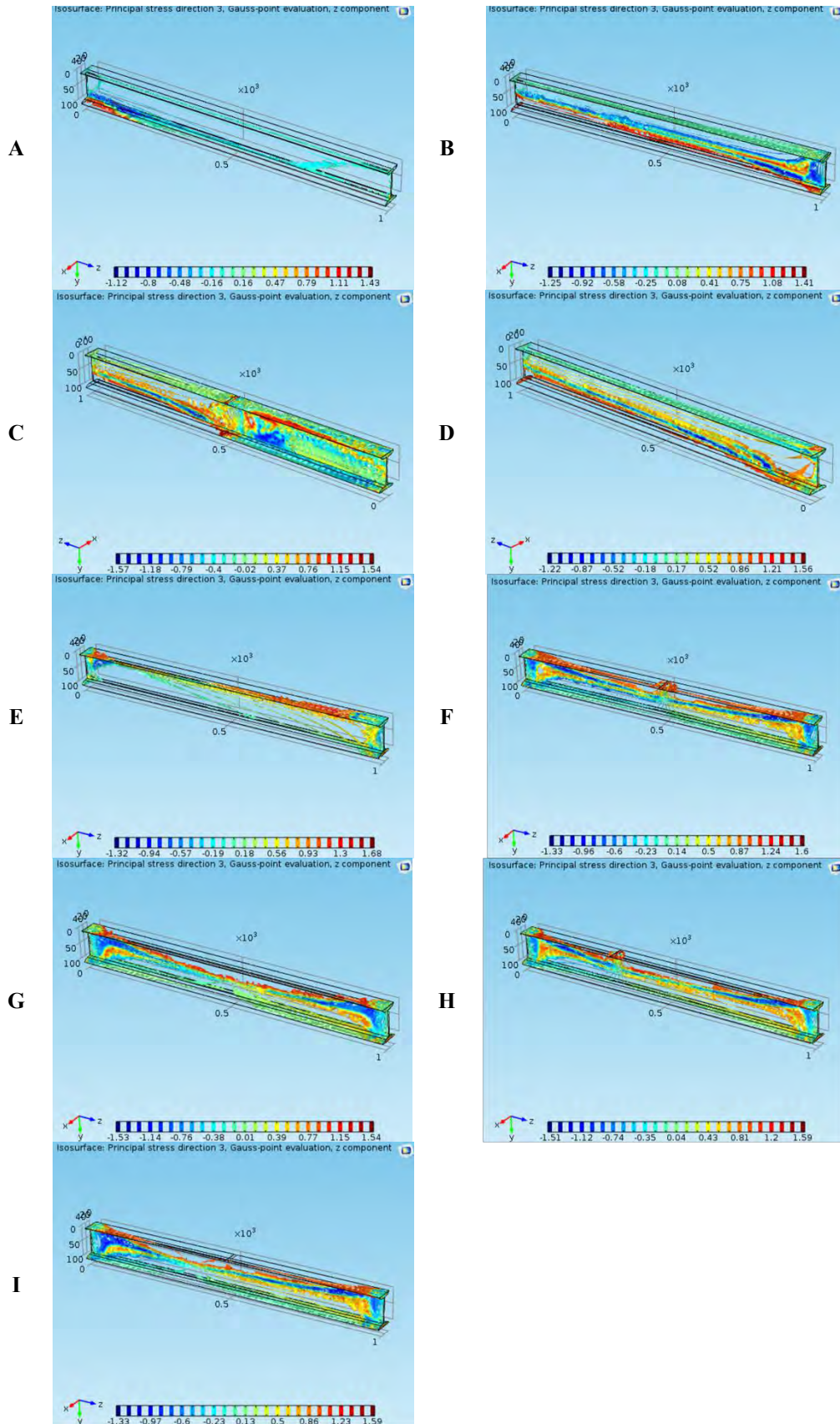
Figure 4 – Principal stress direction 2, x component: A – the first scheme; B – the second scheme; C – the third scheme; D – the fourth scheme; E – the fifth scheme; F – the sixth scheme; G – the seventh scheme; H – the eighth scheme; I – the ninth scheme.

Figure 5 – Principal stress direction 2, y component: A – the first scheme; B – the second scheme; C – the third scheme; D – the fourth scheme; E – the fifth scheme; F – the sixth scheme; G – the seventh scheme; H – the eighth scheme; I – the ninth scheme.
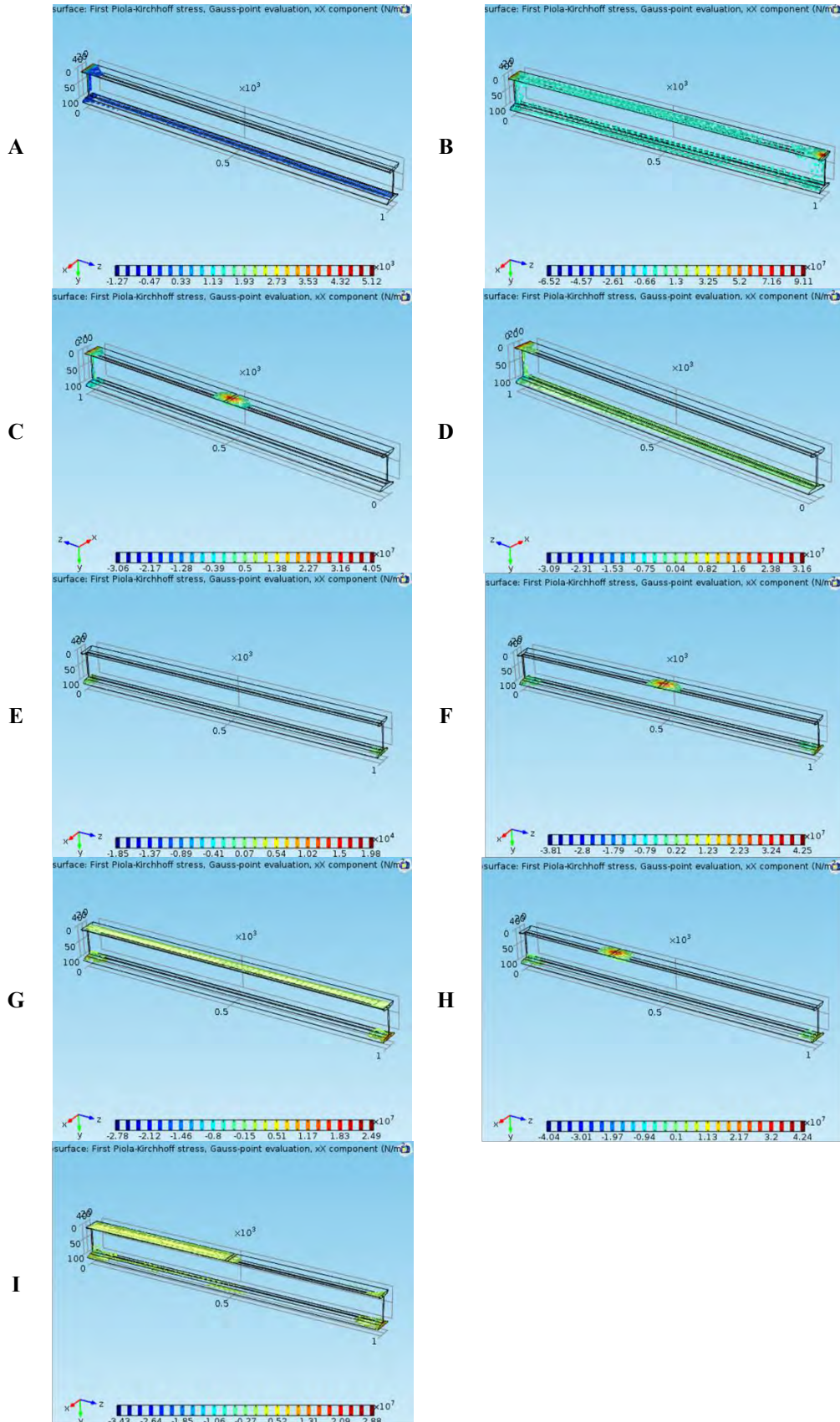
Figure 6 – Principal stress direction 2, z component: A – the first scheme; B – the second scheme; C – the third scheme; D – the fourth scheme; E – the fifth scheme; F – the sixth scheme; G – the seventh scheme; H – the eighth scheme; I – the ninth scheme.
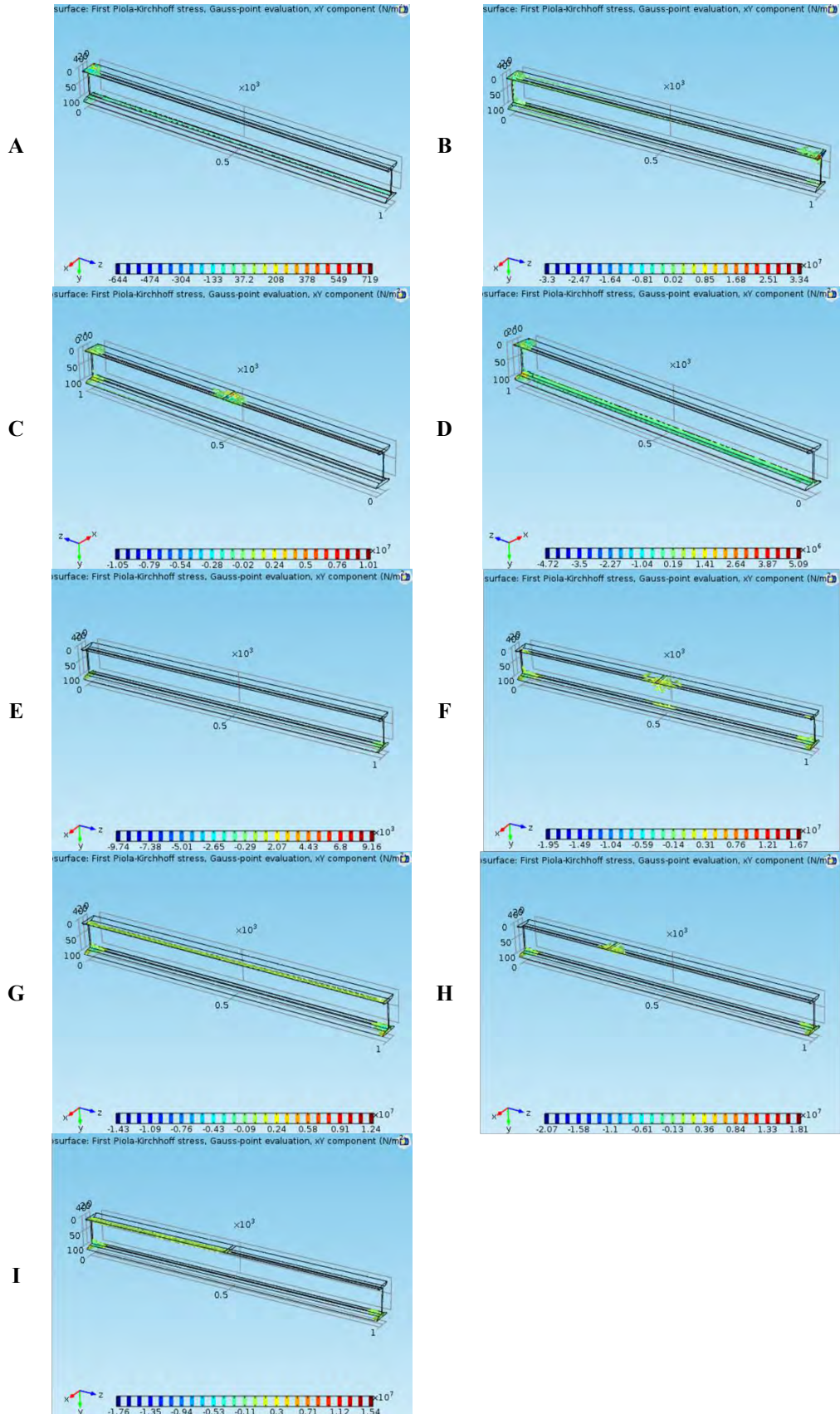
Figure 7 – Principal stress direction 3, x component: A – the first scheme; B – the second scheme; C – the third scheme; D – the fourth scheme; E – the fifth scheme; F – the sixth scheme; G – the seventh scheme; H – the eighth scheme; I – the ninth scheme.

Figure 8 – Principal stress direction 3, y component: A – the first scheme; B – the second scheme; C – the third scheme; D – the fourth scheme; E – the fifth scheme; F – the sixth scheme; G – the seventh scheme; H – the eighth scheme; I – the ninth scheme.

Figure 9 – Principal stress direction 3, z component: A – the first scheme; B – the second scheme; C – the third scheme; D – the fourth scheme; E – the fifth scheme; F – the sixth scheme; G – the seventh scheme; H – the eighth scheme; I – the ninth scheme.
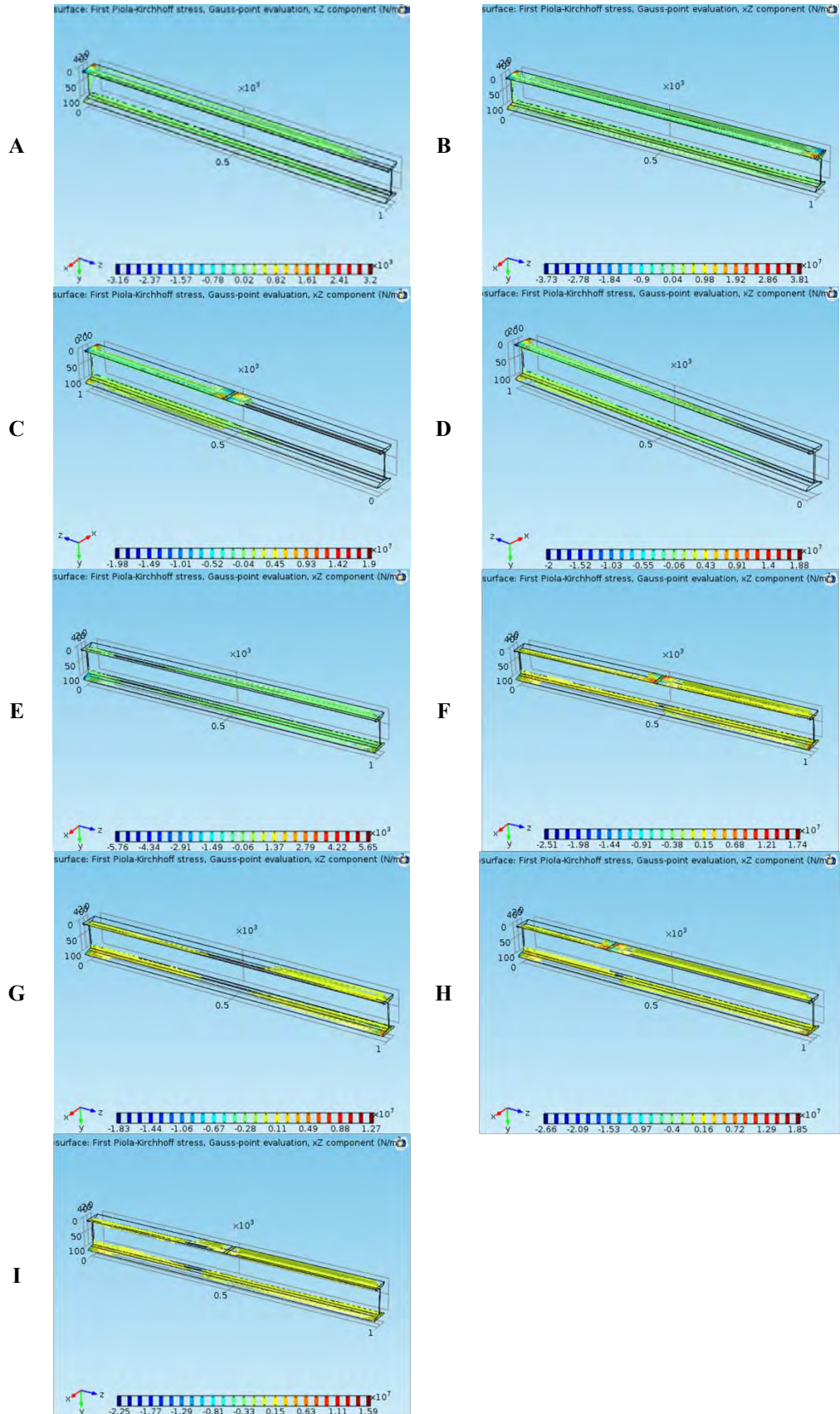
Figure 10 – First Piola-Kirchhoff stress, xX component: A – the first scheme; B – the second scheme; C – the third scheme; D – the fourth scheme; E – the fifth scheme; F – the sixth scheme; G – the seventh scheme; H – the eighth scheme; I – the ninth scheme.
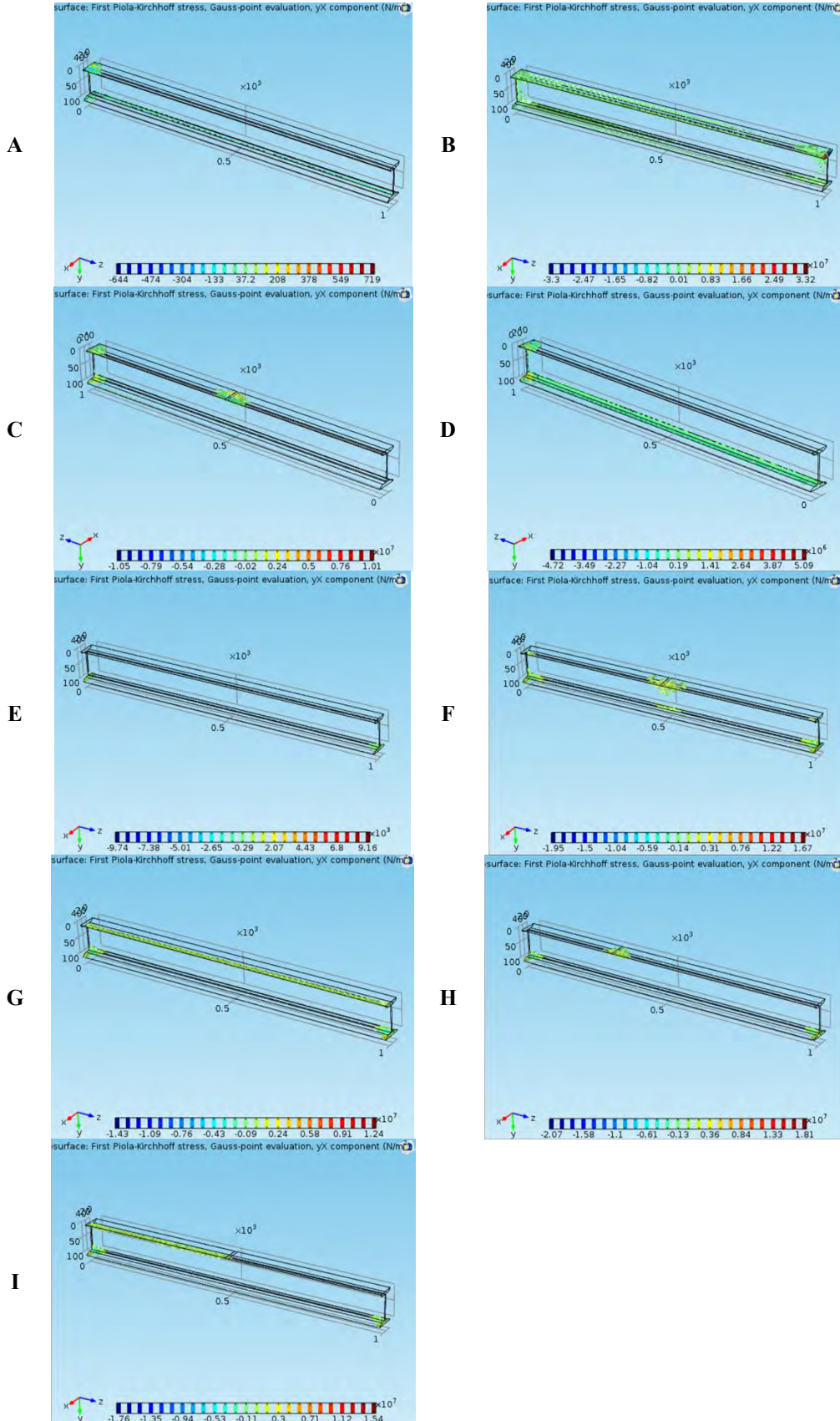
Figure 11 – First Piola-Kirchhoff stress, xY component: A – the first scheme; B – the second scheme; C – the third scheme; D – the fourth scheme; E – the fifth scheme; F – the sixth scheme; G – the seventh scheme; H – the eighth scheme; I – the ninth scheme.
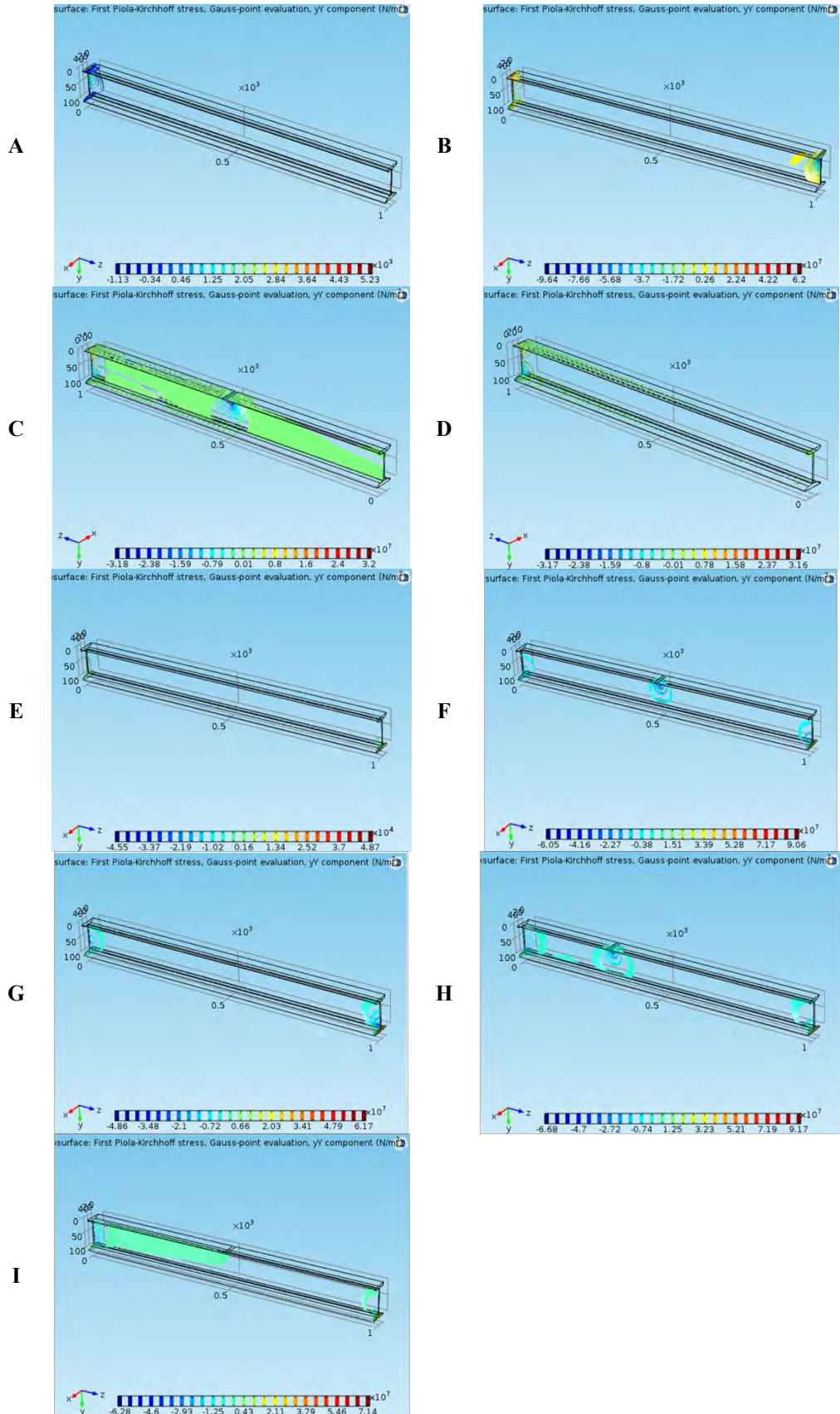
Figure 12 – First Piola-Kirchhoff stress, xZ component: A – the first scheme; B – the second scheme; C – the third scheme; D – the fourth scheme; E – the fifth scheme; F – the sixth scheme; G – the seventh scheme; H – the eighth scheme; I – the ninth scheme.

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Figure 13 – First Piola-Kirchhoff stress, yX component: A – the first scheme; B – the second scheme; C – the third scheme; D – the fourth scheme; E – the fifth scheme; F – the sixth scheme; G – the seventh scheme; H – the eighth scheme; I – the ninth scheme.
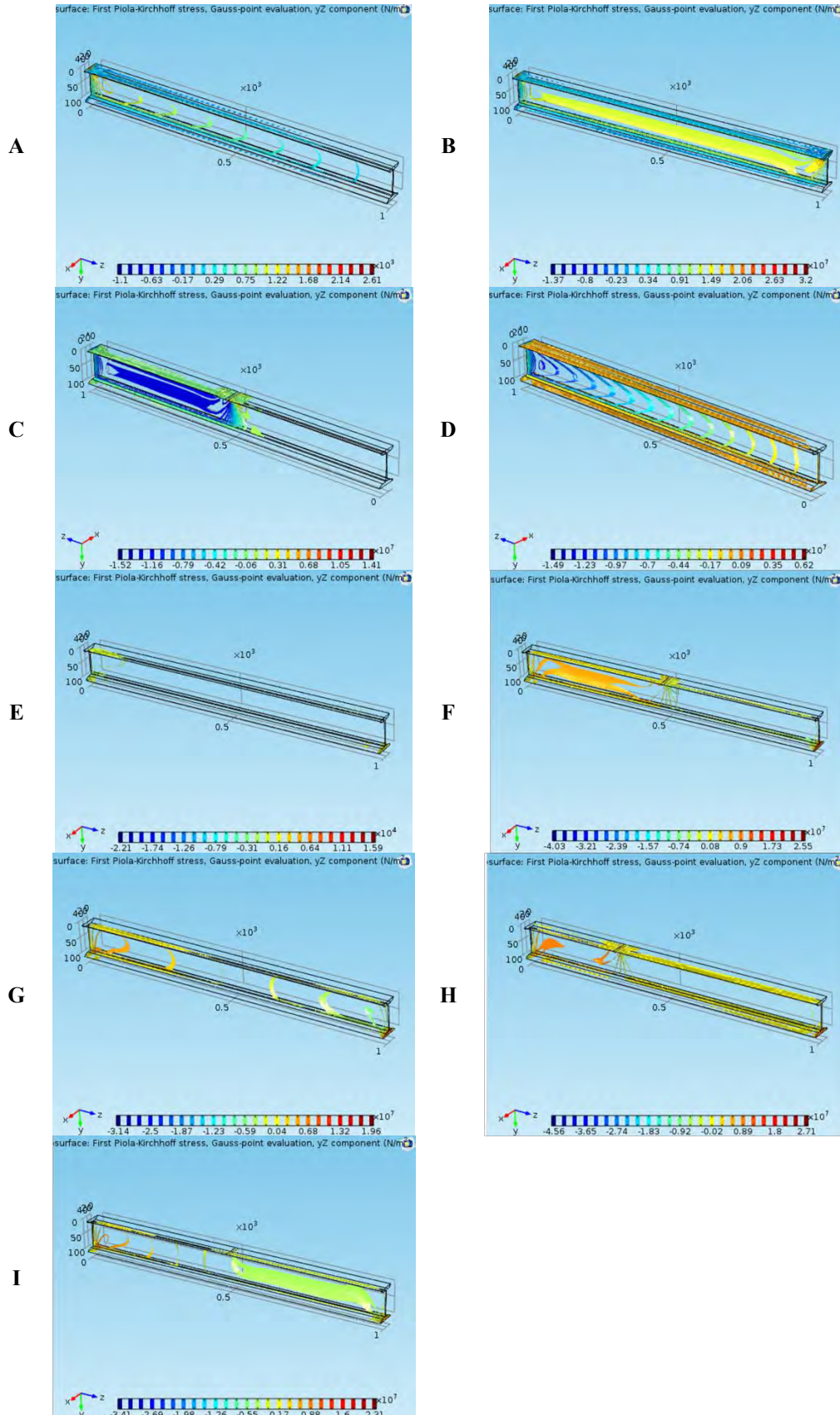
Figure 14 – First Piola-Kirchhoff stress, yY component: A – the first scheme; B – the second scheme; C – the third scheme; D – the fourth scheme; E – the fifth scheme; F – the sixth scheme; G – the seventh scheme; H – the eighth scheme; I – the ninth scheme.
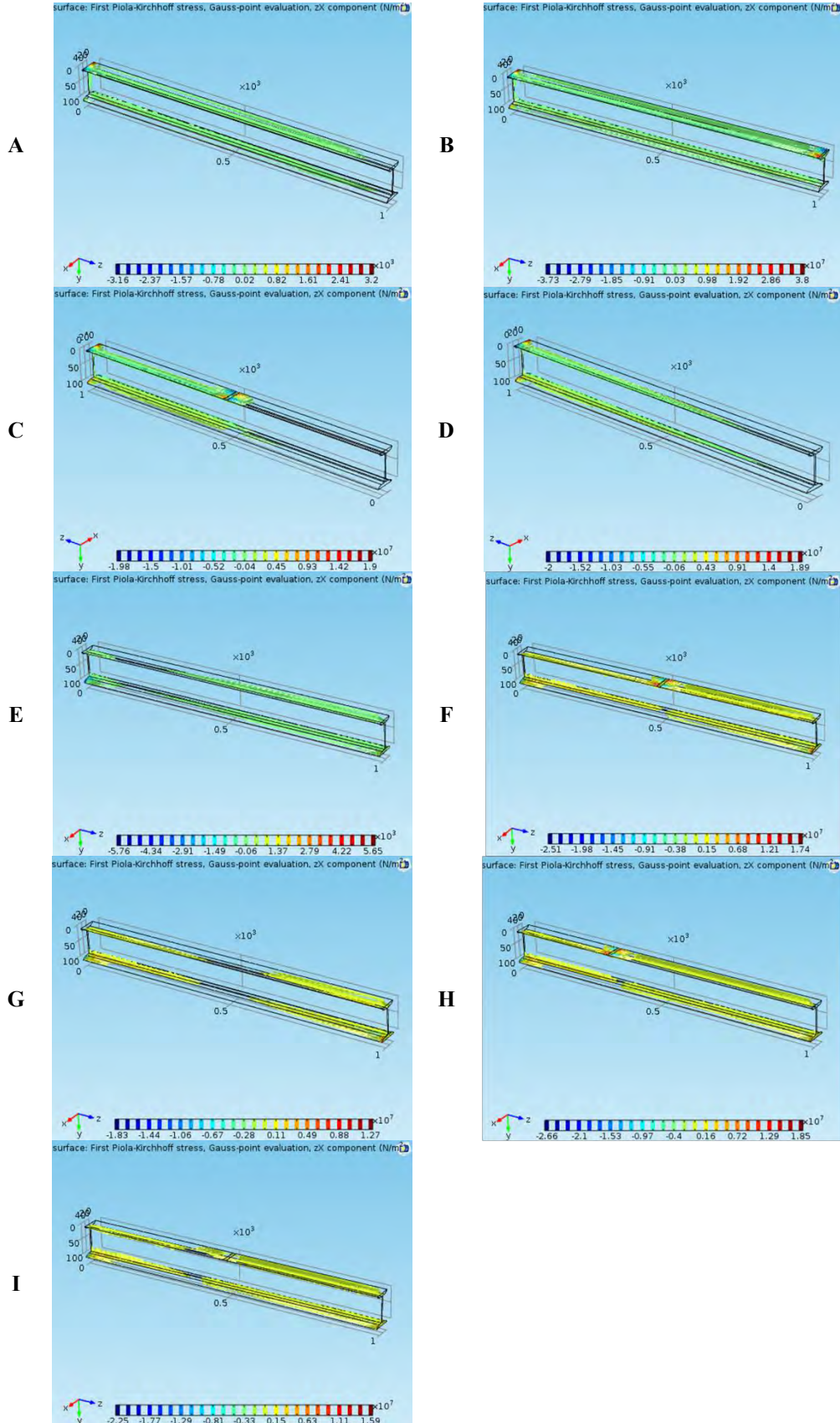
Figure 15 – First Piola-Kirchhoff stress, yZ component: A – the first scheme; B – the second scheme; C – the third scheme; D – the fourth scheme; E – the fifth scheme; F – the sixth scheme; G – the seventh scheme; H – the eighth scheme; I – the ninth scheme.

Figure 16 – First Piola-Kirchhoff stress, zX component: A – the first scheme; B – the second scheme; C – the third scheme; D – the fourth scheme; E – the fifth scheme; F – the sixth scheme; G – the seventh scheme; H – the eighth scheme; I – the ninth scheme.
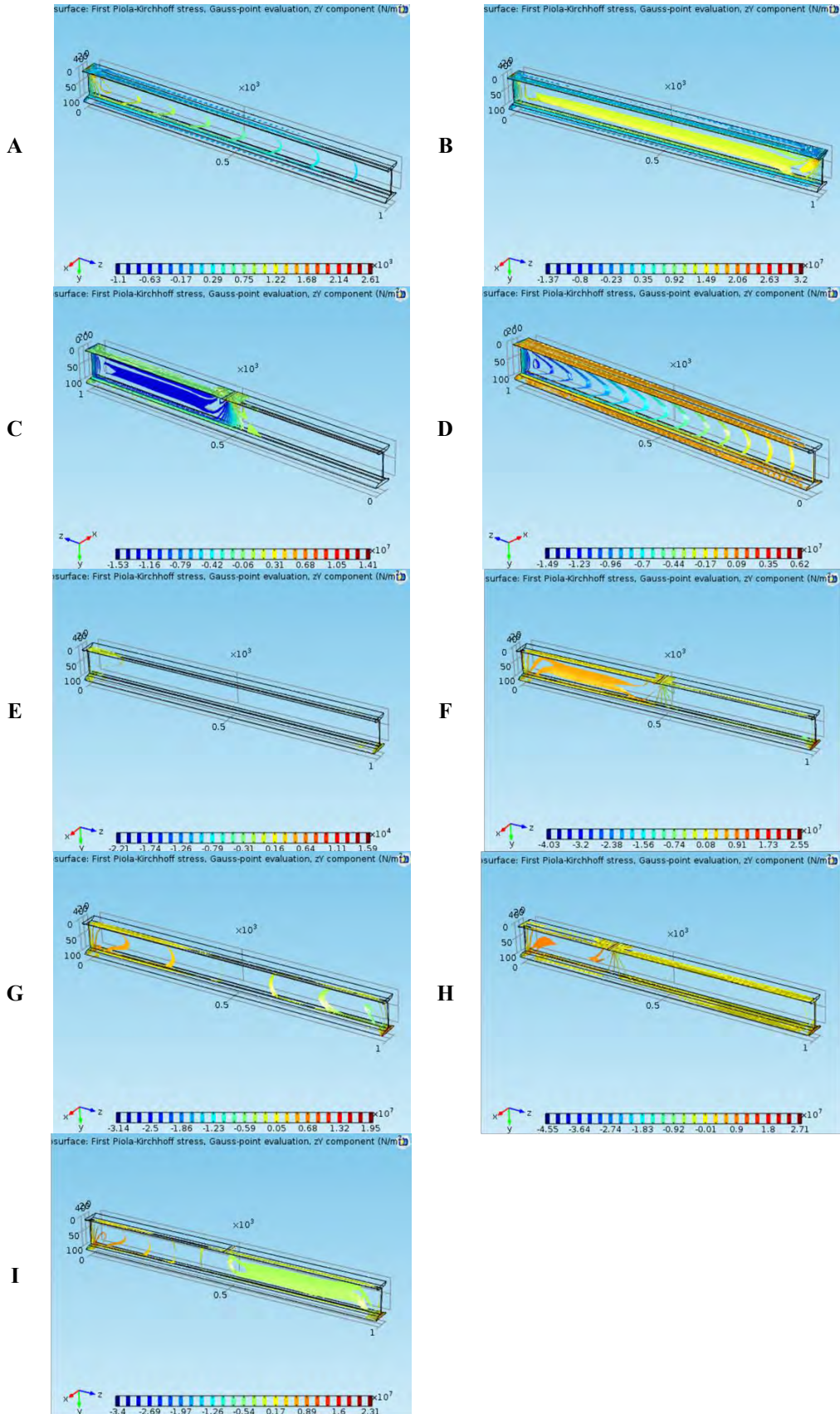
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Figure 17 – First Piola-Kirchhoff stress, zY component: A – the first scheme; B – the second scheme; C – the third scheme; D – the fourth scheme; E – the fifth scheme; F – the sixth scheme; G – the seventh scheme; H – the eighth scheme; I – the ninth scheme.
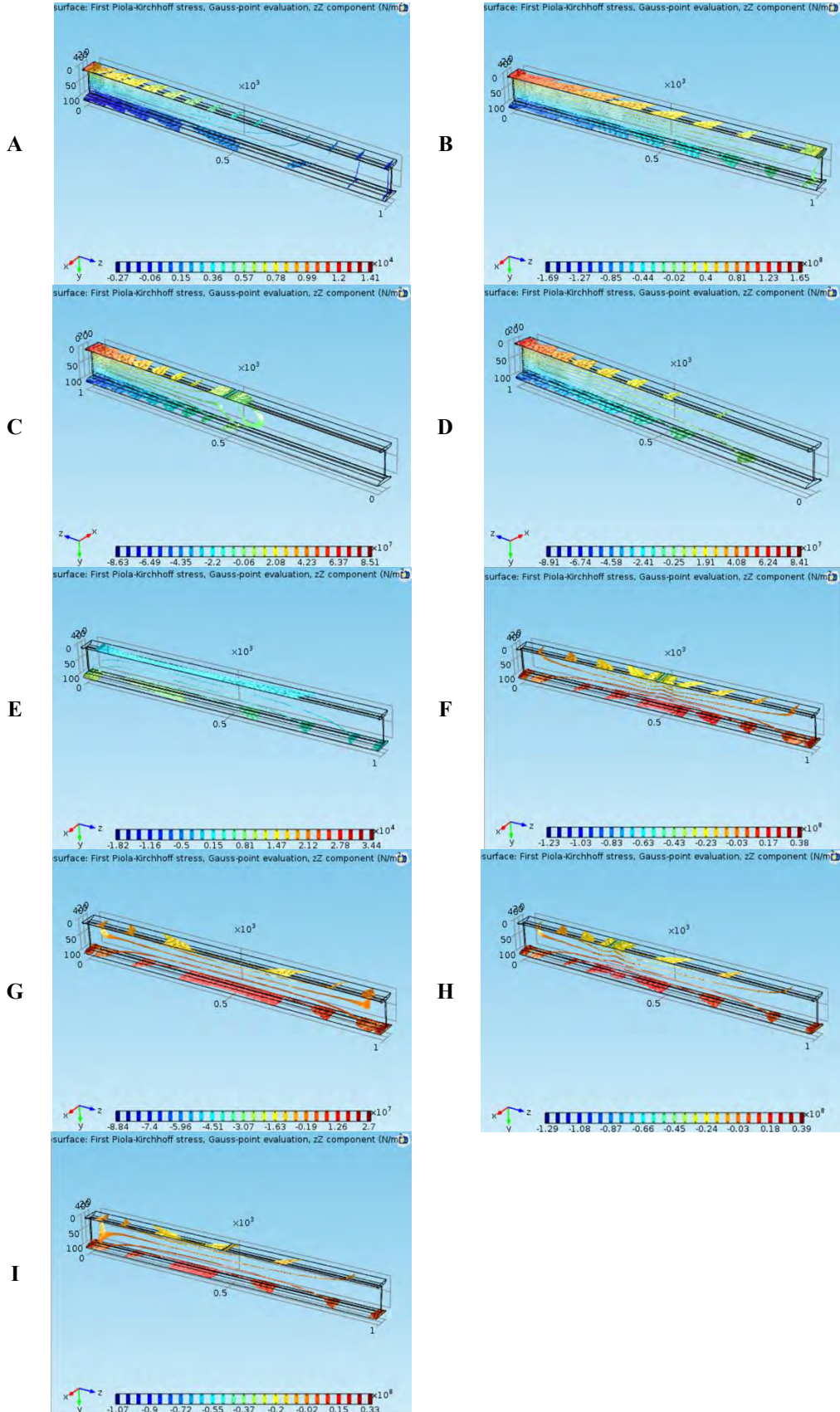
Figure 18 – First Piola-Kirchhoff stress, zZ component: A – the first scheme; B – the second scheme; C – the third scheme; D – the fourth scheme; E – the fifth scheme; F – the sixth scheme; G – the seventh scheme; H – the eighth scheme; I – the ninth scheme.

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