Pelvic Vertical Shear Fractures: the Damping Properties of Ligaments Depending on the Velocity of Vertical Impact Load

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Abstract. The aim of this work was to determine the influence of ligaments and soft tissue on the mechanism of pelvic injuries resulting from shear forces caused by vertical impactors with velocity in the range 1-10 m/s. The elaborated finite element model of the human pelvis (LPC) contains a bi-layered structure of bone, varying stiffness of pelvic ligaments and hyperelastic behavior of cartilage. The performed analysis indicates two limiting values: a velocity of 5 m/s as a limit for bone injuries and a velocity of 3 m/s as a limit for ligament and cartilage destruction. The ligaments having the main role in stabilizing the pelvic girdle under vertical impact load are: sacrospinous, anterior and posterior sacroiliac, iliolumbar, and inferior and posterior pubic. Obtained stress distribution in the pelvis confirms the mechanism of Malgaigne type fracture as described in the literature, indicating the transverse process as a precursor of this fracture causing the stress concentration in the lower part of the pelvis.

INTRODUCTION

The significant role of ligaments in the pelvis injury mechanism was indicated based on an “open book” type fracture, which are most commonly the result of high-velocity trauma related to communication accidents or falls from great heights. The Young-Burgess classification of pelvis fracture was elaborated to predict the mortality and to identify potential needs of non-surgical or operative treatment. According to this classification, it is known that pubic symphysis widening of more than 25 mm indicates injury to anterior sacroiliac, sacrospinous and sacrotuberous ligaments [1]. This classification is, however, too general, causing the stabilizing role of pelvic ligaments to be questioned by several authors [2, 3].

Due to the lack of experimental measurements resulting in sample availability and the possibility of crash accident imitation, numerical analysis provides the opportunity to complete the analysis of the pelvis injury mechanism. Up-to-date FEM analysis was focused on the influence of force acting in a horizontal and frontal direction on pelvic injuries, except to the shearing force. Therefore, the aim of this work was to determine the influence of velocity of vertical impact acting on the pelvis on the stabilizing role of the ligaments apparatus, being the differences in mechanism of pelvic injury under low and high-energy vertical impact load.

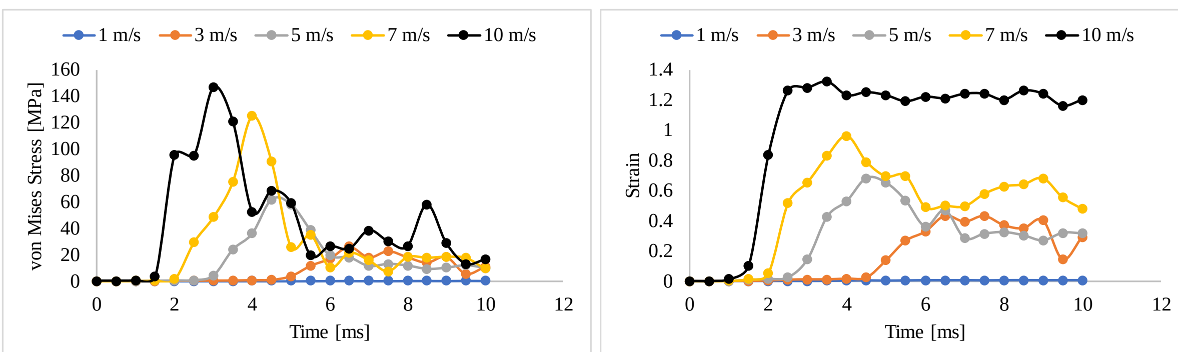
MATERIAL AND METHODS

The elaborated LPC model was used to determine the influence of velocity of impact load (range in 1-10 m/s) on the mechanism of pelvic destruction under vertical impact load. For this purpose, the additional element of model as blocks were used to map the human buttocks and steel frame construction. The numerical analysis was performed using the velocity in range 1-10 m/s acting in vertical direction on the steel block imitating the seat frame during 10 ms. To obtain the effect of fastened belts limiting pelvic movements, the model translation was only accepted in the vertical direction: at the top of the fifth lumbar vertebra by mass value 50 kg, and at the iliac crest by seat belts modelled as a spring with stiffness 98.1 kN/mm.

RESULTS AND DISCUSSION

The increase of velocity of the impact load causes the increase of the maximum von Mises stresses located in the pelvic girdle. Stresses exceeding the ultimate stress of bone (exceeding a value of 125 MPa) were observed under impact load with velocity higher than 7 m/s. In the case of velocity of 1 m/s, the stresses were recorded only in the ilium bones and the sacroiliac joints. There was no propagation of stress to the sacrum bone or to the spinal column. Increasing the velocity of the impact load acting on the pelvis to 3 m/s firstly causes the stress concentration in the ischium and then its further propagation through the pelvic bone to the spine column (30 MPa, 20 ms). A velocity of 5 m/s did not destroy the bone element of the pelvic girdle but did rupture the sacrospinous, anterior and posterior sacroiliac, iliolumbar, and inferior and posterior pubic ligaments. In addition, the sacroiliac cartilage was also destroyed.

The analysis of pelvic injuries under an impact load velocity of 7 and 10 m/s showed the results of the reduction of absorption properties of the ligament apparatus. Initially, the stresses are localized in the ramus of ischium over 2 ms. These stresses are not destructive for bone due to the high elongation of the inferior and posterior pubic ligaments. Further concentration of stresses include the transverse process of the fifth lumbar vertebrae, causing compression fracture of the spine and concentration in the pelvic girdle. The performed analysis of the mechanism of pelvic injuries indicates a velocity equal to 5 m/s as a limit for pelvic strength. Obtained results are consistent with the reports in the literature [1, 4] and previous studies aimed at the Malgaigne type fracture mechanism [5].



(a) (b)

FIGURE 1. The maximum von Mises stress (a) and strain (b) distribution in the lumbar-pelvic complex under vertical impact load (velocity in the range 1-10 m/s) during 10 ms

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