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Material-Point Method Analysis of Bending in Elastic Beams

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The aim of this paper is to test different kinds of spatial interpolation for the material-point method [1]. The interpolations include the traditional linear elements, quadratic elements and cubic splines. A brief introduction to the material-point method is given and the different types of interpolation used are presented. For the cubic splines, a simple scheme to apply essential boundary conditions is given, based on using two rows of grid nodes to describe the boundary. The initial idea is that it may be possible to obtain higher-order accuracy by using higher-order shape functions. However, the use of negative shape functions is not consistent with the material-point method in its current form, necessitating other types of interpolation such as cubic splines in order to obtain smoother representations of field quantities.

Next, a number of simple liner-elastic problems are considered. Firstly, the vibration of a bar is examined. By only prescribing a small velocity amplitude, it is possible to maintain positive shape-function values for the quadratic elements. As suggested by Bardenhagen [2], it is examined whether the different elements are able to maintain the kinetic energy in the mapping from the material points to the grid. Compared to the linear elements, a higher accuracy is only obtained by the nine-node quadratic elements. The accuracy of the cubic splines is in this respect found to be comparable to that of the linear elements.

Secondly, a cantilevered beam subjected to a concentrated force at the free end is considered. The force is applied within the framework of the dynamic material-point method as an equivalent acceleration, gradually applied to the material point at the corner of the beam. The horizontal stresses are compared to the exact stress variation, finding that the same magnitude of the stresses is basically obtained with all the interpolations--even though the stresses are constant within an element using linear interpolation. Further, it is observed that all the computed deflections are smaller than the analytic results. The linear interpolation yields the stiffest beam, while the cubic splines provide the largest deformation, close to the analytic solution.

The final example concerns a box impacting on a beam clamped at both ends. With this kind of simulation, negative grid masses cannot be avoided with an interpolation based on nine-node quadratic elements without adaptive meshing. It is shown that the smoother field representation using the cubic splines yields a physically more realistic behaviour for impact problems than the traditional linear interpolation or interpolation using eight-node serendipity elements.

References

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2 S.G. Bardenhagen, "Energy conservation error in the material point method for solid mechanics", Journal of Computational Physics, 180(1), 383-403, 2002.

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