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COMPUTER MODELING OF BEET HARVESTER DIGGING. BODIES-SOIL INTERACTION

Summary

The objective of the article is to elaborate the beet harvester digging bodies virtual tests using LS-DYNA package installed on the SKIF k-1000 supercomputer in UIIP NAS of Belarus. The process of beet digging out is simulated. For the soil simulation an isotropic material with failure (Mat_FHWA_SOIL) was used. Different types of soil models are obtained by input parameters varying. The calculations were carried out in EXPLICIT and SPH-particles formulations. In the SPH-particle formulation the continuous media is substituted by a set of particles that move with the flux velocity. By means of soil material coefficients and SPH-elements characteristics the viscous media behavior is described. Soil particles displacements during treating were traced.

The objective placed before the paper authors is to elaborate the beet harvester digging bodies virtual tests implemented in LS-DYNA package (Livermore Software Technology Corporation product) [1] that is installed on the SKIF k-1000 supercomputer in UIIP NAS of Belarus [2]. Digging body is two slope plates (plough shares) that are fixed to a frame by bolts. The frame is made by two plane poles fixed to the welded lever of complicated space form with eccentric bearing form. Sinusoid low vertical motion is applied to the frame through the driving shaft by means of eccentric. Also horizontal motion is applied through the tube on the other end of the lever with the beet harvester working movement velocity. For the soil catching during horizontal movement shares are placed non-parallel but sloped to each other at an angle making a wedge with the socket directing to the beet harvester working movement. Thus the shares displacement provides that soil reaction forces direction and their value depend a lot on the labour body constructive parameters as while moving shares are continuously subjected to the non-uniform bending loads distributed on the surface and time. Shares are made from high-test alloyed steel therefore practically all loads they perceive are transmitted to the frame that is supplied by the additional catching. The catch and the bolts may deform elastically during work partially smoothing the non-uniformity of the loads applied to the welded lever details.

LS-DYNA package gives means for applying external loads and for the counting contact interactions between assembly details. Lifting point model is represented by package means as final element detail models with given contact interaction .During beet harvester exploitation direct contact with soil and beetroots have only plough shares. Other lifter point details provide the given kinematics of plough shares movement and their loads. To obtain load and plough movement characteristics the simplified model was built.

To lower the needed processor time the pole, lever, welded boosters, digging shares and their fixing elements are made rigid (*mat_rigid)(). Input drive rotating moment is applied to the eccentric. Lever body swings around the shaft axis due to the contact with the eccentric, the axis being fixed by six degrees of freedom. The output characteristics are got from the digging shares fixtures elements. Velocity and displacement lows in X and Y directions are sinusoids (Figure 2).

In LS-DYNA package the process of beet digging out is simulated (Figure 3). There are more than 14 types of soil included in the LS-DYNA package that work in an explicit analysis. For the soil simulation an isotropic material with failure (Mat_FHWA_SOIL) was used. For soil modeling the isotropic material with failure (Mat_FHWA_SOIL) was chosen. The model has modified Mohr-Coulomb surface based on the geo-technical parameters obtained in laboratory tests. Different types of soil models are obtained by input parameters varying. Namely specific gravity of solid soil, mass density of the soil, density of water used to determine air void strain, angle of internal friction, cohesion, porosity of the soil, parameters for pore-water effects [3] were altered.

Explicit analysis does not allow to trace each particle displacement under the action of the forces applied to the body. The soil is represented by the continuous media in which the substance is distributed uniformly through the box volume without ruptures and gaps. To exclude soil displacements under the shares exertions influence lateral sides and the bottom of the soil box are fixed by all degrees of freedom. Digging share and the beet are made from elastic material that can deform under loads. The gravitational load is applied to the edible root model. The surface contact is applied between all the model parts. As a result of lifter point share force influence on the soil the corresponding displacements of the soil surface and the beetroot are obtained, the movement of the beetroot indicating the displacement of the inner parts of the soil.

The soil behavior and its influence on the beetroot model in the labour plates movement were investigated , smooth particles method (smooth Particle Hydrodynamics) [4]) and kinematical characteristics values (plots in Figure 2) being used. The main idea of the method is the continuous media discretization by a set of particles that move with the flux velocity. Soil model is represented by SPH elements. They can be considered as an aggregate formation centers, the soil cultivated for beetroots planting consisting of them. Each point is prescribed definite mass. By means of soil material coefficients and SPH-elements characteristics the viscous media behavior is described in boundary conditions file, particles with given masses being placed in it. In comparison to the EXPLICIT formulation model the model based on the SPH elements large relative nodes displacements are allowed. Therefore it is possible to trace separate soil parts displacement during treating, soil surface profile changing and places of soil thickening by means of such modeling (Figure 4).

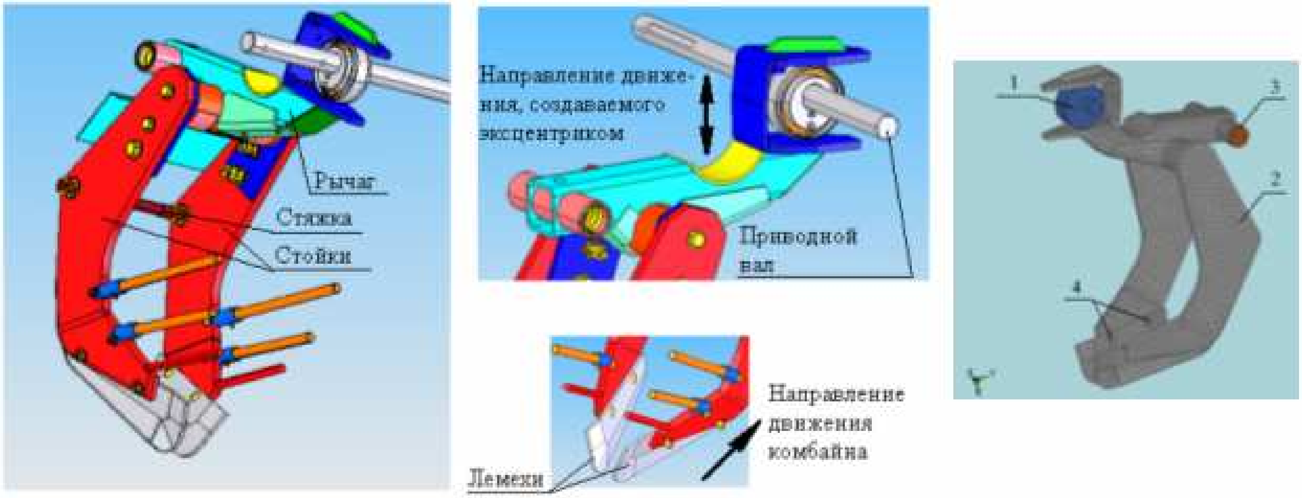


Fig. 1. Beet harvester lifter point constructive scheme and its simplified model

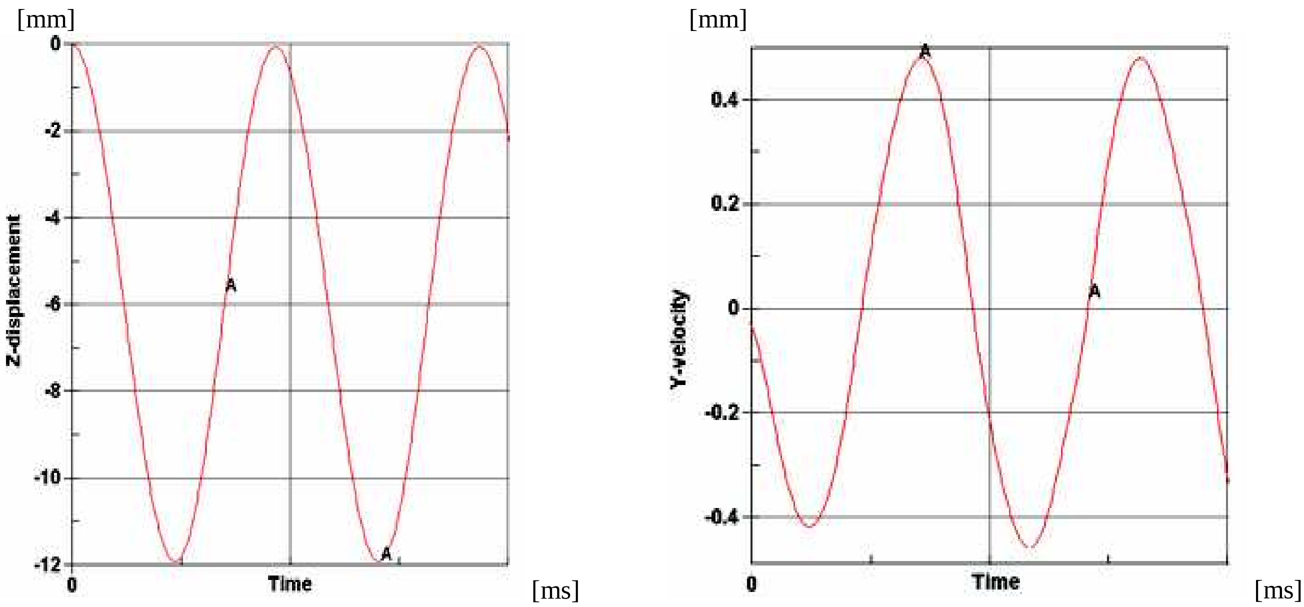


Fig. 2. Plots of shares displacement and velocity

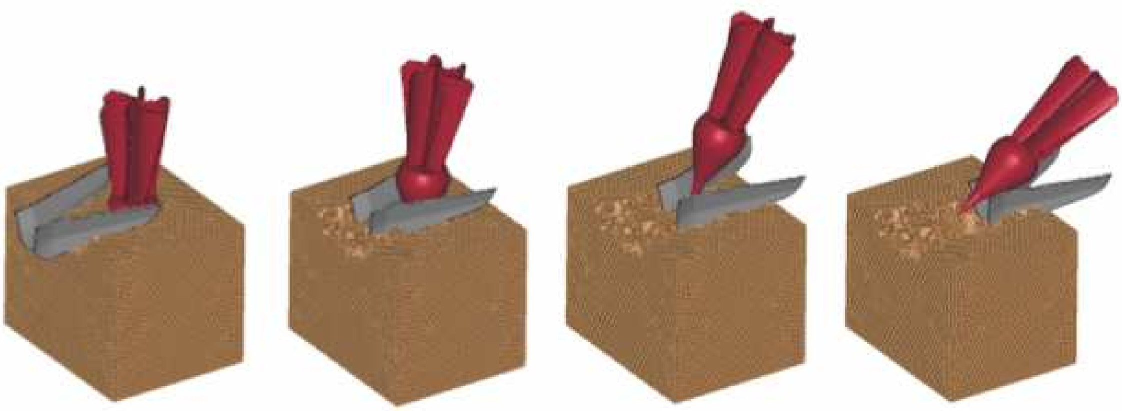


Fig. 3. Beetroot digging out process

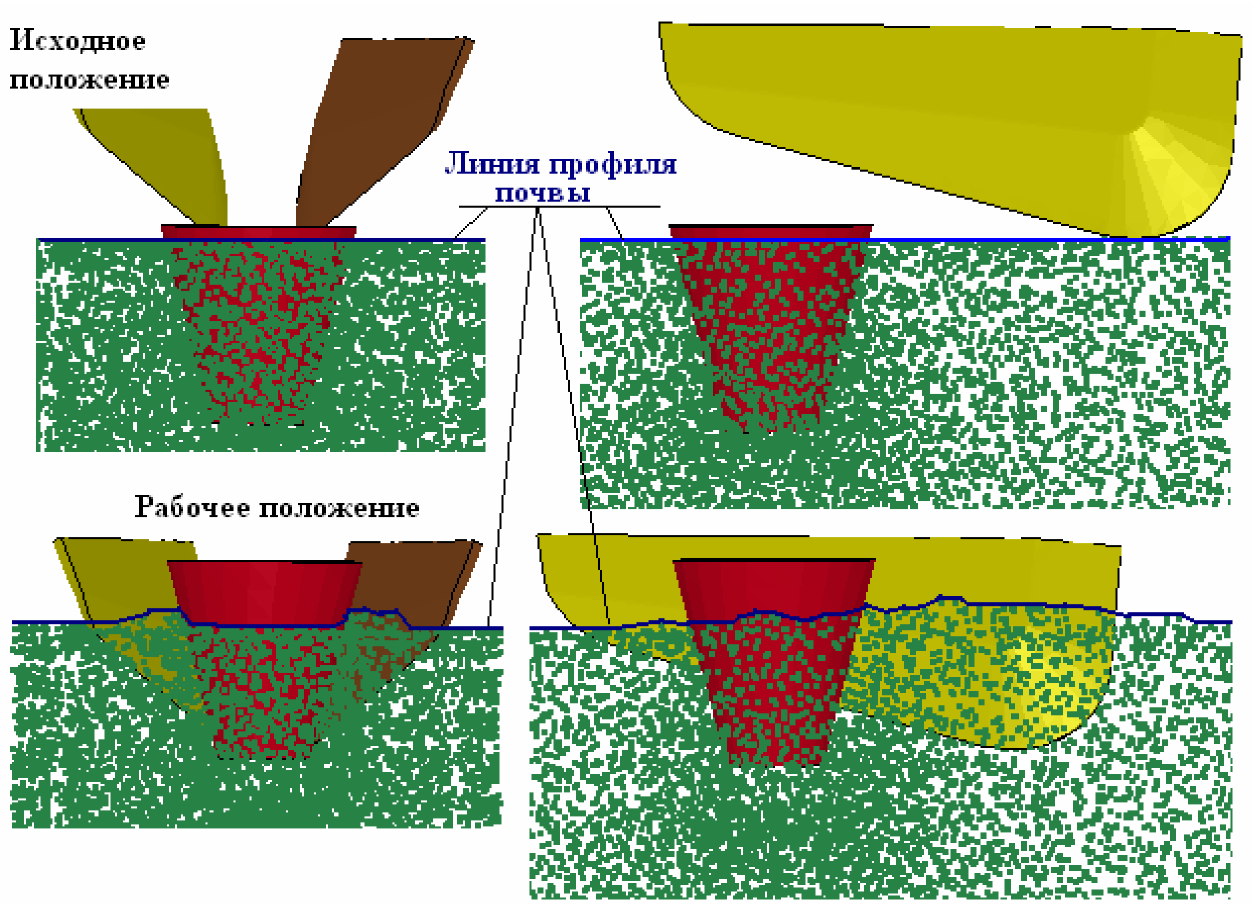


Fig. 4. Soil surface profile changing during lifter point movement

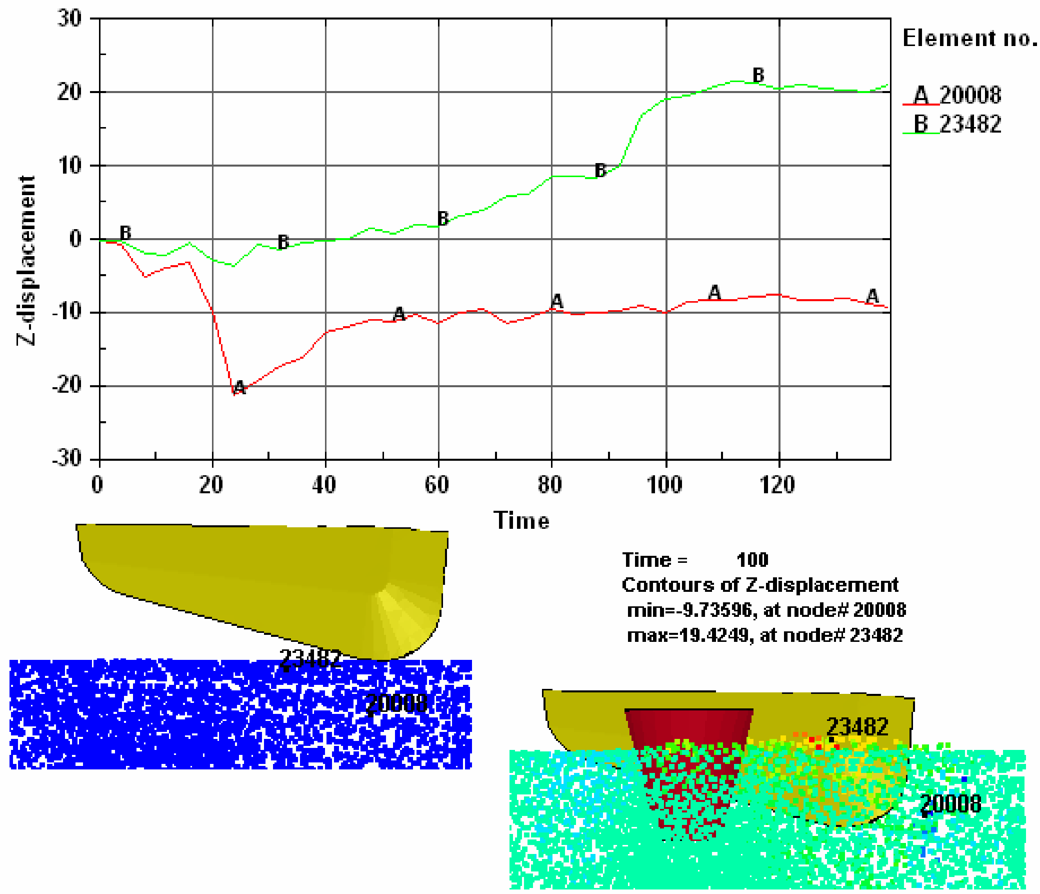
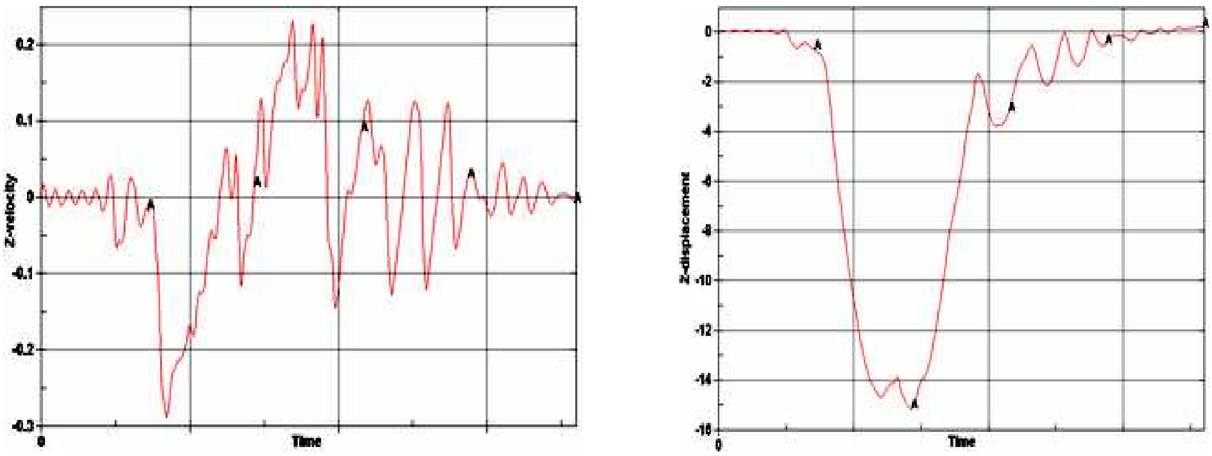


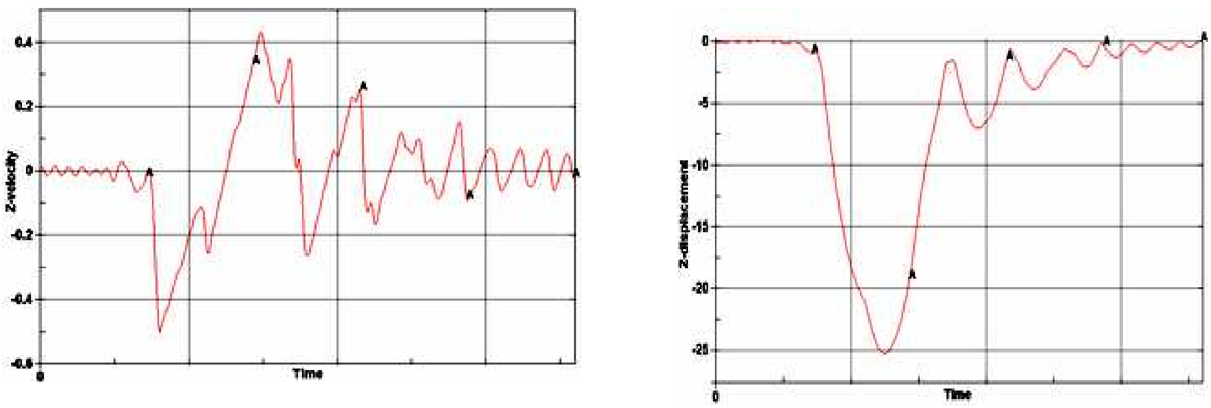
Fig. 5. Relative soil particles displacement due to lifter point movement

Lifter point embedding process investigation was found to be interesting. Separate soil particles displacements plots were obtained. It can be seen from the plots that there are particles affected initially by shares that move downwards and there are particles that start to move upwards in a definite moment due to lateral pressure. Due to lifter point oscillating motion soil particle mixing is occurred. In figure 5 plots of particles mixing are shown, maximum absolute displacement being 1 n 100 ms time.

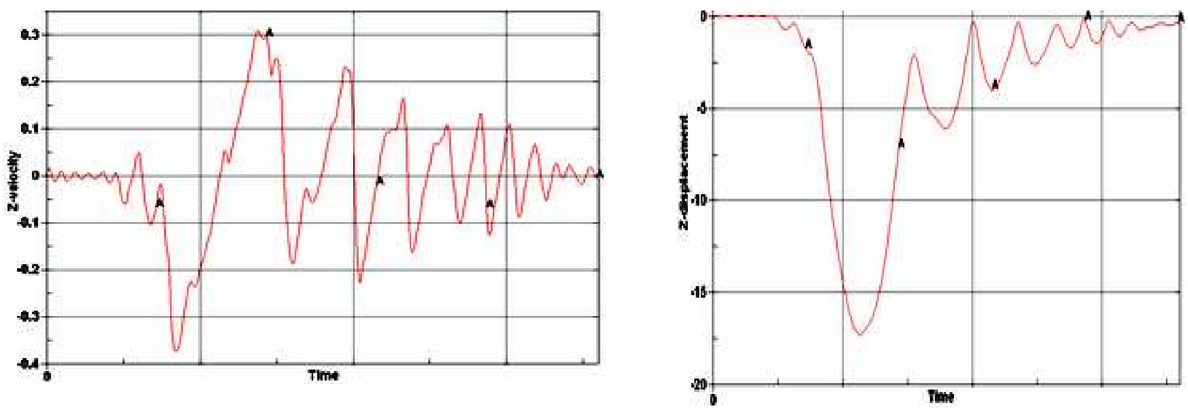
One of the actual beetroot harvesting problems is beetroot damaging by metal labour body of the harvester. To exclude such unwilling situations it is necessary for the beet to be extracted from soil by means of soil pressure, initial direct contact with shares being excluded. Calculations that uses SPH elements made it clear that during lifter point movement the distance between plates and beetroot surface shortens but then a layer that has constant wideness appears between them due to the hydrodynamic properties of soil. Then the simultaneous movement of soil and beet in horizontal direction occurs. This layer does not appear only in the case the beetroot happens to be directly under the plate during its embedding. But as the bottom share point depth oscillates between 70-58 mm during the exploitation the beets which diameters are lower then socket width could not theoretically touch the metal. The influence of the horizontal distance between the beetroot and plate initial bottom point in the initial moment of the plate embedding from 58 mm to 70 mm is also investigated. It was also cleared out that for the modeling of the soil-beet interaction by means of SPH-elements it is necessary to apply gravitation to the beets.



a) rotational frequency is n_1



b) rotational frequency is n_2



c) rotational frequency is n_3

Fig. 6. Nodes displacements and velocities plots of the beetroot at different angular velocities

To investigate driving shaft angular velocity influence on the beetroot model behavior an experiment in EXPLICIT formulation was maintained that is analogous to the SPH-particle one. The simulations that imitates lifter point exploitation regimes with 420, 500 and 600 revolutions per minute were carried out. During this simulation it was found that beetroot digging out occurred only due to forces acting from soil. Calculation results are presented in figure 6 where nodes displacements and velocities of the beetroot model are shown. Z axis direction coincides with gravitational loads direction. Different velocities and displacements shown in figure 6 can be explained by lifting point shares approach to the beetroot in different oscillation motion phases. That is the maximum values of velocity vertical component V_z = 0,50 mm/ms and displacement vertical component S_z = 25,23 mm are obtained at angular velocity 500 rev/min.

To investigate the influence of the oscillation motion phases on the beetroot model behavior additional experiments with different angular velocities are needed.

Speaking of the SPH-particles models investigation method disadvantages one can mention processor time several times higher then usual finite-element models demand and difficulties in searching the appropriate material and material coefficients. It was found out that material number 147 does not work with SPH-elements, material 5 (*MAT_SOIL_AND_FOAM) should be used instead that demands explicit input of curve characteristics of pressure dependence on the volumetric hardening. Therefore to solve the problem of soil-labor bodies interaction modeling the soil characteristics laboratory measuring is necessary. On the final research results effects not only material coefficients but also the characteristics of SPH-elements. Therefore more exact results could be obtained using experimental calibration of the calculation model. In this case the real experiment of the plate embedding in the soil is carried out, the plate being placed under an angle to the upright direction to strengthen the bending forces. The best angle is that equal to the value of the lifting point plates angle. During plate into soil embedding with the constant velocity the dependence of the several points stresses on the embedding depth. Then the calculation model with the same geometric parameters and soil volume is created. The same velocity value is prescribed. In several iterations the model coefficients are found that make the calculation and experimental stresses equal or strong correlating.

To maintain lifter point strength calculation it is necessary to create a model that consists of separate parts joined by welding seams with plastic deformation zones [5]. The calculations are to be carried out in Explicit formulation. To verify the model the calculation results are to be compared with the results obtained for the corresponding solid model. In future this problem is supposed to be solved in ALE formulation in order to receive the whole picture of beetroot digging out process.

Literature

[1] LS-DYNA Keyword User's Manual Version 970 Copyright©1992-2003 Livermore Software Technology Corporation All Rights Reserved (2003)

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