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REVIEW ARTICLE

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Simulating a fall system to support the adjustment of plastic injection molds

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Abstract

Adjusting the contact surfaces, or interferences, in an injection mold is a critical process that can affect the performance of the mold and the quality of the molded parts. This process often involves high impact loads, especially for large molds that involve large masses of inertia in motion and generate significant kinetic energy during mold closure. Impact forces can propagate through the mold structure causing damage to the tool, mold, or even the injection equipment where the mold is placed, causing operational errors due in particular to system vibrations. This study evaluates impact forces during mold closure using numerical simulations in ANSYS, focusing on the mold's fixed part and its support structure. Results demonstrate that integrating energy-absorbing elements significantly reduces transmitted impact energy without compromising stability. This approach enhances safety and efficiency by minimizing vibrations and protecting machinery.

Keywords Injection mold, Mold structure, Impact load, Kinetic energy, Deformation energy

Introduction

The complexity of adjusting injection molds increases with their size (Zhou et al. 2017; Akkaş et al. 2025) directly impacting the quality of molded parts. This work is currently carried out with specific presses that allow simulating up to a certain closing force and manipulating the mold to be adjusted (Alfredo Campo 2006; Tseng et al. 2025). There are several companies that provide this solution, but it is a high-cost solution that does not allow the simulation of a closing pressure equivalent to the injection process (He et al. 2024; Panich et al. 2021). To solve this problem, the mold is sometimes dropped on the other without much control, in a very artisanal and impractical process. The project proposed here tries to solve this problem.

The mold closing process present in this project involves high shock loads that propagate vertically in the structure (Xu et al. 2015). These loads are generated by high kinetic energy of the falling mold (Ulgen et al. 2016). This energy cannot be fully transmitted to the ground because the vibration waves generated would damage adjacent components of the mold structure (Herbut 2021).

To mitigate the transmission of energy to the floor, a fabric-reinforced elastomeric material was identified for its ability to absorb impact kinetic energy upon deformation (R. W., Hertzberg, R. P. Vinci, and J. L. Hertzberg 2020). This material is installed beneath the frame supporting the lower mold. The elastomeric component, known as the "FABREEKA plate," is manufactured by the company FABREEKA (2024), which offers a range of plates with varying thicknesses. These plates are employed in civil construction, vibration testing equipment, and machine tool foundations (Newland and Hunt 1991; Talbot and Hunt 2003).

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Method

To approximate this non-linear problem, we employed an energy-based approach using the law of conservation of mechanical energy (Serway and Jewett 2010). This method assumes that the gravitational potential energy of the mold transforms into kinetic energy upon impact, which is then partially absorbed by the FABREEKA plates. The FABREEKA plate's capacity to absorb energy per unit volume is defined by Eq. 1:

$$E_{av} = \frac{\sigma^{\frac{5}{3}}}{C}; \text{where } C = 985,000\ \mathrm{N}^{\frac{5}{3}}\mathrm{m}^{-\frac{1}{3}}/\mathrm{J} \tag{1}$$

where σ represents the normal contact stress during the impact and C is a material constant provided by FABREEKA. This constant reflects the material's ability to store energy elastically. The material's deformation is described by Eq. 2:

$$\sigma = E_0 \cdot \left(\frac{\delta_f}{t_f}\right)^{\frac{3}{2}}; \text{where } E_0 = 255.2\ \mathrm{MPa} \tag{2}$$

where E_0 is the material's modulus, δ_f is the deformation, and t_f is the plate thickness. These equations allow us to estimate the required plate size for a given level of energy absorption.

Due to the difficulty of placing in finite element software Ansys (Inc and "Ansys user's manual", 2019. 2019), the elastic behavior of the material of the FABREEKA (2024) board in a more precise way, Hooke's Law to this non-linear material was approximated by a straight line, that is, an $Eyf = 80$ MPa was assumed. This simplification will impose some rigidity for minor deformations.

Two case studies FABREEKA

A quite complex machine was designed and before performing the simulations, two simple cases of application of the slabs, which the material company itself gives as an example. In this way, we can have some more confidence in the results of the numerical model of the whole machine.

The effect of the impact generated by falling mold is a non-linear numerical problem of short duration, less than 0.1s. This type of problems are solved with explicit numerical methods (Salveson and Taylor 1996) that take into account the speed of elastic deformation of materials at the contact surface of bodies. The process is highly complex, so only certain commercial software can autonomously manage the iterative process of solving non-linear contact equations produced by the shock process. In this sense, it is necessary to make an explicit dynamic

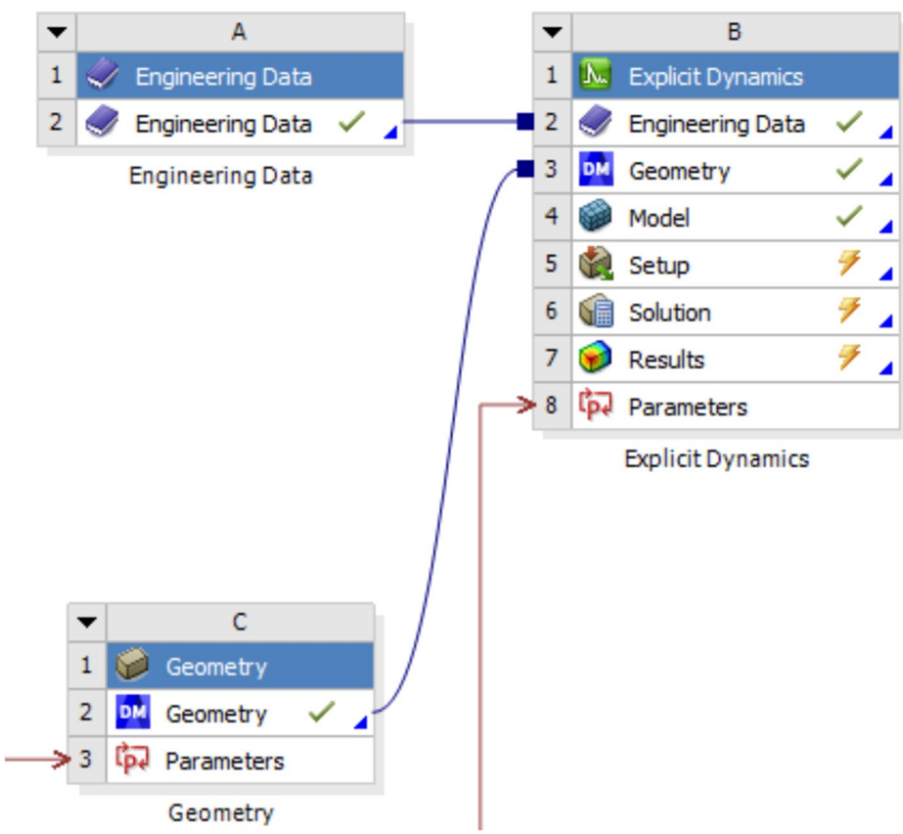

Fig. 1 Project scheme

analysis where very small time steps are used to ensure numerical stability; for this purpose, the Ansys module "Explicit Dynamics" (Inc and "Ansys explicit dynamics analysis guide", 2019. 2019; Martin et al. 2022) was used. This module uses "Hex 100–101" solid finite element (Ko and Bathe 2018), which allows each node to have deformation and kinematic characteristics (Inc and "Ansys explicit dynamics analysis guide", 2019. 2019).

Case 1—drop test

First example is to estimate the thickness and deformation of FABREEKA (2024) plate that will receive a mass with a certain velocity under the following conditions (plate absorbs all the kinetic energy):

- The mass of the falling body is 6803 kg (m).
- The falling speed is 36.6 m/ min (v).
- The plate area is 0.229 m × 0.229 m (A_f).
- The tension on the plate is a maximum of 10.35 MPa (σ).

To determine the thickness of the plate.

Analytical resolution

- Step 1—calculation of the kinetic energy (Eq. 3):

$$E_k = \frac{1}{2} \cdot m \cdot v^2 = 1265.69 \text{ J} \tag{3}$$

- Step 2—calculation the energy absorbed per unit volume (Eq. 4):

$$E_{av} = \frac{\sigma^{\frac{5}{3}}}{C} = 499 \text{ kJ/m}^3 \tag{4}$$

- Step 3—calculation of the plate volume (Eq. 5):

$$V_f = \frac{E_k}{E_{av}} = 0.0025 \text{ m}^3 \tag{5}$$

- Step 4—calculation of the plate thickness (Eq. 6):

$$t_f = \frac{V_f}{A_f} = 0.0484 \text{ m} \Rightarrow t_f = 50 \text{ mm} \tag{6}$$

- Step 5—calculation of the plate deformation considering the material's law (Eq. 7):

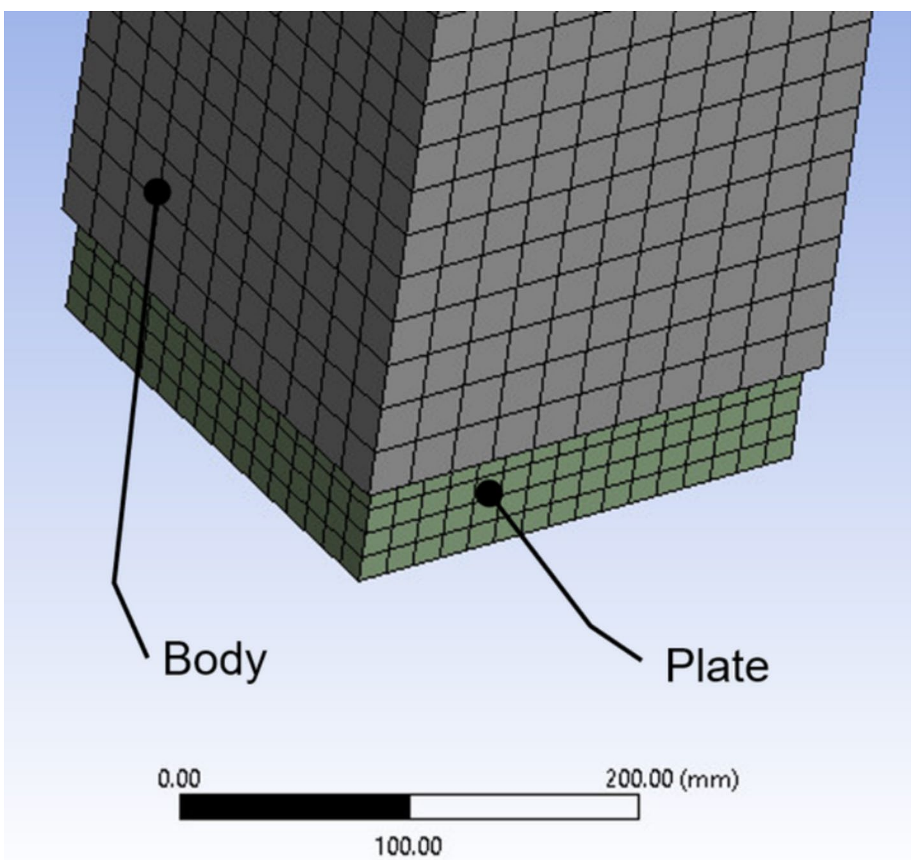

Fig. 2 Plate and body mesh

$$\delta_f = t_f \cdot \left(\frac{\sigma}{E_0}\right)^{\frac{2}{3}} = 5.9\ \text{mm} \tag{7}$$

Finite element analysis

The Ansys program (Huei-Huang Lee (2024) works based on a block scheme (Fig. 1) where some data are inserted, as characteristics of materials and generation of geometries, to carry out the dynamic study. In this block scheme, the "Model" module is responsible for generating the mesh (Fig. 2); in addition to assigning materials to the various parts, fall conditions and support conditions of the model are also imposed. After this work, calculation is carried out and results obtained.

The average vertical displacement of the plate is 5.89 mm (Fig. 3) close to the calculated analytical value of 5.9 mm (step 5).

The average normal stress found on the plate surface is 10.08 MPa (Fig. 4); it is close to the value that was initially admitted of 10.35 MPa.

In this simple problem, a quarter of the model was also successfully tested assuming two planes of symmetry. The results presented are the same, but with the advantage of having about 1/4 of number of nodes, that is, a much lower computational effort (Yeh and Huang 2014; Che and Pang 2015).

Case 2—isolation of the foundations

A block falls from a certain height onto a concrete base and causes a deformation in the concrete. It is intended to place a FABREEKA insulating plate to absorb part of the kinetic energy and reduce the force transmitted to the concrete. The main data used in the calculations are:

- Mass of the falling block is 907kg (m).
- Height of the fall is 1.27m (h).
- Deformation in concrete without the plate is 0.397mm (D).
- Force transmitted to concrete (F_2) is 1/4 of initial force transmitted without the insulating plate (F_1).

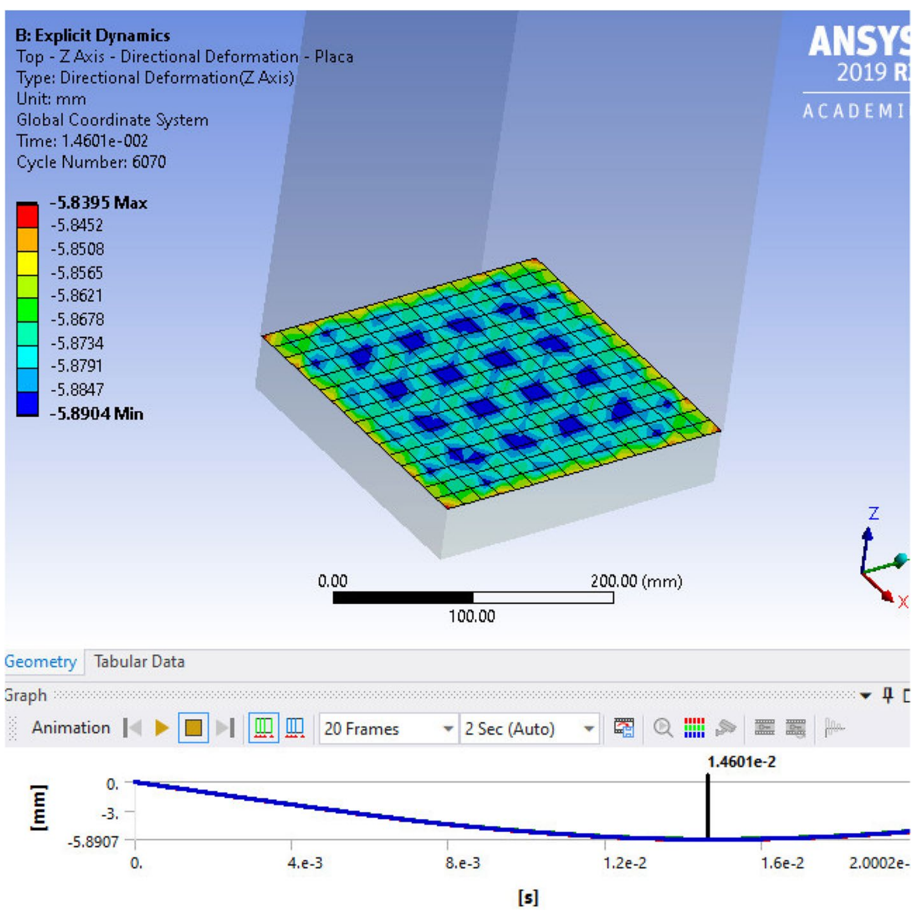

Fig. 3 Vertical plate displacement

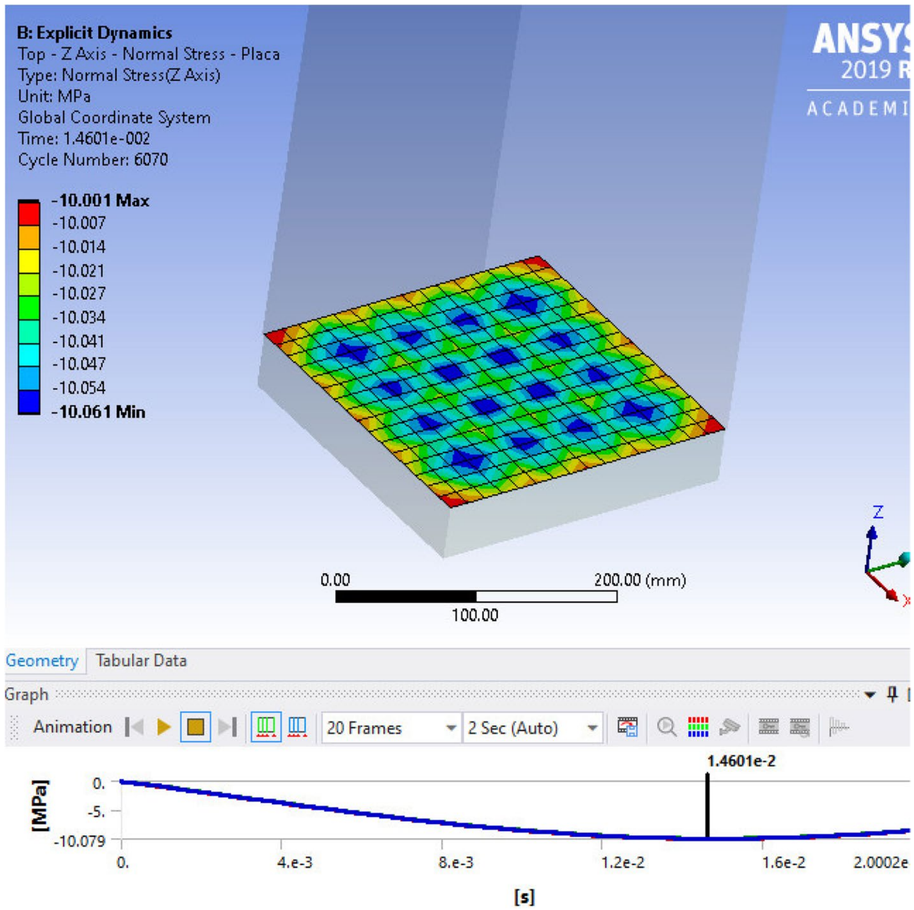

Fig. 4 Normal stress in the plate

Analytical resolution

– Step 1—at the instant before the block meets the concrete, kinetic energy is equal to the potential energy (Eq. 8):

$$E_k = E_P = m \cdot g \cdot h = 11{,}300\ \text{J where g} = 9.806\ \text{m/s}^2 \tag{8}$$

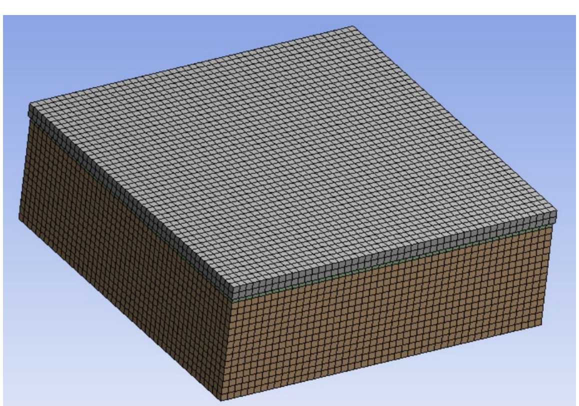

Fig. 5 Set mesh

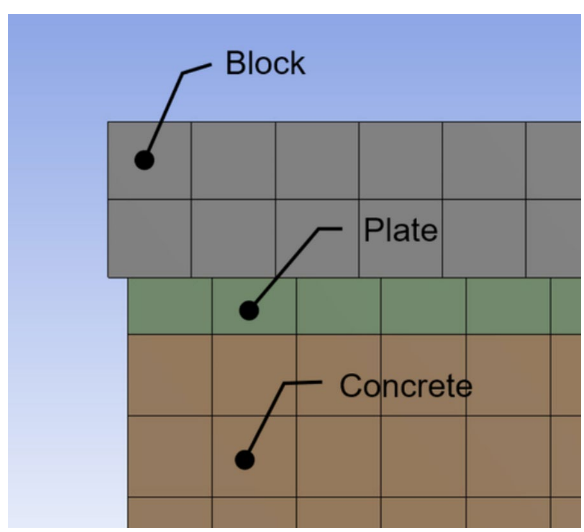

Fig. 6 Block, plate, and concrete mesh

– Step 2—after the initial impact on concrete, kinetic energy is transformed into deformation energy (Eq. 9):

$$E_k = E_{\text{deformation}} = \frac{1}{2} \cdot F_1 \cdot D \Longrightarrow F_1 = 56{,}916{,}560\ \text{N} \tag{9}$$

– Step 3—the transmitted force F_2 was established 1/4 of force F_1 (Eq. 10):

$$F_2 = 0.25 \cdot F_1 = 14{,}229{,}100\ \text{N} \tag{10}$$

reproducing a final displacement in concrete, δ_c, which corresponds to a final deformation energy of concrete, E_c (Eq. 11)

$$\delta_c = 0.25 \cdot D = 0.09925\ \text{mm} \Longrightarrow E_c = \frac{1}{2} \cdot F_2 \cdot \delta_c = 706\ \text{J} \tag{11}$$

– Step 4—the strain energy that the plate will have to absorb is calculated by Eq. 12:

$$E_f = E_c - E_c = 10{,}591.8\ \text{J} \tag{12}$$

Thus, plate will absorb 63.7% of kinetic energy, while concrete will only absorb 6.3%.

– Step 5—if we limit the stress on the plate to $\sigma = 6.9$ MPa, for safety reasons, we can determine the area of the plate using Eq. 13:

$$A_f = \frac{F_2}{\sigma} = 2.062\ \text{m}^2 \tag{13}$$

– Step 6—with the relationship between the kinetic energy per volume unit and the stress generated in the plate, FABREEKA suggests an expression to calculate plate thickness (Eq. 14):

$$t_f = \frac{985{,}000 \cdot E_f}{A_f \cdot \sigma^{5/3}} = 20.23\ \text{mm} \tag{14}$$

– Step 7—calculating the deformation of the plate using the law of materials (Eq. 15):

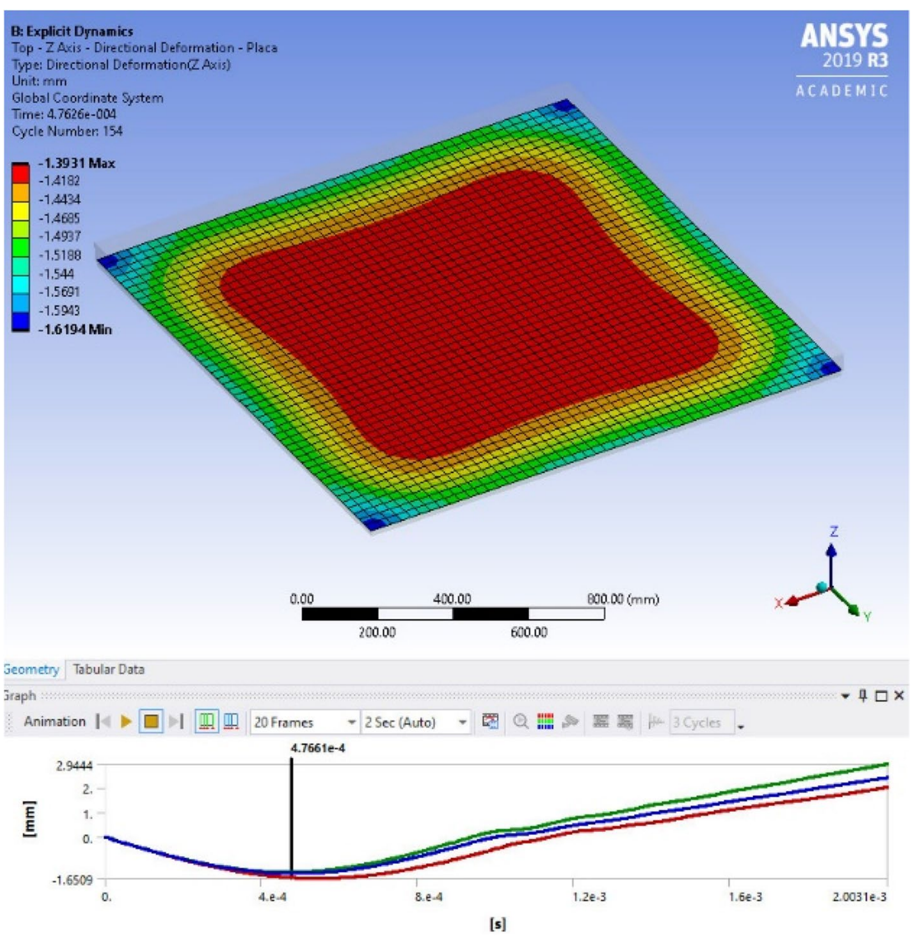

Fig. 7 Plate displacement

$$\delta_f = t_f \cdot \left(\frac{\sigma}{E_0}\right)^{\frac{2}{3}} = 1.8 \text{ mm} \tag{15}$$

Finite element analysis

–To simulate the base deformation, it was chosen a concrete with the same rigidity (Eq. 16):

$$K = \frac{F1}{\delta_f}. \tag{16}$$

Steel was chosen for the block.

Figures 5 and 6 show the three bodies meshes. The set mesh was conditioned by the plate reduced thickness.

After the fall of block, plate and concrete deform as can be seen in Figs. 7 and 8. This contact generates normal stresses shown in Figs. 9 and 10.

Figure 7 shows that the average displacements in the plate are of the order of 1.50 mm, which is not very different from the value $\delta_f = 1.8$ mm, and in Fig. 8 it is possible to see that the average displacements of concrete are of the order of 0.11 mm, which corresponds to the analytically calculated $\delta_c = 0.09925$ mm.

Figures 9 and 10 show the normal stresses average in the plate and concrete close to 6.9 MPa, which coincides with the analytical results.

ErgoSystem equipment

The equipment to be designed is developed by MBM company (2024) and will improve profitability of setting injection molds work, with the following capabilities:

- Moving the two mold parts to operators' bench work position
- Perform both parts controlled movements
- Allow the mold to be closed along vertical axis, on guided way
- Allow the upper mold part to fall onto lower mold part in a controlled way, in order to simulate the closing force and check contact perfection or non-contact using beforehand a colored marker on surfaces in question

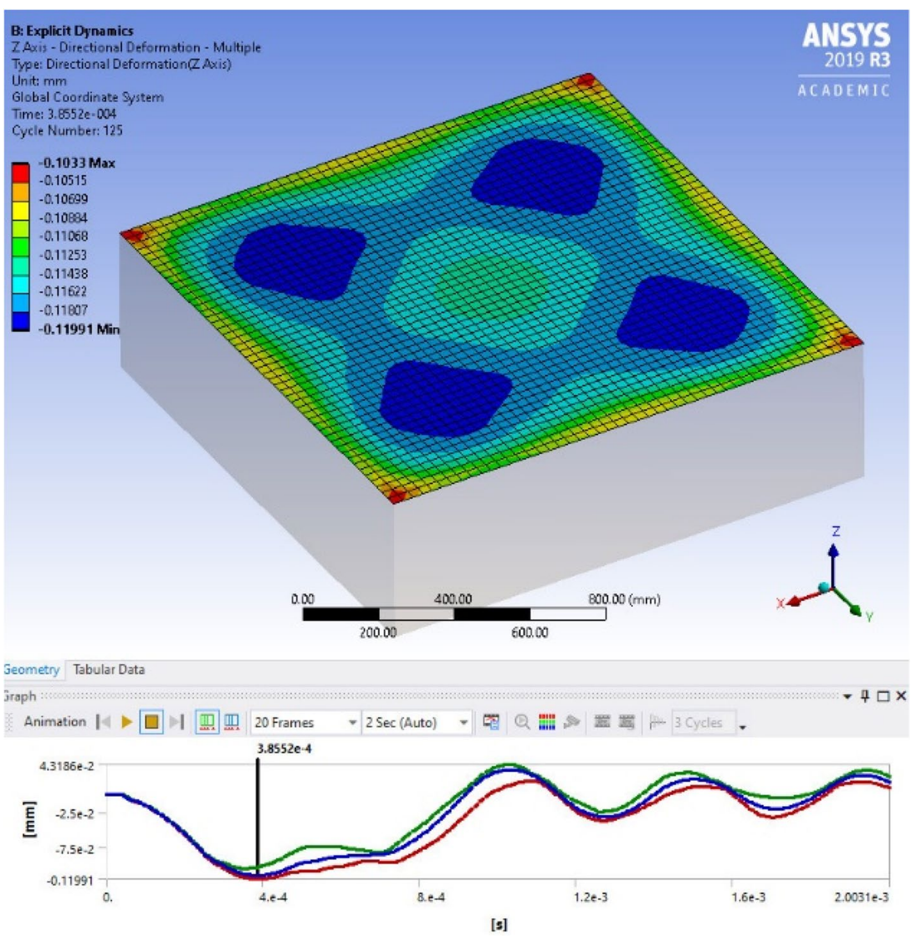

Fig. 8 Concrete displacement

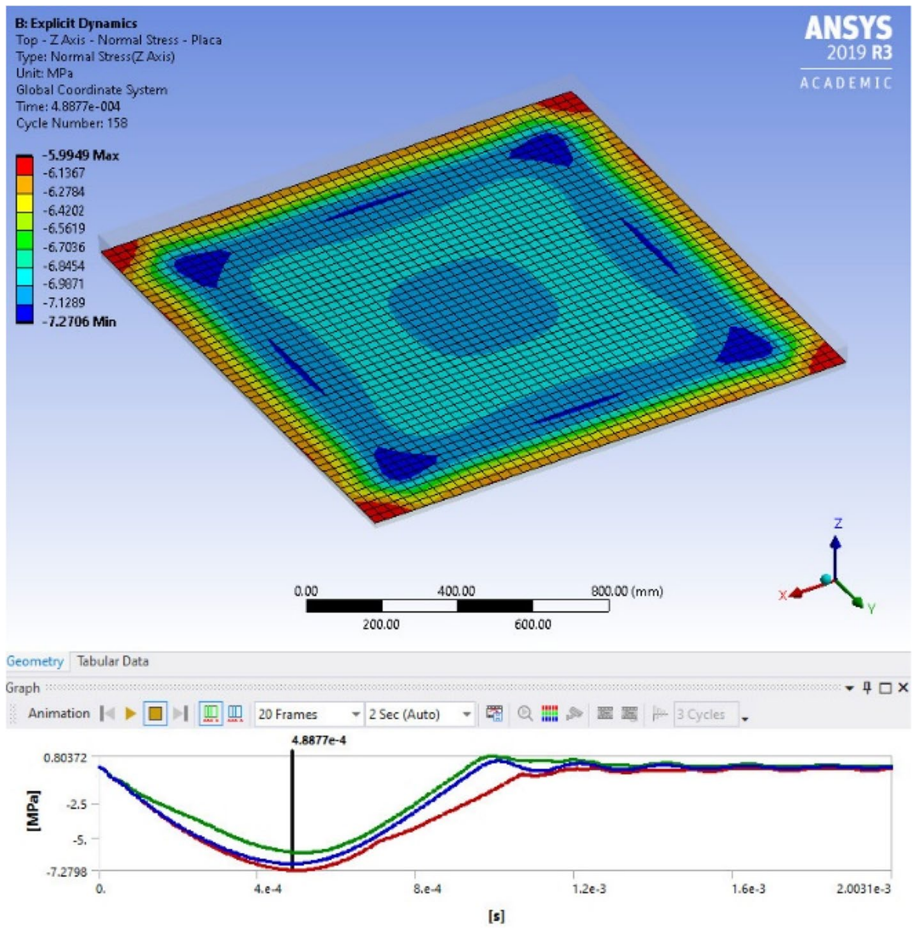

Fig. 9 Normal stress in the plate

The impact of the upper mold part on the lower mold part, when it falls, generates a set of high impact forces on the entire structure supporting the lower mold, which we will try to quantify here.

The kinetic energy of the upper mold will have to be absorbed by the lower support structure, leading to a momentary vertical load on lower structure, much higher than static load value corresponding to upper mold weight.

These structures will have to withstand/absorb transmitted loads without suffering any plastic deformation and without leading to fatigue failure. Supports of the lower structure (AirLoc) will be the main critical points and will have to be given extra attention. The inclusion of energy absorption systems (damping), without disturbing the positional accuracy of the structure, will reduce the energy transmitted to neighboring equipment.

Figure 11 shows the main dimensions of the Ergo-System support structure. A lower mold fixed in a support table and an upper mold that will fall controlled by guides.

Finite element analysis

Computer simulation of entire structure is too cumbersome and time-consuming in computational terms.

The various bodies that make up the structure were identified and, depending on their role in the movement of the molds, the respective geometries were simplified.

In addition to this approximation, it was assumed that the problem has two vertical symmetry planes, which allows us to analyze only 1/4 of structure and thus make the computational problem lighter and also, with symmetry conditions calculation is more stable in the falling process (Yeh and Huang 2014; Kamireddy et al. Nov. 2022).

With the dimensions of the structure shown in Fig. 11, it was assumed a mass of 6000 kg for the upper mold and the same mass for the lower one, considering an overall dimension of 1200 × 1200 × 600 mm. Each of the 4 FABREEKA plates has an area of 590 cm^2 and a thickness of 13 mm. Construction steel characteristics, shown in

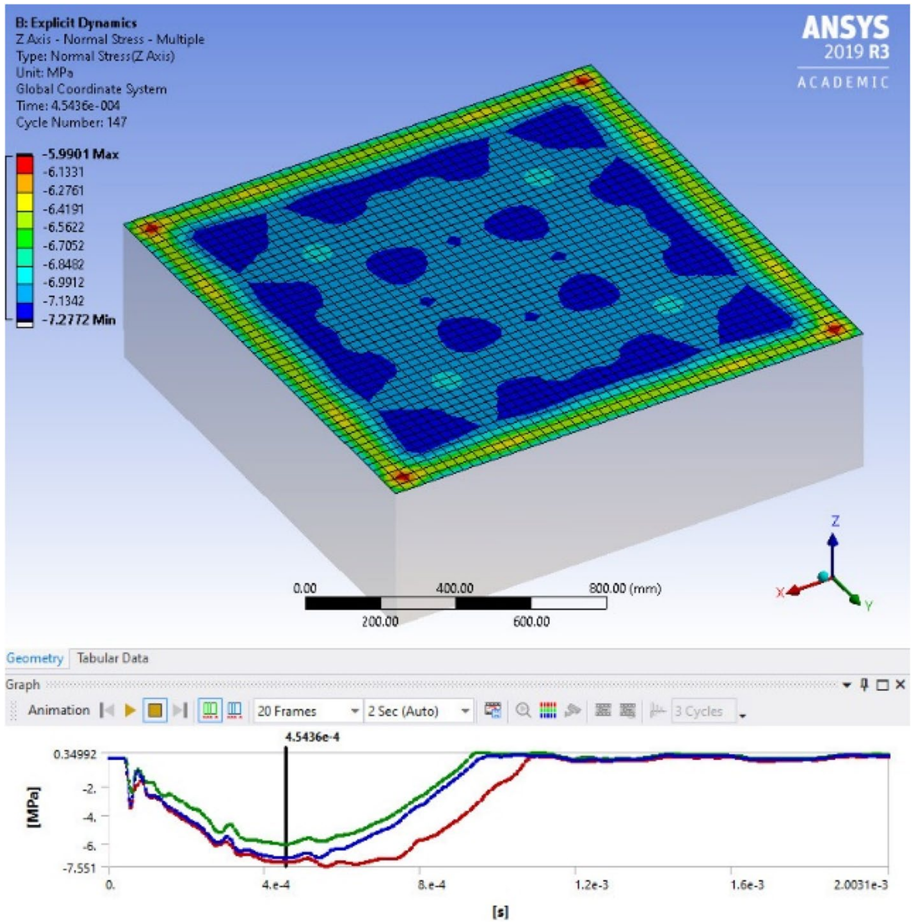

Fig. 10 Normal stress in concrete

Table 1, have been assigned to all bodies except for the FABREEKA plates.

Figures 12a and 13a show the CAD model that represents 1/4 of structure in Fig. 11 CAD model.

Figure 12b shows the finite element model of each of the bodies that make up the structure. The set has 22,380 hexahedral finite elements and contact elements. These contact elements were established between two molds; between the plate and the middle base; and between the plate and the bottom base. The other bodies were rigidly bonded (Bonded 1 and Bonded 2) (Fig. 12b). In this way, it is possible to obtain contact stresses between the two molds and between the plate and the respective bases.

Table 1 Material characteristics

Material	Modulus of elasticity (E)	Poisson coefficient (υ)	Density (ρ)
Component steel	200 GPa	0.3	7850 kg/m^3
FABREEKA plates	80 MPa	0.3	1185 kg/m^3

Figure 13b shows symmetry boundary conditions. In order not to influence the contact surface between the two molds, movement restrictions were only imposed on the indicated edges.

Results

In the mold setting process, upper mold is dropped from various heights to induce shock forces on joint surfaces. In this simulation, upper mold was raised to a height of 5 mm and dropped onto lower mold. Lower base of AirLoc is fixed, as this is where forces will be transmitted to the floor with corresponding vibrations. Ansys "Explicit Dynamics" module was used to carry out drop simulation. The entire energy process of deformation in the crash and fall that takes place over the course of the simulation is managed by the module itself. We only need to indicate the height of fall (which translates into an initial velocity) and the gravity acceleration direction.

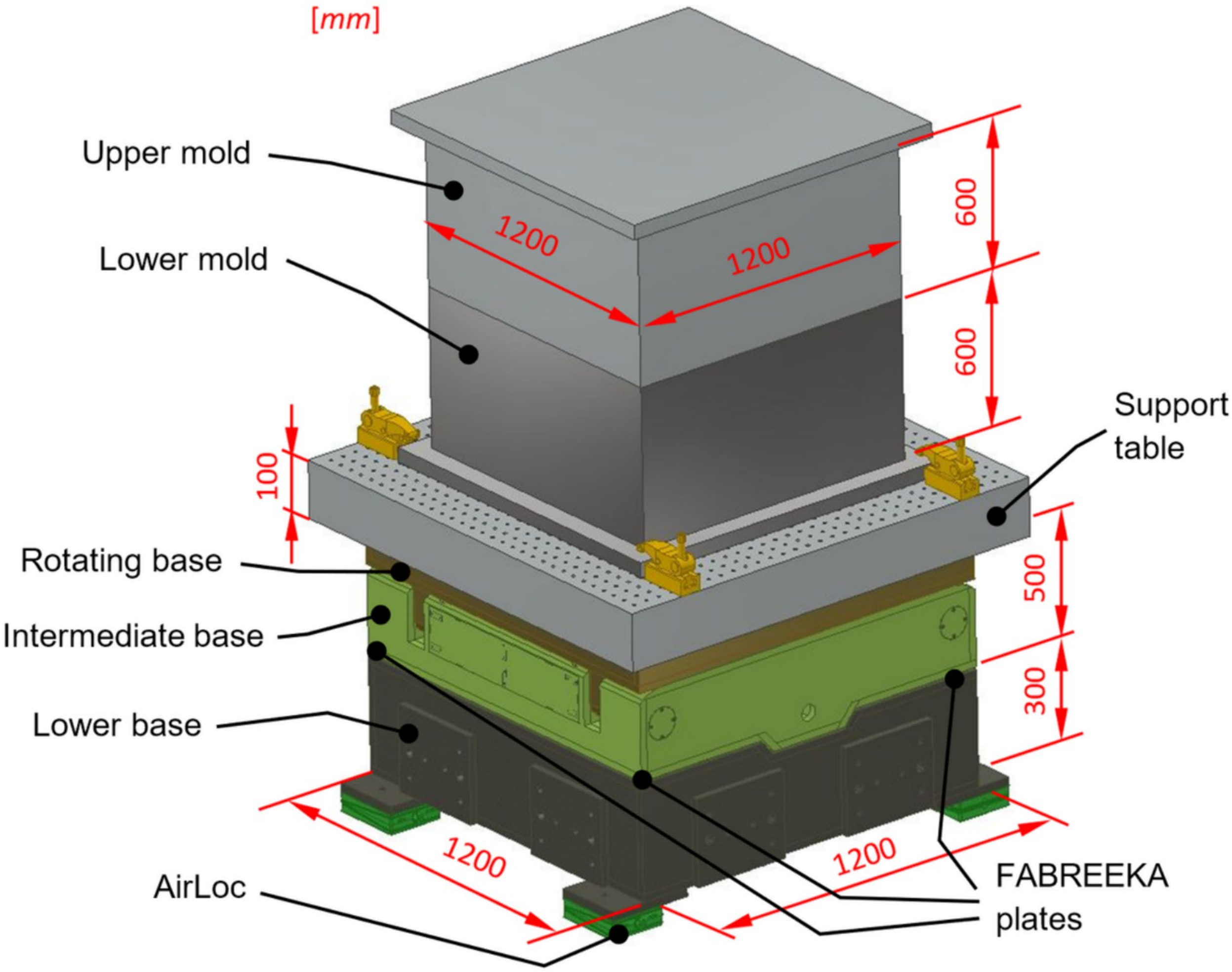

Fig. 11 CAD model of ErgoSystem support structure

Initial condition of a 5 mm fall, h, corresponds a fall speed (Horvat and Jecmenica 2016), v, i.e., a dynamic problem initial condition (Eq. 17).

$$v = \sqrt{2 \cdot g \cdot h} = 313.155 \text{ mm/s} \tag{17}$$

In this way, simulation is carried out with the two molds in contact, but imposing a drop speed, v, on the upper mold. The impact between the molds takes place in a very short time. After a few simulations, simulation time was set between 0 and 0.02 s. Integration time in the calculation process is managed by the "Explicit Dynamics" module itself. A resolution of 1000 points was chosen for the results output.

To demonstrate the advantages of using FABREKKA plate, two simulations were carried out, one model without the plates and the other with them. In this way, we will analyze how important placement of FABREKKA plates is in stress transmission between the bodies and the stress transmitted directly to the ground.

Results of model without a plate

In this model the finite element mesh shown in Fig. 12b without the plate was used, so the lower base and middle base were rigidly bonded. This leaves the model with all bodies rigidly bonded (Bonded 1 + Bonded 2) except the upper mold. Outputs for the surfaces are shown over time with 3 curves, maximum values in green, minimum values in red, and average values in blue. All the graphs of results have these 3 curves.

When upper mold collides with lower mold, after a small vertical downward displacement, it undergoes an upward vertical response, as can be seen in Fig. 14.

The lower mold receives this shock energy and vibrates according to a harmonic curve (Fig. 15).

The collision between the two molds will generate normal contact stresses on both surfaces. Figures 16

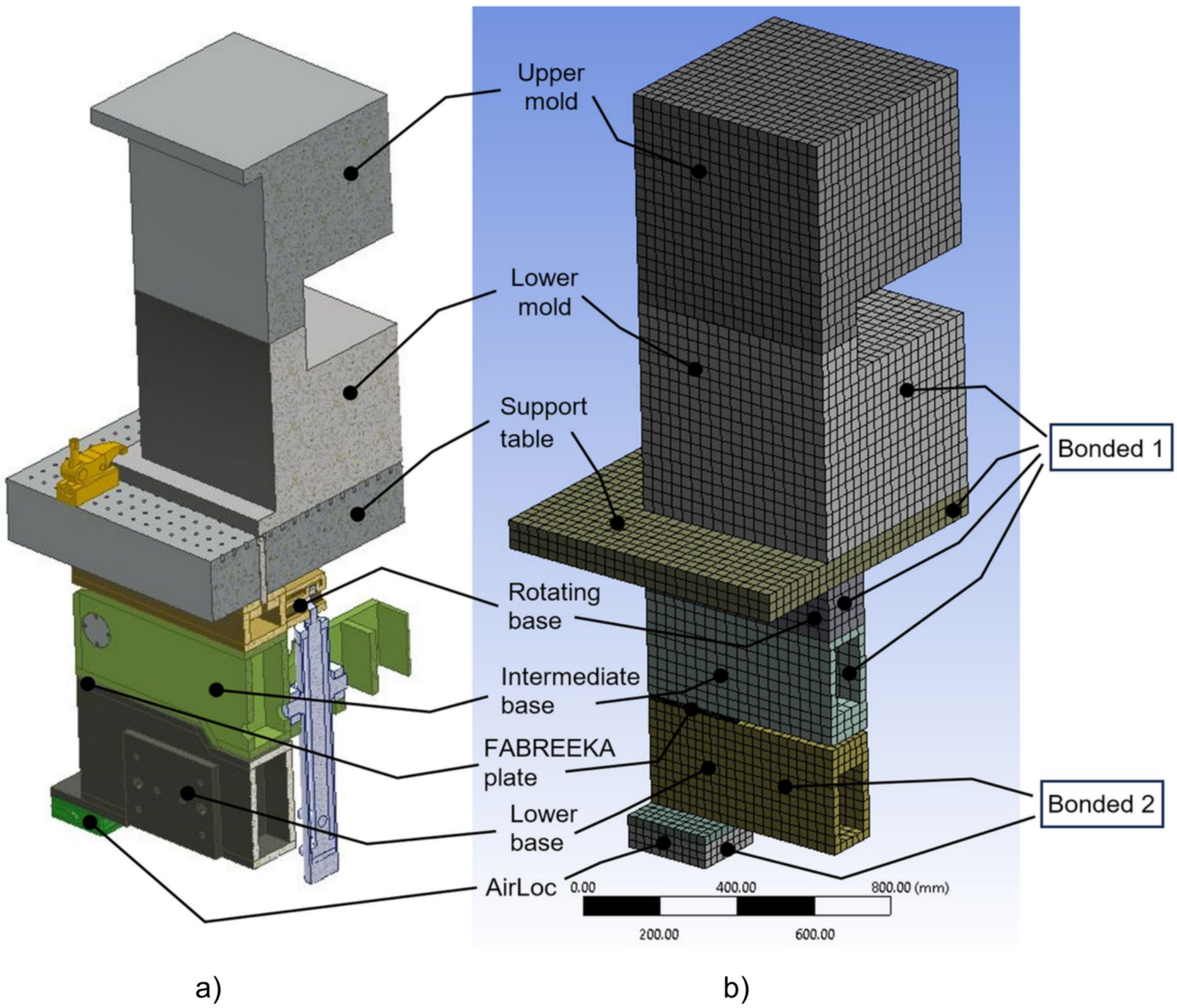

Fig. 12 CAD model of (**a**) and finite element mesh of 1/4 of the set (**b**)

and 17 show the moment of impact and the stress of values. Due to have a somewhat coarse mesh density on the contact surfaces between the molds, we found some stress peaks in some finite elements, and they are represented in the graph by red curve. We only looked at the average stress, the blue line. Minimum value found in the blue curve was −5.6 MPa, which corresponds to a shock force of 1449 tons.

All the energy of bodies is transmitted to AirLoc, and stress level also has a sinusoidal evolution as it will accompany the sinusoidal vertical movement of the structure, as can be seen in the movement of the lower mold in Fig. 15. Minimum average normal stress found at the base of the AirLoc is −15.3 MPa, as shown in Fig. 18, corresponding to a force of 315 tons that will be transmitted to the ground.

Results for the plate model

The insertion of plates between the lower base and the middle base was designed to absorb kinetic energy of bodies after the two molds collided. The entire finite element mesh shown in Fig. 12b was used in this model, so Bonded 1 has finite elements in contact with the upper mold and the plate, while Bonded 2 only has finite elements in contact with the plate.

When upper mold collides with lower mold, it suffers insufficient repulsion in the first instant and has a second, lighter shock in following instants. We can see this behavior in Figs. 19 and 20, and effect of normal contact stresses in Figs. 21 and 22.

Looking only at normal contact stresses level of the first shock (Figs. 21 and 22), the contact stresses level does not change much compared to the model without

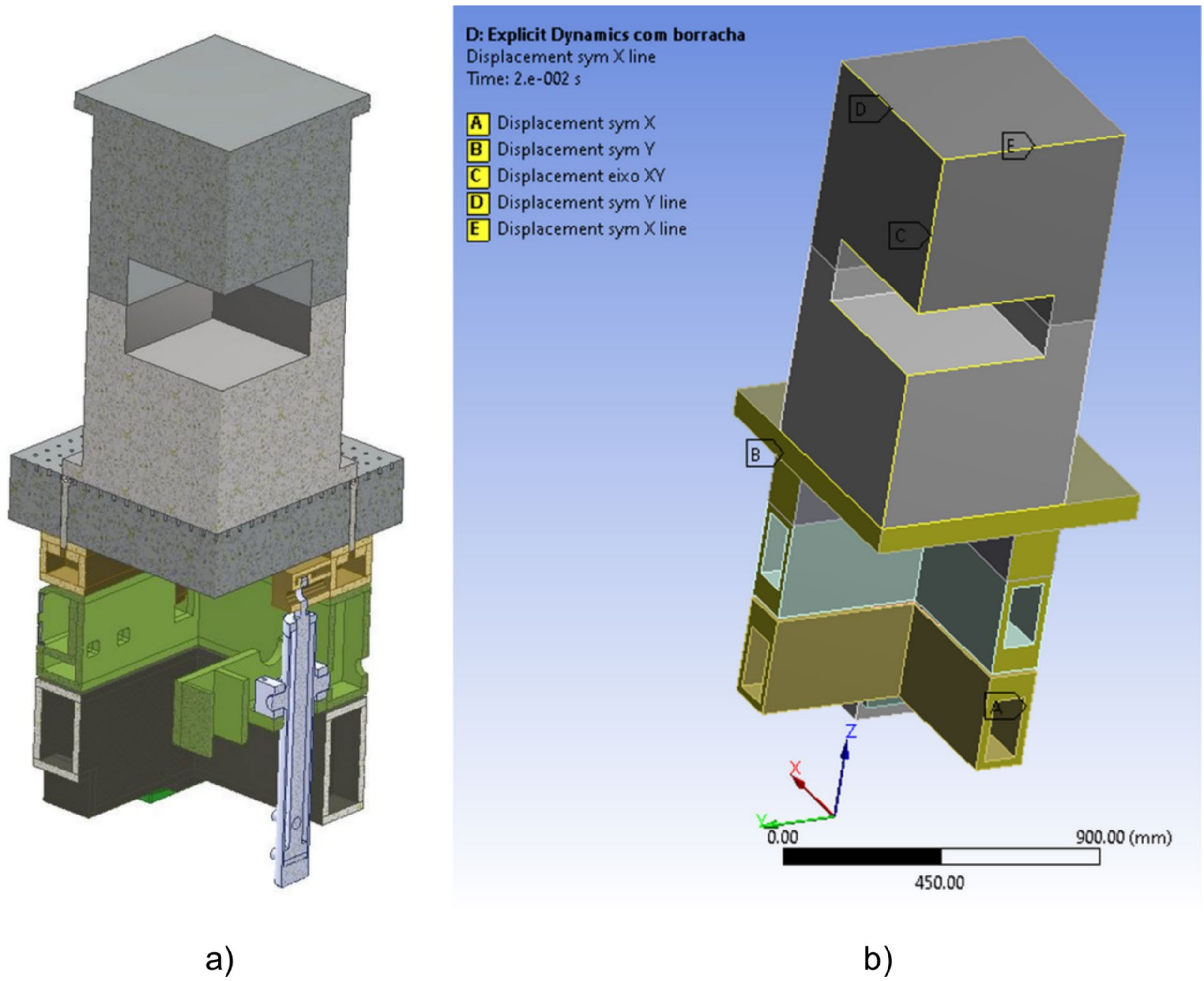

Fig. 13 CAD model of 1/4 (**a**) of the set and boundary conditions (**b**)

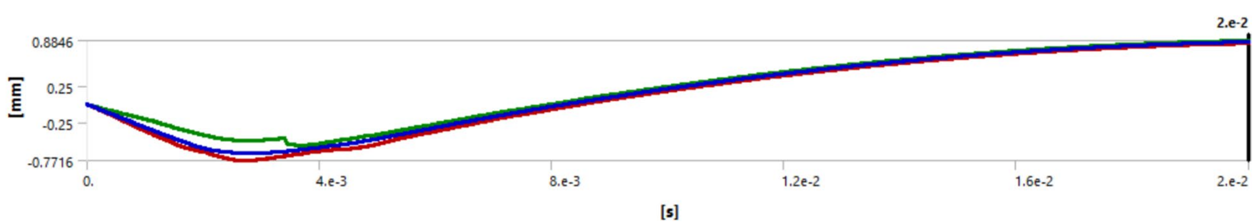

Fig. 14 Vertical displacement of the upper mold of the model without plate

a plate case. The minimum average stress is −5.54 MPa, which corresponds to a shock force of 1423 tons.

FABREEKA plate deforms a moment after the first shock, as can be seen in the comparison between Fig. 23 and Fig. 24.

The bodies above the plate will impose a compressive stress on the plate of −3.74 MPa (Fig. 25), which is perfectly permissible for plates that manufacturer has available.

The minimum average normal stress found at the base of the AirLoc is −4.48 MPa, which corresponds to a force of 99.7 tons that will be transmitted to the ground (Fig. 26).

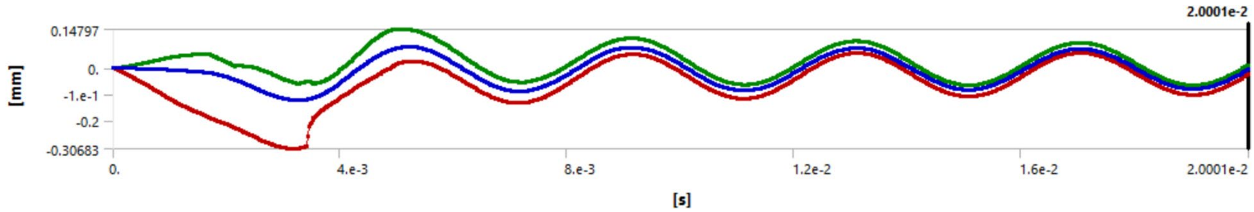

Fig. 15 Vertical displacement of the lower mold of the model without plate

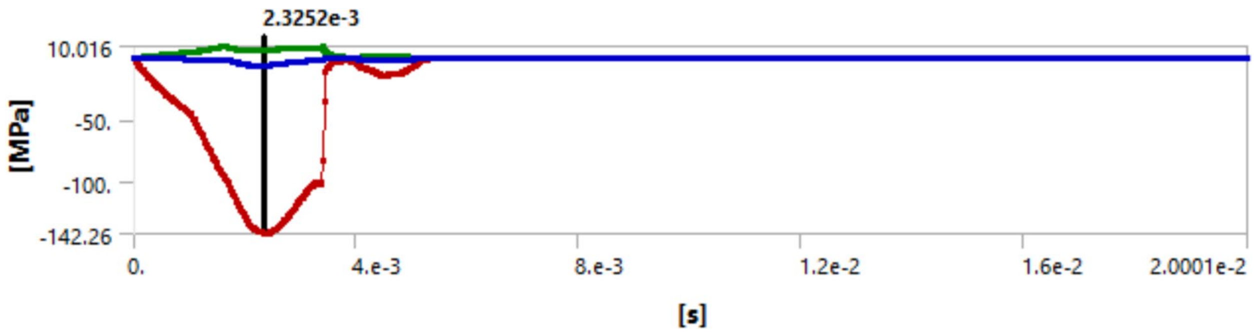

Fig. 16 Normal contact stress in the upper mold of the model without plate

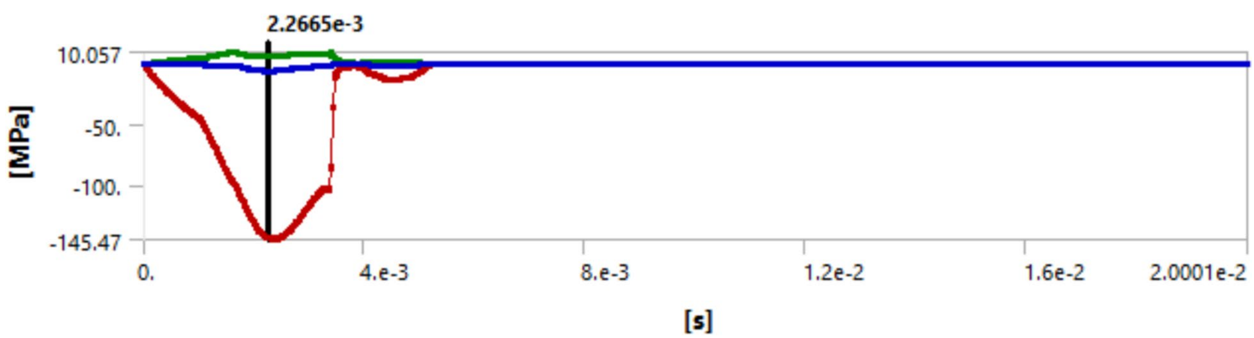

Fig. 17 Normal contact stress in the lower mold of the model without plate

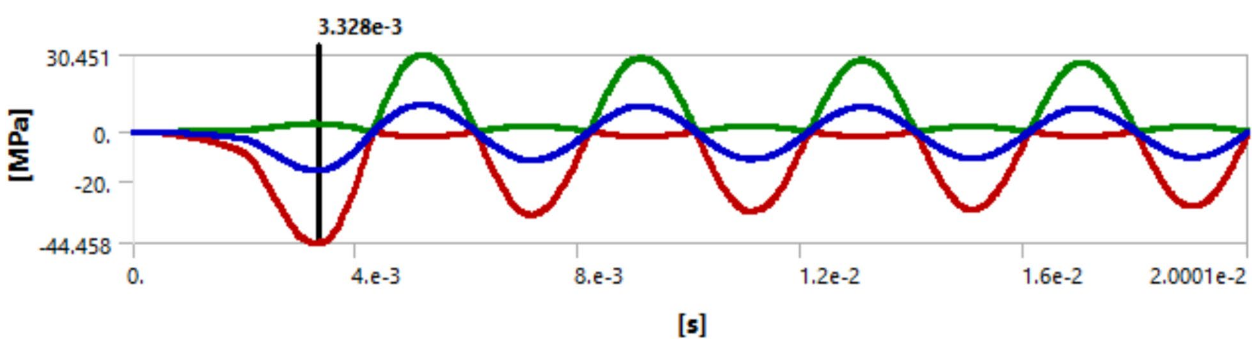

Fig. 18 Normal stress at the base of the HairLoc model without plate

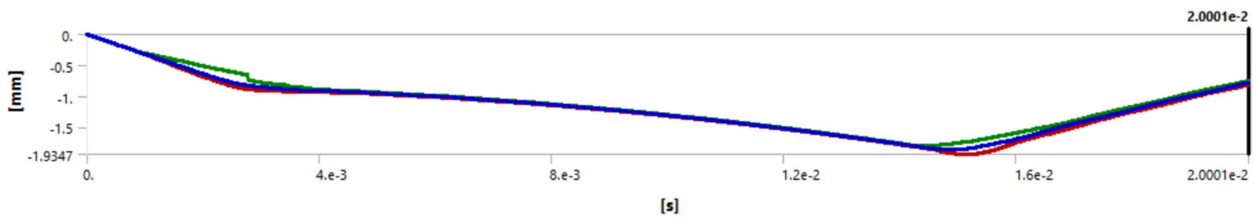

Fig. 19 Vertical displacement of the upper mold of the model with plate

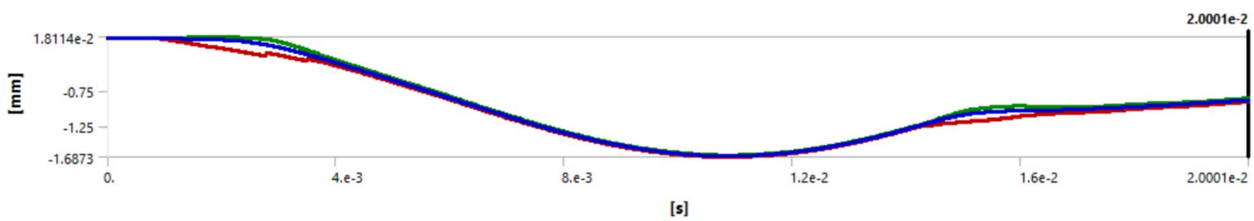

Fig. 20 Vertical displacement of the lower mold of the plate model

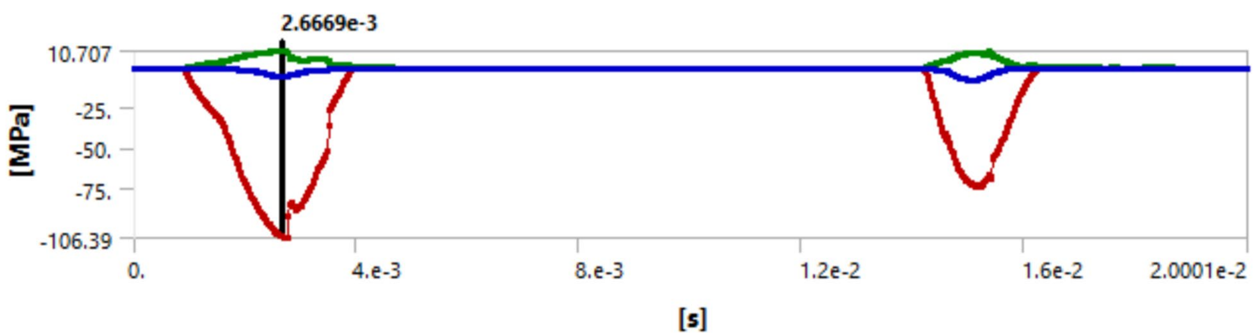

Fig. 21 Normal contact stress in the upper mold of the model with plate

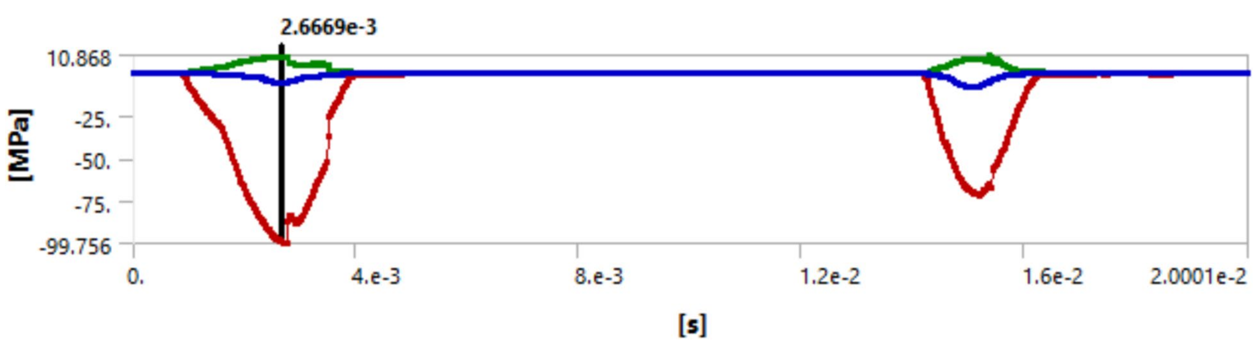

Fig. 22 Normal contact stress in the lower mold of the model with plate

Values in Table 2 show the advantage of using FABREKKA plates, which transform kinetic energy into deformation energy and thus reduce loads transmitted to the ground.

Shock forces between two molds, as expected, are similar for both models. However, force transmitted to the ground is reduced to less than 1/3, and the vibration is greatly dissipated (compare Fig. 18 with Fig. 26), which is in line with the objectives of studied solution.

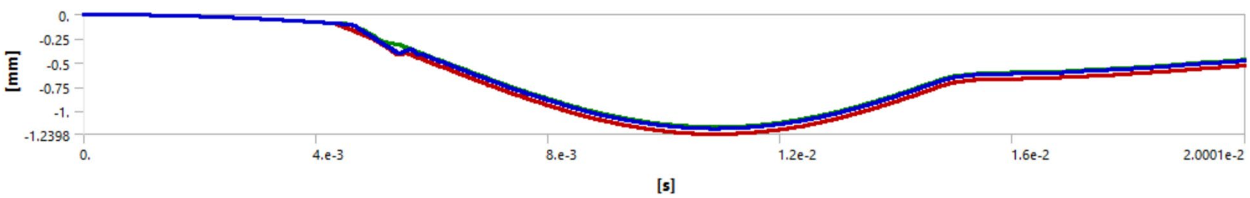

Fig. 23 Vertical displacement of the upper surface of the plate of the model with plate

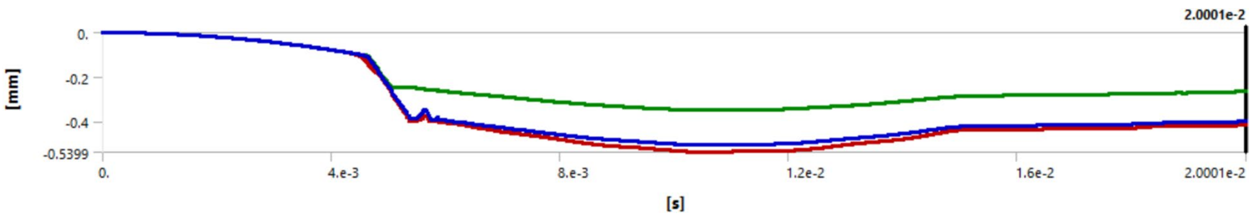

Fig. 24 Vertical displacement of the bottom surface of the plate of the model with plate

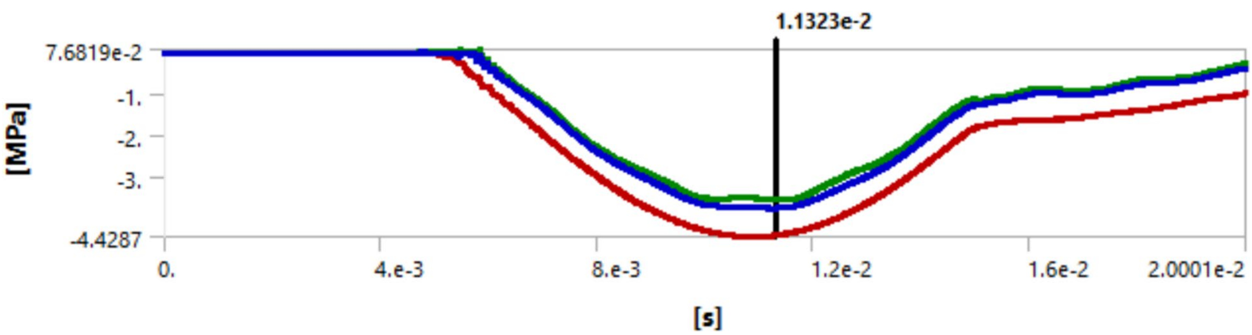

Fig. 25 Normal contact stress on the plate of the model with plate

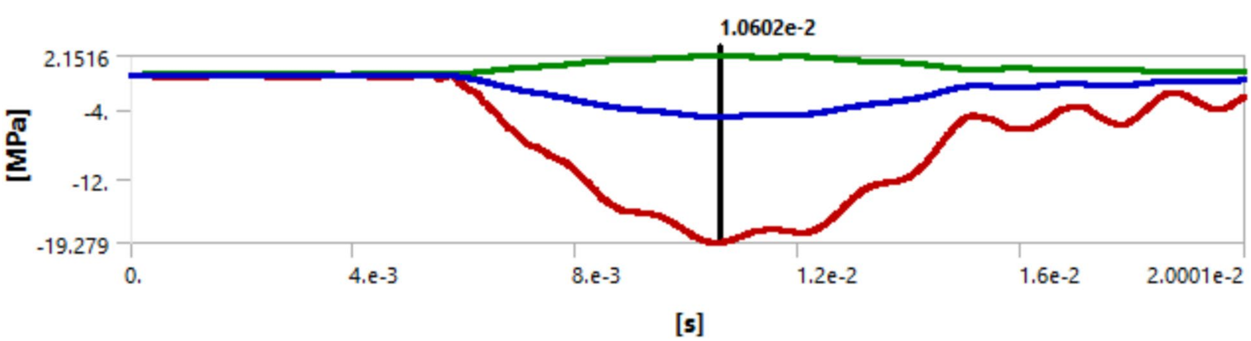

Fig. 26 Normal contact stress at the base of the AirLoc of the model with plate

Correct characterization of plate material in numerical model should further reduce force transmitted to the ground, since a slightly stiffer linear elasticity modulus was assumed for the plate.

Comparison of simulation results

The initial design by MBM (2024) was revised and the entire mold support machine had to be made smaller (see Figs. 27 and 28). Machine was adapted for molds

Table 2 Loads on the structure

	Structure with plate	Structure without plate
Shock force between the two molds	1423 tons	1449 tons
Force transmitted to the base of the 4 HairLoc	99.7 tons	315 tons

Fig. 27 ErgoSystem fully open

Fig. 28 ErgoSystem closed

weighing around 1 ton. The lower part was simplified and the rotation table was removed.

The same FABREKKA plates with 13 mm thickness used in the finite element study were used. The machine has a system of vertical guides to control and guide the fall of upper mold. The machine has already run several drop cycles and has not caused any noticeable vibration in the underlying structures.

Conclusion

The objective of this study was to evaluate the impact generated by the closing force during mold adjustment. A process involving the dropping of one mold onto the other was used to simulate the closing forces present during operation in the injection molding process. ERGOSYSTEM equipment was developed to carry out this task.

Considering the transmission of shock loads to the base of the equipment, insulation material from FABREEKA was chosen to absorb the impact energy. After performing finite element analyses, the following conclusions were drawn:

- Using the Explicit Dynamics method, it was found that two simple finite element models produced results consistent with the analytical solutions provided by the FABREEKA insulator board manufacturer. This validated the use of plate modeling for more complex problems.
- The finite element modeling of the entire ERGOSYSTEM equipment proved to be computationally heavy and unstable when using the Explicit Dynamics method. Assuming double symmetry in the model allowed the reduction of the number of degrees of freedom to one-quarter, which made the non-linear process of Explicit Dynamics more stable.
- In the simulation, placing a 13-mm FABREEKA insulating plate resulted in a one-third reduction in the forces transmitted to the supports (AirLoc).
- The actual equipment constructed was smaller in size than the finite element model. However, the FABREEKA insulation plates used had the same dimensions and thickness (13 mm) as those in the model. Several drop tests were performed, and the results were acceptable: the shock forces did not cause noticeable vibrations in the surrounding structures.

To accurately assess the forces transmitted to the ground, force sensors or accelerometers would be required in the AirLoc supports, which were not available. However, since no vibrations were observed in adjacent structures, this analysis was not conducted.

Nomenclature used in equations

E_k Kinetic energy
E_{av} Energy absorbed per unit volume
E_p Potential energy
E_f Deformation energy of the plate
E_c Final deformation energy of concrete
C Constant strain energy per unit volume
Eyf Estimated modulus of elasticity of the plate
σ Normal compressive stress on the plate
m Mass
V_f Plate volume
v Fall speed
h Drop height
A_f Plate area
t_f Plate thickness
δ_f Plate deformation
δ_c Concrete final deformation

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All the authors contributed to the article.

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Data availability
The authors declare that all data and material are available.

Declarations

Competing interests
The authors declare that there is no conflict of interests regarding the publication of this paper.

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